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Minerals Yearbook



U.S.
DEPARTMENT
OF THE
INTERIOR



BUREAU OF
MINES

1989

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.

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Foreword

This edition of the Minerals Yearbook discusses the performance of the worldwide minerals industry during 1989 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 advanced materials also has been added to the Minerals Yearbook series beginning with the 1989 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 and 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, International Area Reports, 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 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 and materials that were obtained as a result of the mineral information gathering activities of the Bureau of Mines.

The collection, compilation, and analysis of domestic minerals industries data were performed by the staffs of the Branches of Ferrous Metals, Nonferrous Metals, and the Industrial Minerals of the Division of Mineral Commodities. 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 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 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 International Data Section, Branch of Data Collection and Coordination, Division of Statistics and Information Services, 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 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 Jeffrey B. Osmint and Stephen D. Smith

Mr. Osmint, a statistician with 13 years of Government experience in surveys, has been with the Bureau of Mines Branch of Statistics and Methods Development since 1983.

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 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 Bureau of Mines survey activity is the National Materials and Minerals Policy, Research and Development Act of 1980 (Public Law 96-479, 96th Congress), which 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 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. 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. Internal numerical relationships of column and row totals are validated, 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 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 chapter of the "Minerals Yearbook" includes a section entitled "Domestic Data Coverage." This section briefly describes the data sources, the number of establishments

TABLE 2

HELIUM RECOVERY IN THE UNITED STATES[1]

(Thousand cubic feet)

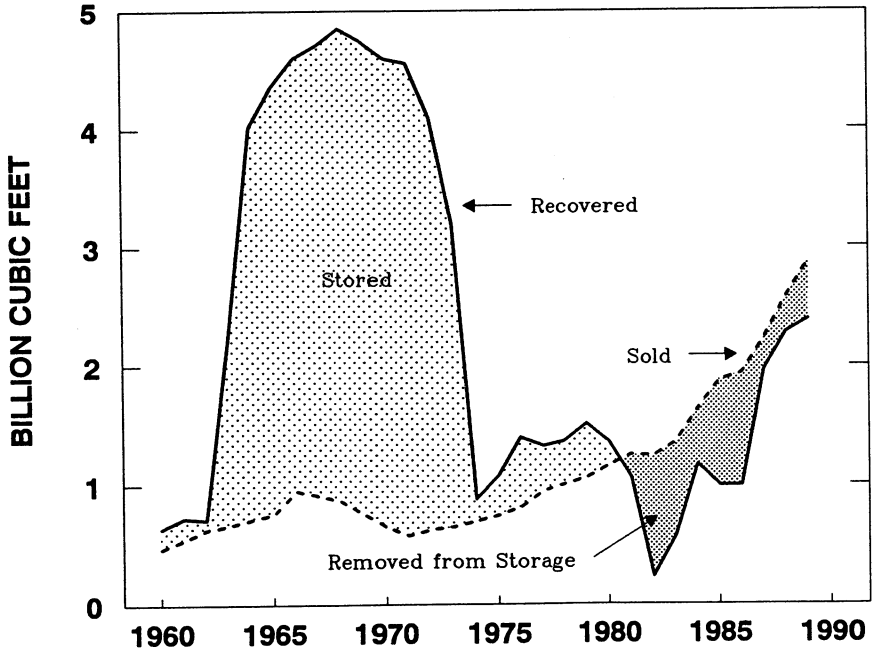
	1985	1986	1987	1988	1989
Crude helium:					
Bureau of Mines total storage	−411,681	−379,827	−289,085	−359,409	−377,508
Private industry:					
Stored by Bureau of Mines	487,576	431,917	730,360	630,748	547,158
Withdrawn	−956,462	−980,209	r−697,266	−551,997	−653,263
Total private industry storage	−468,886	−548,292	r33,094	78,751	−106,105
Total crude helium	−880,567	−928,119	r−255,991	−280,658	−483,613
Stored private crude helium withdrawn from storage and purified by the Bureau of Mines for redelivery to industry	−5,339	−18,658	−6,765	−11,920	−5,482
Grade-A helium:					
Bureau of Mines sold	397,446	333,447	266,594	316,954	350,154
Private industry sold	1,485,662	1,607,963	1,963,750	2,256,997	2,529,226
Total sold	1,883,108	1,941,410	2,230,344	2,573,951	2,879,380
Total stored	−885,906	−946,777	r−262,756	−292,578	−489,095
Grant total recovery	997,202	994,633	r1,967,588	2,281,373	2,390,285

r Revised.

[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



Kansas Refined Helium Co., Otis, KS; Exxon Company, U.S.A., Shute Creek, WY; and Union Carbide Corp., Linde Div., Bushton, Elkhart, and Ulysses, KS. Linde's helium plant at Elkhart, KS, was shut down in 1988 after modifications at their Ulysses, KS, plant were completed and it was restarted.

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 350 MMcf in 1989, an increase of about 10% when compared with last year's sales. This increase was due largely to the U.S. Department of Defense Strategic Defense Initiative projects and the National Aeronautics and Space Administration's (NASA) resumption of space shuttle flights, which include associated projects that use large volumes of helium. Sales to the U.S. Department of Energy continue to decline.

The Federal agencies purchase their major helium requirements from the Bureau of Mines. Direct helium purchases by Defense, NASA, Energy, 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

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

To produce reliable aggregated data, the Bureau employs efficient procedures for handling instances of nonresponse. Failure to return the initial survey form results in a second mailing of the form. If the second form is not returned, telephone calls are made to the nonrespondents. The followup calls provide the necessary data to complete the survey forms and/or verify questionable data entries. Periodic visits to important minerals establishments are also made by Bureau commodity specialists or State Mineral Officers to gather missing data and to explain the importance of the establishment's reporting. By describing the use of the published statistics and showing the impact of nonresponse, the Bureau 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 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 "Minerals Yearbook" tables. However, if a company gives permission in writing, the Bureau may release data otherwise withheld because of proprietary considerations if the data from other producers in an aggregated cell are protected from disclosure.

International Data

International data are collected by country specialists in the 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 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 preprints before the bound volumes are available.

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

"State Mineral Summaries" 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.

"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 chapters of the "Minerals Yearbook," the "Mineral Industry Surveys," the "Mineral Commodity Summaries," the "State Mineral Summaries," and "Information Circulars," contact Publications Distribution, Bureau of Mines, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236.

Electronic Data Dissemination

In addition to the Bureau's printed publications, current "Mineral Industry Surveys" for several commodities and selected chapters 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) 634-4637 using a modem set to 1200 or 2400 baud, 8 data bits, no parity, and one stop bit. Further information on how to use the MINES-DATA system may be obtained from the system operator by calling (202) 634-9632.

STATISTICAL SUMMARY

This chapter 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 commodity chapters of Volume I and in the State chapters 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 chapter 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		1987		1988		1989	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS							
Bauxite metric tons, dried equivalent		575,574	$10,916	587,889	$10,566	W	W
Beryllium concentrates	metric tons	W	W	5,308	6	4,592	$5
Copper[2]	do.	1,243,638	2,261,833	r1,416,928	r3,764,353	1,497,458	4,322,922
Gold[2]	kilograms	153,870	2,216,027	200,914	2,831,281	265,541	3,266,210
Iron ore (includes byproduct material)	thousand metric tons	47,983	1,503,087	57,113	1,716,661	58,299	1,901,722
Iron oxide pigments (crude)	metric tons	38,803	3,598	39,711	3,815	45,575	3,645
Lead[2]	do.	311,381	246,720	384,983	315,222	410,915	356,477
Magnesium metal	do.	124,307	381,914	141,983	469,767	152,066	508,668
Molybdenum[3]	thousand pounds	69,868	179,286	r101,283	r271,039	139,124	421,427
Nickel[3]	short tons	—	—	—	—	382	2,600
Platinum-group metals[e]	kilograms	3,110	44,686	4,970	67,622	6,280	85,318
Silver[2]	metric tons	1,241	279,675	1,661	349,339	2,007	354,973
Zinc[2]	do.	216,327	199,924	244,314	324,249	275,883	499,103
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	110,422	XX	116,954	XX	222,944
Total metals[4]		XX	7,438,000	XX	10,241,000	XX	11,946,000
INDUSTRIAL MINERALS (EXCEPT FUELS)							
Abrasives[5]	metric tons	11,587	$957	13,313	$1,183	1,257	$189
Asbestos	do.	50,600	17,198	W	W	17,427	W
Barite	thousand metric tons	406	15,810	404	15,512	290	12,625

See footnotes at end of table.

TABLE 1—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1987		1988		1989	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Boron minerals	metric tons	1,256,452	$475,092	1,149,404	$429,667	1,114,007	$429,806
Bromine[e]	thousand kilograms	151,954	107,000	163,293	144,000	175,000	188,650
Cement:							
Masonry	thousand short tons	3,680	259,926	3,574	243,941	3,329	229,441
Portland	do.	74,868	3,646,561	74,074	3,575,906	74,202	3,592,255
Clays	metric tons	43,234,014	1,202,284	44,515,041	1,400,820	42,254,269	1,515,300
Diatomite	do.	596,928	134,239	628,680	143,774	617,164	136,754
Emery	short tons	1,945	W	W	W	—	—
Feldspar	do.	720,000	26,100	715,484	28,082	721,256	28,029
Fluorspar	metric tons	[e]63,500	W	[e]63,500	W	[e]66,000	W
Garnet (abrasive)	do.	38,353	4,350	42,506	4,707	42,604	4,408
Gem stones		NA	21,389	NA	43,580	NA	42,901
Gypsum	thousand short tons	15,612	106,977	16,390	109,205	17,624	128,448
Helium:							
Crude	million cubic feet	730	16,068	W	W	W	W
Grade-A	do.	2,230	82,540	2,574	95,238	2,879	106,523
Iodine	kilograms	W	W	[r]998,000	W	1,508,000	23,947
Lime	thousand short tons	15,733	786,125	[r]17,052	[r]817,893	17,152	852,113
Mica (scrap)	thousand metric tons	146	8,201	130	6,793	119	6,273
Peat	thousand short tons	958	21,020	[r]908	[r]20,320	769	17,636
Perlite	do.	533	16,494	[r]645	17,652	601	16,301
Phosphate rock	thousand metric tons	40,954	793,280	45,389	887,809	49,817	1,082,797
Potash (K_2O equivalent)	do.	1,262	195,700	1,521	240,300	1,595	271,515
Pumice	do.	356	4,493	353	4,129	424	8,213
Salt	thousand short tons	36,493	684,170	37,997	680,174	38,356	776,846
Sand and gravel:							
Construction	do.	[e]895,200	[e]3,002,500	923,400	3,126,000	[e]897,300	[e]3,249,000
Industrial	do.	28,010	364,100	28,480	388,000	29,205	410,200
Sodium compounds:							
Soda ash	do.	8,891	593,685	9,632	644,973	9,915	764,146
Sodium sulfate (natural)	do.	382	33,086	398	31,377	375	31,104
Stone:[6]							
Crushed	thousand short tons	1,200,100	5,248,600	[e]1,247,800	[e]5,558,000	1,213,400	5,325,800
Dimension	short tons	1,183,849	190,153	[e]1,189,333	[e]196,289	1,206,995	208,311
Sulfur (Frasch)	thousand metric tons	3,610	386,834	4,341	430,814	3,780	378,712
Talc and pyrophillite	thousand short tons	1,281,789	28,872	[r]1,359,937	[r]31,185	1,381,335	W
Tripoli	metric tons	104,259	975	99,928	864	105,229	2,537
Vermiculite	short tons	302,926	33,105	303,544	33,948	293,320	32,550
Combined value of aplite, calcium chloride (natural), graphite (natural, 1988-89), kyanite, lithium minerals, magnesite, magnesium compounds, marl (greensand), olivine, pyrites, staurolite, wollastonite, and values indicated by symbol W		XX	[r]395,795	XX	[r]452,436	XX	496,445
Total industrial minerals[4]		XX	18,904,000	XX	19,805,000	XX	20,370,000
Grand total[4]		XX	26,342,000	XX	30,045,000	XX	32,316,000

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

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

[6]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 1989

Mineral	Principal producing States, in order of quantity	Other producing States
Abrasives[1]	AR, IN, OH.	
Antimony (content of ores, etc.)	MT.	
Aplite	VA.	
Asbestos	CA and VT.	
Barite	GA, NV, MO, TN.	IL, MT.
Bauxite	AR, AL, GA.	
Beryllium concentrate	UT.	
Boron minerals	CA.	
Bromine	AR.	
Calcium chloride (natural)	MI and CA.	
Cement:		
Masonry	FL, PA, IN, MI.	All other States except AK, CT, DE, LA, MA, MN, NV, NH, NJ, NC, ND, RI, VT, WI.
Portland	CA, PA, TX, MI.	All other States except CT, DE, LA, MA, MN, NH, NJ, NC, ND, RI, VT, WI.
Clays	GA, WY, FL, TN.	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	(2)	
Feldspar	NC, CA, CT, GA.	ID, OK, SD.
Fluorspar	IL and NV.	
Garnet (abrasive)	ID and NY.	
Gold (content of ores, etc.)	NV, CA, UT, SD.	AK, AZ, CO, ID, MI, MT, NM, OR, SC, WA.
Graphite (natural)	MT.	
Gypsum	TX, IA, MI, OK.	AR, AZ, CA, CO, IN, KS, LA, MT, NM, NV, NY, OH, SD, UT, VA, WA, WY.
Helium	KS, WY, TX, NM.	
Iodine	OK.	
Iron ore (includes byproduct)	MN, MI, MO, UT.	CA, MT, NM, NY, SD, TX.
Iron oxide pigments (crude)	GA, VA, MI, MO.	AZ.
Kyanite	VA.	
Lead (content of ores, etc.)	MO, ID, CO, AK.	AZ, IL, MY, NM, NY, SD, TN.
Lime	MO, OH, PA, AL.	All other States except AK, CT, DE, FL, GA, HI, KS, ME, MD, MS, NH, NJ, NM, NY, NC, RI, SC, VT.
Lithium minerals	NC and NV.	
Magnesite	NV.	
Magnesium compounds	MI, CA, FL, DE.	TX, UT.
Magnesium metal	TX, WA, UT.	
Manganiferous ore	SC.	
Marl (greensand)	NJ.	
Mercury	NV, CA, UT.	
Mica (scrap)	NC, GA, SC, SC.	CO, PA, SD.
Molybdenum	CO, AZ, NV, ID.	CA, MY, NM, UT.
Nickel	OR.	
Olivine	NC AND WA.	
Peat	MI, FL, MN, IL.	CO, GA, IA, IN, MA, MD, ME, MT, NC, ND, NJ, NY, OH, PA, SC, WA, WI.
Perlite	NM, AZ, ID, CA.	CO, NV.
Phosphate rock	FL, NC, ID, UT.	MT, TN.
Platinum-group metals	MT.	

See footnotes at end of table.

TABLE 2—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1989

Mineral	Principal producing States, in order of quantity	Other producing States
Potassium salts	NM, UT, CA, MI.	
Pumice	CA, OR, NM, ID.	HI, KS.
Pyrites (ore and concentrate)	AZ.	
Rare-earth metal concentrate	CA and FL.	
Salt	NY, OH, LA, MI.	AL, AZ, CA, KS, NM, NV, TX, UT, WV.
Sand and gravel:		
Construction	CA, TX, OH, AZ.	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, MT, UT.	AK, AZ, CA, CO, IL, MI, MO, NM, NY, OR, SC, SD, TN, WA.
Sodium carbonate (natural)	WY and CA.	
Sodium sulfate (natural)	CA, TX, UT.	
Staurolite	FL.	
Stone:		
Crushed	PA, FL, VA, GA.	All other States except DE, ND.
Dimension	VT, IN, GA, SD.	All other States except AK, DE, FL, HI, KY, LA, MS, NE, NV, NJ, ND, OR, RI, UT, WV, WY.
Sulfur (Frasch)	TX and LA.	
Talc and pyrophyllite	MT, VT, TX, NC.	AL, AR, CA, GA, NY, OR, VA.
Tin	AK and AZ.	
Titanium concentrates	FL and CA.	
Tripoli	IL, OK, AR, 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.)	TN, MO, NY, CO.	AK, ID, IL, MT, NM.
Zircon concentrate	FL, NJ, AL.	

[1]Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.
[2]No production reported.

TABLE 3

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1989

State	Value (thousands)	Rank	Percent U.S. total	Principal minerals, in order of value
Alabama	$462,752	22	1.43	Stone (crushed), cement (portland), lime, and sand and gravel (construction).
Alaska	213,352	36	.66	Gold, sand and gravel (construction), zinc, and silver.
Arizona	3,040,368	1	9.41	Copper, sand and gravel (construction), molybdenum, cement (portland).
Arkansas	381,909	26	1.18	Bromine, stone (crushed), cement (portland), sand and gravel (construction).
California	2,854,116	2	8.83	Sand and gravel (construction), cement (portland), boron, gold.
Colorado	453,990	23	1.40	Molybdenum, sand and gravel (construction), cement (portland), gold.
Connecticut	113,217	41	.35	Stone (crushed), sand and gravel (construction), feldspar, sand and gravel (industrial).
Delaware[1]	6,201	50	.02	Magnesium compounds, sand and gravel (construction), gem stones.
Florida	1,608,263	4	4.98	Phosphate rock, stone (crushed), cement (portland), sand and gravel (construction).
Georgia	1,387,295	8	4.29	Clays, stone (crushed), cement (portland), stone (dimension).
Hawaii[1]	92,051	44	.28	Stone (crushed), cement (portland), sand and gravel (construction), cement (masonry).
Idaho	366,310	28	1.13	Phosphate rock, silver, molybdenum, gold.
Illinois	633,361	17	1.96	Stone (crushed), cement (portland), sand and gravel (construction), sand and gravel (industrial).
Indiana	434,115	24	1.34	Stone (crushed), cement (portland), sand and gravel (construction), stone (dimension).
Iowa	282,702	33	.87	Stone (crushed), cement (portland), sand and gravel (construction), gypsum (crude).
Kansas	318,131	31	.98	Salt, cement (portland), stone (crushed), helium (Grade-A).
Kentucky	330,659	30	1.02	Stone (crushed), lime, cement (portland), sand and gravel (construction).
Louisiana	379,722	27	1.18	Sulfur (Frasch), salt, sand and gravel (construction), stone (crushed).
Maine	64,654	46	.20	Sand and gravel (construction), cement (portland), stone (crushed), stone (dimension).
Maryland	342,050	29	1.06	Stone (crushed), cement (portland), sand and gravel (construction), cement (masonry).
Massachusetts	144,126	39	.45	Stone (crushed), sand and gravel (construction), stone (dimension), lime.
Michigan	1,598,971	5	4.95	Iron ore (includes byproduct material), cement (portland), sand and gravel (construction), stone crushed).
Minnesota	1,438,135	7	4.45	Iron ore (includes byproduct material), sand and gravel (construction), stone (crushed), stone (dimension).
Mississippi	107,610	42	.33	Sand and gravel (construction), clays, cement (portland), stone (crushed).
Missouri	1,050,056	11	3.25	Lead, cement (portland), stone (crushed), lime.
Montana	599,239	18	1.85	Copper, gold, platinum-group metals, molybdenum.
Nebraska	103,817	43	.32	Sand and gravel (construction), cement (portland), stone (crushed), lime.
Nevada	2,319,068	3	7.18	Gold, silver, sand and gravel (construction), molybdenum.
New Hampshire[1]	33,240	47	.10	Sand and gravel (construction), stone (dimension), stone (crushed), clays.
New Jersey	248,883	34	.77	Stone (crushed), sand and gravel (construction), sand and gravel (industrial), zircon concentrates.
New Mexico	1,124,592	10	3.48	Copper, potassium salts, sand and gravel (construction), silver.
New York	745,168	14	2.31	Stone (crushed), salt, cement (portland), sand and gravel (construction).
North Carolina	581,568	19	1.80	Stone (crushed), phosphate rock, lithium minerals, sand and gravel (construction).
North Dakota	13,660	48	.04	Sand and gravel (construction), lime, clays, peat.
Ohio	699,156	15	2.16	Stone (crushed), sand and gravel (construction),salt, lime.
Oklahoma	219,031	35	.68	Stone (crushed), cement (portland), iodine, sand and gravel (construction).
Oregon	185,556	37	.57	Stone (crushed), sand and gravel (construction), cement (portland), lime.
Pennsylvania	1,000,669	12	3.10	Stone (crushed), cement (portland), sand and gravel (construction), lime.
Rhode Island[1]	11,072	49	.03	Stone (crushed), sand and gravel (construction), sand and gravel (industrial), gem stones.
South Carolina	425,297	25	1.32	Stone (crushed), gold, cement (portland), clays.
South Dakota	284,358	32	.88	Gold, cement (portland), sand and gravel (construction), stone (dimension).
Tennessee	638,407	16	1.98	Stone (crushed), zinc, cement (portland), clays.
Texas	1,462,453	6	4.53	Cement (portland), magnesium metal, stone (crushed), sulfer (Frasch).
Utah	1,290,450	9	3.99	Copper, gold, magnesium metal, cement (portland).
Vermont	88,902	45	.28	Stone (crushed), stone (dimension), sand and gravel (construction), talc and pyrophyllite.
Virginia	509,130	20	1.58	Stone (crushed), sand and gravel (construction), lime, cement (portland).
Washington	480,879	21	1.49	Sand and gravel (construction), magnesium metal, gold, stone (crushed).
West Virginia	125,498	40	.39	Stone (crushed), cement (portland), salt, sand and gravel (industrial).
Wisconsin[1]	185,277	38	.57	Stone (crushed), sand and gravel (construction), sand and gravel (industrial), lime.
Wyoming	827,361	13	2.56	Sodium carbonate (natural), clays, helium (Grade-A), sand and gravel (construction).
Undistributed	9,043	—	—	
Total[2]	32,316,000	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 PER CAPITA AND PER SQUARE MILE IN 1989, BY STATE

State	Area (square miles)	Population (thousands)	Total (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Alabama	51,705	4,118	$462,752	8,950	27	112	21
Alaska	591,004	527	213,352	361	49	405	7
Arizona	114,000	3,556	3,040,368	26,670	5	855	3
Arkansas	53,187	2,406	381,909	7,180	31	159	14
California	158,706	29,063	2,854,116	17,984	10	98	24
Colorado	104,091	3,317	453,990	4,361	37	137	16
Connecticut	5,018	3,239	113,217	22,562	7	35	44
Delaware	2,044	673	[1]6,201	3,034	44	9	50
Florida	58,664	12,671	1,608,263	27,415	3	127	18
Georgia	58,910	6,436	1,387,295	23,549	6	216	11
Hawaii	6,471	1,112	[1]92,051	14,225	18	83	31
Idaho	83,564	1,014	366,310	4,384	36	361	9
Illinois	56,345	11,658	633,361	11,241	22	54	39
Indiana	36,185	5,593	434,115	11,997	21	78	32
Iowa	56,275	2,840	282,702	5,024	35	100	23
Kansas	82,277	2,513	318,131	3,867	39	127	19
Kentucky	40,409	3,727	330,659	8,183	29	89	25
Louisiana	47,751	4,382	379,722	7,952	30	87	27
Maine	33,265	1,222	64,654	1,944	46	53	40
Maryland	10,460	4,694	342,050	32,701	1	73	33
Massachusetts	8,284	5,913	144,126	17,398	11	24	47
Michigan	58,527	9,273	1,598,971	27,320	4	172	13
Minnesota	84,402	4,353	1,438,135	17,039	12	330	10
Mississippi	47,689	2,621	107,610	2,256	45	41	42
Missouri	69,697	5,159	1,050,056	15,066	17	204	12
Montana	147,046	806	599,239	4,075	38	743	5
Nebraska	77,355	1,611	103,817	1,342	48	64	37
Nevada	110,561	1,111	2,319,068	20,975	9	2,087	1
New Hampshire	9,279	1,107	[1]33,240	3,582	41	30	46
New Jersey	7,787	7,736	248,883	31,961	2	32	45
New Mexico	121,593	1,528	1,124,592	9,249	24	736	6
New York	49,107	17,950	745,168	15,174	15	42	41
North Carolina	52,669	6,571	581,568	11,042	23	89	26
North Dakota	70,703	660	13,660	193	50	21	48
Ohio	41,330	10,907	699,156	16,916	13	64	38
Oklahoma	69,956	3,224	219,031	3,131	43	68	34
Oregon	97,073	2,820	185,556	1,912	47	66	36
Pennsylvania	45,308	12,040	1,000,669	22,086	8	83	30
Rhode Island	1,212	998	[1]11,072	9,135	26	11	49
South Carolina	31,113	3,512	425,297	13,669	19	121	20
South Dakota	77,116	715	284,358	3,687	40	398	8
Tennessee	42,144	4,940	638,407	15,148	16	129	17
Texas	266,807	16,991	1,462,453	5,481	33	86	28
Utah	84,899	1,707	1,290,450	15,200	14	756	4
Vermont	9,614	567	88,902	9,247	25	157	15
Virginia	40,767	6,098	509,130	12,489	20	83	29
Washington	68,138	4,761	480,879	7,057	32	101	22
West Virginia	24,231	1,857	125,498	5,179	34	68	35
Wisconsin	56,153	4,867	[1]185,277	3,300	42	38	43
Wyoming	97,809	475	827,361	8,459	28	1,742	2
Undistributed	XX	XX	9,043	XX	XX	XX	XX
Total[2] or average	3,618,700	247,639	[3]32,316,000	8,930	XX	130	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 604,000.

[3]Data do not add to total shown because of independent rounding.

Sources: Bureau of Mines and Bureau of the Census.

TABLE 5

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
ALABAMA							
Cement:							
Masonry	thousand short tons	291	$17,626	273	$16,457	252	$13,852
Portland	do.	3,600	160,878	3,524	157,214	3,169	130,590
Clays[2]	metric tons	2,031,163	16,217	2,282,670	16,039	1,878,070	18,537
Gem stones		NA	7	NA	5	NA	W
Lime	thousand short tons	1,232	52,200	1,450	66,576	1,481	70,361
Sand and gravel:							
Construction	do.	e10,300	e35,600	11,742	41,417	e10,400	e36,500
Industrial	do.	580	5,025	871	8,507	805	8,092
Stone (crushed)	do.	30,018	146,247	e29,700	e140,100	31,737	167,332
Combined value of bauxite, clays (bentonite), salt, stone (crushed granite 1989, dimension), talc and pyrophyllite (1988-89), zircon concentrates, (1988-89), and value indicated by symbol W		XX	12,843	XX	13,180	XX	17,487
Total		XX	446,643	XX	459,495	XX	462,751
ALASKA							
Gem stones		NA	$86	NA	$50	NA	W
Gold[4]	kilograms	3,812	r54,895	4,210	59,320	5,756	$70,800
Sand and gravel (construction)	thousand short tons	e27,200	e73,400	17,200	48,749	e17,000	e48,500
Silver[4]	metric tons	(5)	111	1	135	W	W
Stone (crushed)	thousand short tons	2,033	8,945	e1,800	e8,400	2,900	20,300
Combined value of cement (portland), lead (1989), tin, zinc (1989), and values indicated by symbol W		XX	4,010	XX	2,040	XX	73,752
Total		XX	141,447	XX	118,694	XX	213,352
ARIZONA							
Clays	short tons	218,151	$1,905	185,620	$1,590	188,211	$2,506
Copper[4]	metric tons	751,073	1,365,994	r842,728	r2,238,875	898,315	2,593,292
Diatomite	do.	7,257	1,208	W	W		
Gem stones		NA	3,000	NA	3,300	NA	2,821
Gold[4]	kilograms	1,791	25,798	4,549	64,106	2,810	34,564
Lime	do.	546	21,932	674	29,637	W	W
Perlite	thousand short tons	49	1,361	W	W	W	W
Pumice	thousand metric tons	907	7	907	7	—	—
Sand and gravel: Construction	do.	e38,100	e141,300	32,399	123,854	e33,900	e133,900
Industrial	do.	W	W	119	3,045	W	W
Silver[4]	metric tons	114	25,666	152	31,974	171	30,186
Stone:							
Crushed	thousand short tons	7,712	33,999	e7,400	e33,000	6,649	28,552
Dimension	short tons	W	e1	W	W		
Combined value of cement, gypsum, iron oxide pigments (crude, 1989), lead (1988-89), molybdenum, pyrites, salt, tin (1988-89), and values indicated by symbol W		XX	129,398	XX	235,596	XX	214,546
Total		XX	1,750,360	XX	2,766,193	XX	3,040,367

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
ARKANSAS							
Abrasives[6]	metric tons	W	W	1,120	$429	W	W
Clays	do.	824,082	$8,651	844,466	15,376	901,308	$17,391
Gem stones		NA	1,800	NA	2,300	NA	4,041
Sand and gravel:							
Construction	thousand short tons	e7,200	e23,900	7,722	26,201	e7,500	e25,500
Industrial	do.	505	5,147	669	6,784	545	5,507
Stone:							
Crushed	do.	15,234	63,847	e17,100	e70,100	318,791	376,419
Dimension	short tons	10,541	629	e10,541	e629	W	W
Combined value of bauxite, bromine,[e] cement, gypsum, lime, stone (crushed slate and dolomite, 1989), talc and pyrophyllite, tripoli, vanadium (1989), and values indicated by symbol W		XX	160,188	XX	184,970	XX	253,051
Total		XX	264,162	XX	306,789	XX	381,909
CALIFORNIA							
Boron minerals[7]	metric tons	625,051	$475,092	577,877	$429,667	1,114,007	$429,806
Cement:							
Masonry	thousand short tons	W	W	8	730	W	W
Portland	do.	9,937	593,859	10,423	601,152	10,911	642,020
Clays	metric tons	2,083,200	33,045	2,015,488	31,620	2,195,830	39,243
Gem stones		NA	3,367	NA	3,365	NA	2,982
Gold[4]	kilograms	18,743	269,937	22,442	316,246	29,804	366,595
Gypsum	thousand short tons	1,468	11,719	1,490	11,222	1,734	13,066
Lime	do.	465	25,745	r458	r20,242	395	24,503
Mercury	metric tons	(5)	(5)	W	W	W	W
Peat	thousand short tons	W	W	2	119	—	—
Pumice	short tons	42,000	1,539	35,000	1,245	79	4,612
Sand and gravel:							
Construction	thousand short tons	e141,600	e561,300	141,946	622,074	e138,300	e670,800
Industrial	do.	2,241	41,472	2,444	42,078	2,426	43,863
Silver[4]	metric tons	4	854	15	3,148	21	3,650
Stone:							
Crushed	thousand short tons	44,315	186,504	e49,100	e275,000	54,887	238,034
Dimension	short tons	33,335	4,554	e42,048	e5,991	28,829	5,564
Combined value of asbestos, barite (1987-88), calcium chloride (natural), copper (1988-89), diatomite, feldspar, diatomite, feldspar, iron ore (includes byproduct material, 1988-89), magnesium compounds, molybdenum, perlite, potassium salts, rare-earth metal concentrates, salt, sodium carbonate (natural), sodium sulfate (natural), talc and prophyllite, titanium concentrates ilmenite, 1989), tungsten ore concentrates, wollastonite (1987), and values indicated by symbol W		XX	342,298	XX	334,755	XX	369,378
Total		XX	2,551,285	XX	2,698,654	XX	2,854,116

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
COLORADO							
Clays	metric tons	264,944	$1,763	247,471	$1,890	265,435	$2,064
Copper[4]	do.	W	W	898	2,386	W	W
Gem stones		NA	100	NA	100	NA	240
Gold[4]	kilograms	5,561	80,091	5,126	72,237	3,448	42,411
Peat	thousand short tons	W	W	W	W	W	412
Sand and gravel (construction)	do.	e22,800	e84,300	21,566	69,882	e25,300	e104,000
Silver[4]	metric tons	27	6,033	27	5,588	W	W
Stone:							
Crushed	thousand short tons	8,045	33,465	e10,600	e42,400	37,261	32,435
Dimension	short tons	3,000	133	e3,450	e143	5,310	398
Combined value of cement, gypsum, lead, lime, mica (crude, 1989), molybdenum, perlite, pyrites (1987), sand and gravel (industrial), stone (crushed traprock, 1989), vanadium, zinc, and values indicated by symbol W		XX	167,104	XX	169,379	XX	272,030
Total		XX	372,989	XX	364,005	XX	453,990
CONNECTICUT							
Gem stones		NA	$2	NA	$2	NA	$2
Sand and gravel (construction)	thousand short tons	e8,400	e37,000	8,275	32,102	e5,800	e24,700
Stone:							
Crushed	do.	11,412	76,668	e11,400	e76,900	311,480	378,734
Dimension	short tons	18,140	1,646	e19,718	e1,914	W	W
Combined value of clays (common), feldspar, mica (scrap, 1987-88), sand and gravel (industrial), stone (crushed granite, 1989), and value indicated by symbol W		XX	6,959	XX	7,198	XX	9,780
Total		XX	122,275	XX	118,116	XX	113,216
DELAWARE							
Gem stones		NA	$1	NA	$1	NA	$1
Marl (greensand)	short tons	W	W	750	10	—	—
Sand and gravel (construction)	thousand short tons	e2,300	e6,400	1,933	5,988	e1,900	e6,200
Total[8]		XX	6,401	XX	5,999	XX	6,201
FLORIDA							
Cement:							
Masonry	thousand short tons	390	$24,069	411	$25,892	477	$31,231
Portland	do.	3,565	165,944	3,682	168,719	4,357	207,857
Clays	metric tons	541,760	39,496	536,922	44,423	2563,687	246,941
Peat	thousand short tons	363	6,068	266	5,091	235	4,515
Sand and gravel:							
Construction	do.	e30,000	e74,900	18,654	53,083	e17,900	e55,500
Industrial	do.	1,884	19,713	636	6,928	681	7,768
Stone (crushed)	do.	378,992	3350,537	e 383,200	e 3374,400	83,995	341,397
Combined value of clays (common), gem stones, magnesium compounds (1988-89), phosphate rock, rare-earth metal concentrates, staurolite, stone (crushed marl 1987-88), titanium concentrates (ilmenite and rutile), and zircon concentrates		XX	665,510	XX	713,345	XX	913,054
Total		XX	1,346,237	XX	1,391,881	XX	1,608,263

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
GEORGIA							
Clays	metric tons	9,484,392	$756,093	10,274,358	$908,771	9,768,312	$1,004,954
Gem stones		NA	20	NA	20	NA	21
Sand and gravel:							
Construction	thousand short tons	e9,000	e26,900	9,526	30,185	e6,100	e18,900
Industrial	do.	W	W	W	W	537	7,013
Stone:							
Crushed	do.	60,834	318,903	e57,400	e317,200	50,417	262,805
Dimension	short tons	179,207	21,683	e190,472	e27,768	3145,545	312,087
Talc and pyrophyllite	do.	20,100	286	26,000	260	W	W
Combined value of barite, bauxite, cement, feldspar, iron oxide pigments (crude), mica (scrap), peat, stone (dimension marble, 1989), and values indicated by symbol W		XX	88,485	XX	89,621	XX	81,515
Total		XX	1,212,370	XX	1,373,825	XX	1,387,295
HAWAII							
Cement:							
Masonry	thousand short tons	10	$1,559	10	$1,531	10	$1,566
Portland	do.	324	26,550	354	28,880	493	40,495
Gem stones		NA	25	NA	W	NA	44
Lime	thousand short tons	3	W	W	W	—	—
Sand and gravel (construction)	do.	e700	e3,500	652	3,173	e600	e3,200
Stone (crushed)	do.	5,732	41,548	e5,700	e41,000	6,205	46,746
Combined value of other industrial minerals and values indicated by symbol W		XX	297	XX	348	XX	(9)
Total		XX	73,479	XX	74,932	XX	392,051
IDAHO							
Clays[2]	metric tons	8,114	W	8,519	W	W	W
Copper[4]	do.	W	W	2,269	$6,028	2,950	$8,516
Feldspar	short tons	—	—	—	—	12,800	720
Gem stones		NA	$507	NA	500	NA	500
Gold[4]	kilograms	3,041	43,797	3,218	45,349	3,057	37,602
Lime	thousand short tons	97	5,149	W	W	W	W
Phosphate rock	thousand metric tons	3,411	47,072	4,706	81,011	W	W
Sand and gravel:							
Construction	thousand short tons	e7,200	e28,000	6,914	19,897	e5,800	e18,900
Industrial	do.	W	W	483	5,089	459	5,037
Silver[4]	metric tons	W	W	340	71,512	439	77,651
Stone (crushed)	thousand short tons	3,852	15,346	e3,400	e13,100	3,298	12,609
Combined value of antimony (1988-89), cement, clays, (bentonite, common, kaolin), garnet (abrasive), lead, molybdenum (1987, 1989), perlite, pumice, stone (dimension), vanadium, zinc, and values indicated by symbol W		XX	r129,502	XX	48,130	XX	204,775
Total		XX	269,373	XX	290,616	XX	366,310
ILLINOIS							
Cement (portland)	thousand short tons	2,119	$86,210	2,307	$101,760	2,776	$117,224
Clays[2]	metric tons	211,328	977	163,571	704	142,207	641
Gem stones		NA	15	NA	30	NA	W

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
ILLINOIS—Continued							
Sand and gravel:							
Construction	thousand short tons	e28,300	e$93,300	30,098	$93,504	e33,000	e$108,900
Industrial	do.	4,346	45,547	4,328	56,142	4,582	52,935
Stone:							
Crushed	do.	52,102	216,212	e57,900	e251,200	360,829	3256,832
Dimension	short tons	W	W	e1,175	e129	W	W
Combined value of barite (1989), cement (masonry), clays (fuller's earth), copper, fluorspar, lead, lime, peat, silver, stone (crushed sandstone, 1989), tripoli, zinc, and values indicated by symbol W		XX	74,945	XX	84,157	XX	96,829
Total		XX	517,206	XX	587,626	XX	633,361
INDIANA							
Cement:							
Masonry	thousand short tons	422	$32,299	405	$27,442	357	$24,054
Portland	do.	2,320	103,177	2,315	107,179	2,364	108,297
Clays	metric tons	2940,451	24,056	1,035,837	4,630	871,179	3,836
Gem stones		NA	10	NA	10	NA	W
Peat	thousand short tons	44	W	54	W	34	607
Sand and gravel:							
Construction	do.	e18,900	e65,200	25,923	79,985	e29,600	e99,200
Industrial	do.	230	1,357	362	1,829	W	W
Stone:							
Crushed	do.	31,067	106,770	e36,600	e130,000	336,188	3136,252
Dimension	short tons	183,609	23,115	e195,444	e24,956	3198,531	327,212
Combined value of abrasives, clays (fire clay 1987), gypsum, lime, stone (crushed marl and miscellaneous, 1989, dimension sandstone, 1989), and values indicated by symbol W		XX	27,881	XX	30,358	XX	34,657
Total		XX	363,865	XX	406,389	XX	434,115
IOWA							
Cement:							
Masonry	thousand short tons	W	W	W	W	47	$4,450
Portland	do.	2,139	$104,457	2,029	$98,930	2,072	102,387
Clays	metric tons	428,907	1,495	403,923	1,588	439,323	1,773
Gem stones		NA	W	NA	W	NA	10
Gypsum	thousand short tons	1,874	12,887	2,047	13,710	2,273	16,884
Peat	do.	24	W	r15	433	W	W
Sand and gravel (construction)	do.	e19,000	e63,800	11,880	36,087	e12,800	e37,800
Stone:							
Crushed	do.	25,991	110,106	e29,200	e128,500	28,049	111,182
Dimension	short tons	W	W	W	e588	15,151	613
Combined value of other industrial minerals and values indicated by symbol W		XX	12,332	XX	10,420	XX	7,603
Total		XX	305,077	XX	290,256	XX	282,702
KANSAS							
Cement:							
Masonry	thousand short tons	52	$3,150	50	$2,988	42	$2,514
Portland	do.	1,697	81,045	1,569	72,805	1,505	69,390
Clays[2]	metric tons	547,650	2,576	555,739	2,632	533,099	2,700
Gem stones		NA	3	NA	3	NA	W
Salt[10]	thousand short tons	1,689	70,148	1,284	55,753	1,948	82,212

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
KANSAS—Continued							
Sand and gravel:							
Construction	thousand short tons	e15,600	e$37,800	10,760	$25,329	e13,000	e$33,200
Industrial	do.	127	1,400	W	W	230	2,690
Stone:							
Crushed	do.	19,319	69,628	e17,300	e72,700	315,850	356,976
Dimension	short tons	11,423	445	e6,889	e219	W	W
Combined value of clay (bentonite), gypsum, helium (crude and Grade-A), pumice, salt (brine), stone (crushed sandstone and quartzite, 1989), and values indicated by symbol W		XX	53,409	XX	59,284	XX	68,449
Total		XX	319,604	XX	291,713	XX	318,131
KENTUCKY							
Clays[2]	metric tons	801,287	$3,393	762,324	$3,217	716,990	$3,357
Gem stones		NA	3	NA	3	NA	W
Sand and gravel (construction)	thousand short tons	e7,100	e15,200	6,325	15,243	e5,500	e15,100
Stone (crushed)	do.	43,330	173,222	e50,700	e207,900	448,178	4187,849
Zinc[4]	metric tons	10	9	W	W	—	—
Combined value of cement, clays (ball clay, fire clay), lime, sand and gravel (industrial, 1987, 1989), stone (crushed dolomite, 1989), and values indicated by symbol W		XX	98,508	XX	118,616	XX	124,353
Total		XX	290,335	XX	344,979	XX	330,659
LOUISIANA							
Clays	metric tons	323,778	$9,192	340,900	$9,535	233,992	$6,115
Gem stones		NA	1	NA	3	NA	14
Salt	thousand short tons	12,498	108,999	14,274	108,982	13,218	115,203
Sand and gravel:							
Construction	do.	e12,200	e43,600	14,233	52,820	e13,600	e54,400
Industrial	do.	289	3,997	318	4,786	572	9,664
Stone (crushed)	do.	34,390	336,514	e 33,700	e 329,200	3,206	24,414
Sulfur (Frasch)	thousand metric tons	1,458	W	1,719	W	1,334	W
Combined value of cement [masonry (1987-88), portland, (1987-88)], gypsum, lime, stone (crushed miscellaneous, (1987-88), and values values indicated by symbol W		XX	221,918	XX	229,210	XX	169,912
Total		XX	424,221	XX	434,536	XX	379,722
MAINE							
Gem stones		NA	$1,172	NA	$150	NA	W
Sand and gravel (construction)	thousand short tons	e8,600	e22,100	10,183	33,007	e8,600	e$30,100
Stone:							
Crushed	do.	2,010	7,532	e1,400	e5,300	1,591	8,801
Dimension	short tons	7,512	5,924	e7,512	e5,924	W	W
Combined value of cement, clays (common), garnet (abrasive 1987-88), peat (1988-89), and values indicated by symbol W		XX	28,729	XX	23,379	XX	25,753
Total		XX	65,457	XX	67,760	XX	64,654

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
MARYLAND							
Cement (portland)	thousand short tons	1,829	$90,020	1,808	$89,083	1,871	$94,002
Clays	metric tons	347,501	1,940	357,833	2,016	351,464	1,882
Gem stones		NA	5	NA	5	NA	3
Lime	thousand short tons	9	486	6	329	—	—
Peat	do.	W	W	7	W	3	W
Sand and gravel (construction)	do.	e19,600	e92,900	19,266	95,169	e16,900	e84,500
Stone:							
Crushed	do.	30,136	151,579	e32,700	e167,000	30,841	153,375
Dimension	short tons	22,843	1,516	e20,729	e1,515	27,529	2,072
Combined value of other industrial minerals and values indicated by symbol W		XX	6,688	XX	7,804	XX	6,216
Total		XX	345,134	XX	362,921	XX	342,050
MASSACHUSETTS							
Gem stones		NA	$1	NA	$1	NA	$3
Sand and gravel:							
Construction	thousand short tons	e21,800	e75,300	22,168	79,364	e13,900	e57,000
Industrial	do.	56	922	W	W	34	601
Stone:							
Crushed	do.	14,907	78,969	e17,500	e91,900	11,880	67,768
Dimension	short tons	76,579	12,747	W	W	67,533	10,302
Combined value of clays (common), lime, peat, and values indicated by symbol W		XX	8,583	XX	20,973	XX	8,452
Total		XX	176,522	XX	192,238	XX	144,126
MICHIGAN							
Cement:							
Masonry	thousand short tons	263	$23,004	265	$22,915	255	$22,286
Portland	do.	4,755	207,332	5,253	231,141	5,449	253,324
Clays	metric tons	1,209,730	5,338	1,248,121	4,432	1,249,198	4,599
Gem stones		NA	25	NA	25	NA	10
Gypsum	thousand short tons	1,977	12,190	1,958	11,630	2,089	15,589
Iron ore	thousand metric tons	12,509	W	14,623	W	15,045	W
Lime	thousand short tons	569	30,320	714	36,088	621	32,479
Peat	do.	281	5,290	r322	6,256	286	6,082
Sand and gravel:							
Construction	do.	e42,800	e105,300	53,508	138,171	e48,000	e132,000
Industrial	do.	2,792	22,451	3,045	27,150	2,865	24,577
Stone (crushed)	do.	37,909	109,514	e38,800	e120,300	40,905	123,678
Combined value of bromine (1987-88), calcium chloride (natural), copper, gold, iron oxide pigments (crude), magnesium compounds, potassium salts (1989), salt, silver, stone (dimension), and values indicated by symbol W		XX	844,846	XX	989,453	XX	984,347
Total		XX	1,365,610	XX	1,587,561	XX	1,598,971
MINNESOTA							
Gem stones		NA	$40	NA	$40	NA	$42
Iron ore	thousand metric tons	34,274	1,012,788	40,735	1,134,539	41,044	1,285,807
Peat	thousand short tons	30	W	29	r1,414	27	1,415
Sand and gravel (construction)	do.	e25,200	e67,400	33,769	72,678	e33,700	e82,600

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
MINNESOTA—Continued							
Stone:							
Crushed	thousand short tons	8,995	$29,246	e8,300	e$28,200	8,760	$30,218
Dimension	short tons	41,354	12,967	e45,000	e13,000	44,605	16,031
Combined value of clays (common, kaolin), lime, sand and gravel (industrial) and value indicated by symbol W		XX	20,308	XX	18,015	XX	22,022
Total		XX	1,142,749	XX	1,267,886	XX	1,438,135
MISSISSIPPI							
Clays[2]	short tons	838,826	$13,044	1,093,316	$24,564	899,373	$23,573
Gem stones		NA	1	NA	1	NA	5
Sand and gravel (construction)	thousand short tons	e14,700	e47,000	13,314	38,806	e15,600	e51,500
Stone (crushed)	do.	1,492	9,621	e1,500	e9,000	1,069	3,994
Combined value of cement (masonry, portland), clays (ball clay, fuller's earth, 1987), and sand and gravel (industrial)		XX	40,413	XX	31,029	XX	28,539
Total		XX	110,079	XX	103,400	XX	107,611
MISSOURI							
Barite	thousand metric tons	24	$2,030	24	$1,930	W	W
Cement:							
Masonry	thousand short tons	167	10,027	153	6,310	W	W
Portland	do.	5,110	185,317	4,679	184,755	4,922	$182,005
Clays[2]	metric tons	1,338,858	10,414	1,435,045	12,171	1,479,898	14,665
Iron ore	thousand metric tons	756	W	816	W	1,060	W
Lead[4]	metric tons	W	W	353,194	289,194	366,931	318,320
Sand and gravel:							
Construction	thousand short tons	e10,900	e30,400	11,217	32,941	e10,000	e32,500
Industrial	do.	622	7,786	744	9,876	750	9,972
Silver[4]	metric tons	37	8,276	45	9,550	53	9,456
Stone:							
Crushed	thousand short tons	54,910	184,824	e52,100	e183,000	51,754	171,848
Dimension	short tons	3,212	454	e3,644	e547	W	W
Zinc[4]	metric tons	34,956	32,306	41,322	54,842	50,790	91,885
Combined value of clays (fuller's earth), copper, gem stones, iron oxide pigments (crude), lime, and values indicated by symbol W		XX	391,206	XX	182,833	XX	219,405
Total		XX	863,040	XX	967,949	XX	1,050,056
MONTANA							
Clays[2]	metric tons	26,199	$98	91,802	$1,416	95,743	$1,835
Gem stones		NA	1,302	NA	1,602	NA	2,500
Gold[4]	kilograms	234,365	104,984	294,976	129,291	11,623	142,965
Gypsum	thousand short tons	24	W	27	W	W	W
Lead[4]	metric tons	W	W	8,266	6,768	W	W
Platinum-group metals	do.	W	W	W	W	6,280	85,318
Sand and gravel (construction)	thousand short tons	e6,800	e18,800	7,984	20,225	e5,800	e13,900
Silver[4]	metric tons	185	41,619	192	40,457	194	34,367
Stone (crushed)	thousand short tons	1,463	3,585	e1,800	e4,500	2,846	9,718
Talc and pyrophyllite	do.	356,231	11,334	377,789	11,309	500,424	12,718
Zinc[4]	metric tons	W	W	18,935	25,130	W	W

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
MONTANA—Continued							
Combined value of barite (1987, 1989), cement, clay (fire clay), copper, graphite (natural 1988-89), iron ore, lime, molybdenum, peat, phosphate rock, sand and gravel (indistrial), stone (dimension), vermiculite, and values indicated by symbol W		XX	$186,456	XX	r$332,630	XX	$295,918
Total		XX	368,178	XX	573,328	XX	599,239
NEBRASKA							
Clays	metric tons	202,963	$721	215,419	$786	224,624	$880
Gem stones		NA	10	NA	10	NA	2
Sand and gravel (construction)	thousand short tons	e10,300	e26,300	11,229	28,928	e15,200	e41,800
Stone (crushed)	do.	4,316	19,461	e4,900	e22,000	3,978	20,050
Combined value of cement, lime, and sand and gravel (industrial)		XX	43,256	XX	39,468	XX	41,085
Total		XX	89,748	XX	91,192	XX	103,817
NEVADA							
Barite	thousand metric tons	279	$4,778	289	$5,053	209	$3,473
Clays[2]	metric tons	10,704	810	26,186	2,143	57,264	5,457
Gem stones		NA	280	NA	280	NA	1,402
Gold[4]	kilograms	83,341	1,200,269	114,322	1,611,020	154,573	1,901,280
Perlite	short tons	W	W	5,000	142	5	136
Sand and gravel:							
Construction	thousand short tons	e10,600	e30,700	15,729	50,928	e20,000	e70,000
Industrial	do.	578	W	602	W	718	W
Silver[4]	metric tons	379	85,429	608	127,760	625	110,442
Stone (crushed)	thousand short tons	31,264	35,700	e 31,300	e 35,700	1,560	4,638
Combined value of cement (portland), clays [fuller's earth (1987), kaolin], copper (1988), diatomite, fluorspar, gypsum, lead (1988), lime, lithium minerals, magnesite, mercury, molybdenum (1989), salt, stone (crushed dolomite), and values indicated by symbol W		XX	r128,063	XX	r151,356	XX	222,240
Total		XX	1,456,029	XX	1,954,382	XX	2,319,068
NEW HAMPSHIRE							
Gem stones		NA	$310	NA	$100	NA	$51
Sand and gravel (construction)	thousand short tons	e9,100	e33,300	9,089	32,614	e6,000	e20,400
Stone:							
Crushed	do.	2,479	10,386	e2,400	e9,800	771	4,020
Dimension	short tons	67,479	10,684	e73,393	e10,546	55,305	8,769
Total[8]		XX	54,680	XX	53,060	XX	33,240
NEW JERSEY							
Clays[2]	metric tons	5,430	$140	14,954	$368	18,492	$400
Gem stones		NA	3	NA	3	NA	3
Peat	thousand short tons	32	614	43	797	W	638
Sand and gravel:							
Construction	do.	e15,200	e61,200	18,318	74,183	e15,200	e68,400
Industrial	do.	2,112	27,872	1,860	25,437	1,797	26,138
Stone (crushed)	do.	317,576	3111,951	e 319,300	e 3123,500	20,799	140,998

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
NEW JERSEY—Continued							
Zircon concentrates	metric tons	W	W	W	W	W	$8,988
Combined value of clays (common), marl (greensand), stone (crushed limestone, 1987-88), and values indicated by symbol W		XX	$12,444	XX	$17,544	XX	$3,318
Total		XX	214,224	XX	241,832	XX	248,883
NEW MEXICO							
Clays	metric tons	46,491	$141	28,555	$83	31,012	$94
Copper[4]	do.	246,532	448,373	258,660	687,182	259,432	748,939
Gem stones		NA	200	NA	200	NA	279
Gold[4]	kilograms	W	W	W	W	1,076	13,231
Perlite	short tons	437,000	13,611	458,000	14,294	487	13,080
Potassium salts	thousand metric tons	1,323	174,200	1,271	213,800	1,365	242,619
Pumice	do.	79	991	76	852	77	795
Sand and gravel (construction)	thousand short tons	e8,600	e31,000	8,787	31,367	e11,800	e45,400
Stone:							
Crushed	do.	4,503	15,919	e3,500	e13,900	2,784	11,672
Dimension	short tons	21,893	626	e21,893	e626	W	W
Combined value of cement, gypsum, helium (Grade-A), iron ore (includes byproduct material), lead, mica (scrap), molybdenum, pyrites (1987), salt, silver, zinc (1989), and values indicated by symbol W		XX	52,783	XX	r60,368	XX	48,483
Total		XX	737,844	XX	1,022,672	XX	1,124,592
NEW YORK							
Cement:							
Masonry	thousand short tons	W	W	W	W	138	$7,971
Portland	do.	W	W	W	W	2,654	134,032
Clays	metric tons	610,205	$3,562	551,375	$3,654	531,559	3,429
Emery	short tons	1,945	W	W	W	—	—
Gem stones		NA	135	NA	200	NA	350
Peat	thousand short tons	1	34	W	W	W	10
Salt	do.	4,918	119,962	4,614	127,994	5,424	161,427
Sand and gravel:							
Construction	do.	e31,400	e112,900	33,884	124,341	e31,600	e118,500
Industrial	do.	58	651	53	625	53	633
Stone:							
Crushed	do.	38,103	188,694	e39,900	e193,500	39,851	201,749
Dimension	short tons	38,553	5,822	e30,751	e4,333	23,756	3,575
Combined value of garnet, gypsum, iron ore (includes byproduct material, 1988-89), lead, silver, talc and prophyllite, wollastonite, zinc, and values indicated by symbol W		XX	218,620	XX	241,053	XX	113,492
Total		XX	650,380	XX	695,700	XX	745,168
NORTH CAROLINA							
Clays	metric tons	2,929,351	$15,282	2,880,103	$16,349	2,270,384	$15,529
Feldspar	short tons	512,386	15,562	507,986	17,312	480,436	14,024
Gem stones		NA	550	NA	688	NA	784
Mica (scrap)	thousand metric tons	91	5,607	79	4,512	73	4,192
Peat	thousand short tons	W	W	21	W	W	W

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
NORTH CAROLINA—Continued							
Sand and gravel:							
Construction	thousand short tons	e8,600	e$30,100	11,076	$38,459	e11,200	e$43,700
Industrial	do.	1,184	15,329	1,246	15,953	1,627	19,902
Stone:							
Crushed	do.	48,847	237,181	e50,500	e250,000	51,519	257,976
Dimension	short tons	32,669	5,128	e31,977	e5,026	62,665	10,477
Combined value of lithium minerals, olivine, phosphate rock, talc and pyrophyllite, and values indicated symbol W		XX	152,178	XX	181,135	XX	214,984
Total		XX	476,917	XX	529,434	XX	581,568
NORTH DAKOTA							
Clays	metric tons	45,451	$100	76,918	$147	47,903	W
Gem stones		NA	2	NA	2	NA	$10
Lime	thousand short tons	127	11,912	108	7,094	107	5,439
Sand and gravel (construction)	do.	e4,900	e10,200	3,772	8,079	e3,600	e8,100
Combined value of peat, salt (1987-88), sand and gravel (industrial, 1987), stone (crushed miscellaneous, 1987-88) and value indicated by symbol W		XX	4,097	XX	3,485	XX	111
Total		XX	26,311	XX	18,807	XX	13,660
OHIO							
Cement:							
Masonry	thousand short tons	139	$11,964	129	$11,140	128	$11,233
Portland	do.	1,748	83,661	1,424	70,816	1,446	73,230
Clays	metric tons	2,891,446	12,714	3,365,164	14,423	3,519,668	14,983
Gem stones		NA	10	NA	10	NA	18
Lime	thousand short tons	1,926	93,108	2,065	87,431	1,888	94,157
Peat	do.	W	W	W	W	8	182
Salt	do.	3,276	104,099	3,795	115,860	W	W
Sand and gravel:							
Construction	do.	e36,400	e136,900	46,104	156,318	e44,400	e148,700
Industrial	do.	1,249	21,292	1,361	23,441	1,394	24,662
Stone:							
Crushed	do.	51,590	300,096	e48,000	e252,000	46,426	183,190
Dimension	short tons	47,816	2,427	e38,300	e3,137	59,923	3,455
Combined value of other industrial minerals and values indicated by symbol W		XX	2,510	XX	2,676	XX	145,346
Total		XX	768,781	XX	737,252	XX	699,156
OKLAHOMA							
Cement:							
Masonry	thousand short tons	41	$2,436	W	W	W	W
Portland	do.	1,415	54,870	1,432	$42,131	1,236	$39,360
Clays	metric tons	723,300	1,783	684,067	1,803	565,956	1,619
Gem stones		NA	8	NA	18	NA	W
Gypsum	thousand short tons	1,828	13,336	2,173	13,393	2,523	14,369
Iodine	kilograms	W	W	1,015,210	W	1,505,714	23,947
Sand and gravel:							
Construction	thousand short tons	e10,500	e24,200	9,273	22,654	e8,500	e20,000
Industrial	do.	1,243	17,078	1,268	17,381	1,216	18,310

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
OKLAHOMA—Continued							
Stone:							
Crushed[3]	thousand short tons	25,155	$83,732	e26,300	e$92,000	23,598	$81,969
Dimension	short tons	8,311	861	e7,746	e785	8,290	762
Combined value of feldspar, lime, salt (1987-88), stone (crushed dolomite, (1987-88), crushed granite, 1989), tripoli, and values indicated by symbol W		XX	24,915	XX	29,972	XX	18,695
Total		XX	223,219	XX	220,137	XX	219,031
OREGON							
Clays	metric tons	242,966	$986	225,001	$1,049	210,893	$875
Gem stones		NA	350	NA	894	NA	1,304
Nickel (content of ores and concentrates)	short tons	—	—	—	—	382	2,600
Sand and gravel (construction)	thousand short tons	e13,000	e42,200	14,880	52,657	e14,400	e49,700
Stone (crushed)	do.	20,663	73,902	e22,200	e77,600	3r18,407	3r81,204
Talc and pyrophyllite	short tons	150	14	W	W	225	18
Combined value of cement, diatomite, gold, lime, pumice, silver, stone (crushed dolomite and quartzite, 1989), value indicated by symbol W		XX	43,544	XX	45,988	XX	49,854
Total		XX	160,996	XX	178,188	XX	185,555
PENNSYLVANIA							
Cement:							
Masonry	thousand short tons	397	$30,464	391	$28,713	349	$26,473
Portland	do.	6,325	334,709	6,309	329,634	5,757	301,980
Clays[2]	metric tons	1,094,176	4,751	1,248,139	5,843	1,049,973	4,936
Gem stones		NA	5	NA	5	NA	5
Lime	thousand short tons	1,574	93,430	1,641	91,214	1,660	92,139
Peat	do.	18	513	21	736	20	746
Sand and gravel (construction)	do.	e14,800	e72,900	19,826	91,966	e19,500	e94,600
Stone:							
Crushed	do.	97,213	458,676	e104,600	e470,700	3r93,123	3r455,004
Dimension	short tons	60,118	10,177	e59,022	e9,584	44,267	10,032
Combined value of clays (kaolin), mica (scrap), sand and gravel (industrial), stone (crushed granite, 1989), tripoli (1987-88), and value indicated by symbol W		XX	10,872	XX	14,098	XX	14,754
Total		XX	1,016,497	XX	1,042,493	XX	1,000,669
RHODE ISLAND							
Gem stones		NA	$1	NA	$1	NA	$2
Sand and gravel (construction)	thousand short tons	e2,700	e10,900	1,853	7,847	1,100	3,900
Stone (crushed)	do.	1,228	7,797	e1,500	e9,400	11r1,208	7,170
Total[8]		XX	18,698	XX	17,248	XX	11,072

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
SOUTH CAROLINA							
Cement (portland)	thousand short tons	2,567	$117,878	2,533	$118,670	2,188	$99,083
Clays	metric tons	[2]1,989,948	[2]38,244	1,867,829	40,541	1,596,153	39,075
Gem stones		NA	10	NA	10	NA	10
Sand and gravel:							
Construction	thousand short tons	[e]7,500	[e]19,500	7,529	20,751	[e]7,500	[e]23,300
Industrial	do.	844	15,188	859	15,271	842	16,635
Stone:							
Crushed[3]	do.	24,278	105,387	[e]23,500	[e]105,800	24,429	111,656
Dimension	short tons	2,319	312	[e]353	[e]31	W	W
Combined value of cement (masonry), clays (fuller's earth 1987), gold, manganiferous ore, mica (scrap), peat, silver, stone (crushed shell), vermiculite, and value indicated by symbol W		XX	44,806	XX	56,728	XX	135,538
Total		XX	341,325	XX	357,802	XX	425,297
SOUTH DAKOTA							
Cement:							
Masonry	thousand short tons	4	W	4	W	W	W
Portland	do.	519	W	490	W	W	W
Gem stones		NA	$100	NA	$100	NA	$150
Gold[4]	kilograms	W	W	13,981	197,026	16,123	198,318
Lead[4]	metric tons	—	—	—	—	4	3
Sand and gravel (construction)	thousand short tons	[e]9,600	[e]19,100	7,929	18,681	[e]6,400	[e]20,800
Silver[4]	metric tons	W	W	3	552	4	705
Stone:							
Crushed	thousand short tons	5,070	18,515	[e]5,500	[e]20,600	3,833	14,303
Dimension	short tons	50,718	18,209	[e]43,297	[e]16,472	54,623	17,738
Combined value of beryllium concentrates (1987), clays (common), feldspar, gypsum, iron ore (1988-89), lime, mica (scrap), and values indicated by symbol W		XX	206,968	XX	32,288	XX	32,341
Total		XX	262,892	XX	285,719	XX	284,358
TENNESSEE							
Clays[2]	metric tons	1,143,846	$25,480	1,165,736	$27,696	1,137,152	$26,292
Sand and gravel (construction)	thousand short tons	[e]7,900	[e]28,900	6,836	23,343	[e]6,100	[e]21,900
Stone:							
Crushed	do.	51,406	227,263	[e]52,200	[e]235,000	52,917	252,785
Dimension	short tons	3,360	573	[e]3,942	[e]567	4,888	437
Zinc[4]	metric tons	115,699	106,926	119,954	159,201	W	W
Combined value of barite, cement, clays (bentonite 1988, common 1989, fuller's earth), copper, gem stones, lead, lime, phosphate rock, pyrites, (1987), sand and gravel (industrial), silver, and value indicated by symbol W		XX	138,670	XX	139,842	XX	336,993
Total		XX	527,812	XX	585,649	XX	638,407

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987		1988		1989	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
TEXAS							
Cement:							
Masonry	thousand short tons	172	$11,283	136	$10,800	133	$10,735
Portland	do.	7,318	319,996	7,000	292,256	7,200	286,236
Clays[2]	metric tons	3,007,706	14,825	2,714,451	17,468	2,276,629	15,962
Gem stones		NA	345	NA	340	NA	W
Gypsum	thousand short tons	1,874	14,254	1,943	15,790	1,993	17,044
Lime	do.	1,140	59,027	1,192	55,935	1,304	60,829
Salt	do.	7,810	60,857	7,802	62,925	7,856	69,934
Sand and gravel:							
Construction	do.	e48,200	e178,600	50,370	171,167	e43,900	e155,800
Industrial	do.	1,509	22,843	1,631	26,645	1,661	29,107
Stone:							
Crushed	do.	84,347	276,477	e82,000	e271,300	76,823	252,982
Dimension	short tons	75,426	10,030	e66,354	e8,310	81,268	12,449
Sulfur (Frasch)	thousand metric tons	2,152	W	2,622	W	2,446	W
Talc and pyrophyllite	short tons	255,039	4,380	260,950	4,466	266,513	4,564
Combined value of clays [ball clay, fuller's earth (1987), kaolin], helium (crude and Grade-A), iron ore, magnesium compounds, magnesium metal, sodium sulfate (natural), and values indicated by symbol W		XX	457,814	XX	531,416	XX	546,812
Total		XX	1,430,731	XX	1,468,818	XX	1,462,454
UTAH							
Beryllium concentrates	metric tons	5,499	$6	5,308	$6	1,592	$5
Cement (portland)	thousand short tons	935	50,565	772	39,664	W	W
Clays	metric tons	285,903	1,959	308,585	2,469	321,949	2,633
Gem stones		NA	105	NA	370	NA	659
Lime	thousand short tons	562	17,894	365	17,252	373	17,974
Salt	do.	1,108	34,264	1,006	35,294	1,183	40,421
Sand and gravel:							
Construction	do.	e21,000	e56,700	17,843	49,796	e14,300	e41,500
Industrial	do.	6	11	3	60	3	60
Stone:							
Crushed	do.	7,989	23,606	e7,300	e20,600	4,683	19,176
Dimension	short tons	2,004	93	e2,004	e93	—	—
Combined value of cement (masonry), copper, gold, gypsum, iron ore, magnesium compounds, magnesium metal, mercury, molybdenum, phosphate rock, potassium salts, silver, sodium sulfate (natural, 1988-89), vanadium, and value indicated by symbol W		XX	514,661	XX	849,243	XX	1,168,022
Total		XX	699,864	XX	1,014,847	XX	1,290,450

See footnotes at end of table.

TABLE 5—Continued

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

Mineral	1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
VERMONT						
Gem stones	NA	$10	NA	$10	NA	$10
Sand and gravel (construction) thousand short tons	e4,700	e10,800	6,047	17,478	e6,900	e20,400
Stone:						
Crushed do.	32,159	320,400	e 32,000	e 318,000	3,119	28,110
Dimension short tons	103,923	30,074	e105,000	e30,500	100,698	31,413
Combined value of other industrial minerals	XX	12,160	XX	10,957	XX	8,969
Total	XX	73,444	XX	76,945	XX	88,902
VIRGINIA						
Clays[2] metric tons	1,065,437	$6,291	1,010,114	$6,614	1,001,394	$6,302
Gem stones	NA	20	NA	20	NA	27
Lime thousand short tons	699	29,435	741	33,875	821	38,353
Sand and gravel (construction) do.	e12,100	e43,400	12,551	42,573	e12,900	e49,700
Stone:						
Crushed do.	60,376	295,903	e66,000	e326,700	64,061	328,050
Dimension short tons	9,077	2,720	e10,000	e2,900	W	W
Combined value of aplite, cement, clays (fuller's earth), gypsum, iron oxide pigments (crude), kyanite, sand and gravel (industrial), talc and pyrophyllite, vermiculite, and value indicated by symbol W	XX	83,673	XX	81,830	XX	86,698
Total	XX	461,442	XX	494,512	XX	509,130
WASHINGTON						
Cement (portland) thousand short tons	1,282	$63,600	979	$48,233	W	W
Clays metric tons	377,020	2,356	376,924	2,235	233,267	$1,591
Gem stones	NA	200	NA	200	NA	208
Peat thousand short tons	7	191	5	142	W	W
Sand and gravel:						
Construction do.	e25,300	e78,900	31,170	94,402	e37,800	e124,700
Industrial do.	294	5,186	W	W	W	W
Stone:						
Crushed do.	14,754	49,618	e13,900	e48,700	13,259	55,624
Dimension short tons	297	42	e697	e60	W	W
Combined value of calcium chloride (natural, 1987-88), cement (masonry), copper (1987), diatomite, gold, gypsum, lime, magnesium metal, olivine, silver, and values indicated by symbol W	XX	238,341	XX	265,362	XX	298,756
Total	XX	438,434	XX	459,334	XX	480,879
WEST VIRGINIA						
Clays metric tons	241,345	$565	239,473	$586	251,385	$553
Gem stones	NA	1	NA	1	NA	1
Sand and gravel (construction) thousand short tons	e1,000	e3,200	1,653	6,099	e2,300	e6,700
Stone (crushed) do.	12,458	50,947	e11,600	e47,600	310,904	342,538
Combined value of cement, lime, peat (1987-88), salt, sand and gravel (industrial), and stone (crushed granite, 1989)	XX	89,308	XX	73,169	XX	75,706
Total	XX	144,021	XX	127,455	XX	125,498

See footnotes at end of table.

TABLE 5—Continued

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

Mineral		1987 Quantity	1987 Value (thousands)	1988 Quantity	1988 Value (thousands)	1989 Quantity	1989 Value (thousands)
WISCONSIN							
Gem stones		NA	$15	NA	$15	NA	W
Lime	thousand short tons	393	21,733	452	23,986	437	$18,129
Peat	do.	9	237	11	270	13	309
Sand and gravel:							
Construction	do.	e23,900	e57,000	25,048	60,080	e21,700	e56,400
Industrial	do.	1,314	15,168	1,351	15,458	1,514	22,399
Stone:							
Crushed	do.	322,757	371,776	e 328,500	e 398,300	26,520	83,664
Dimension	short tons	36,903	3,697	e49,900	e6,200	35,587	4,376
Combined value of other industrial minerals and value indicated by by symbol W		XX	16,846	XX	564	XX	(9)
Total		XX	186,472	XX	204,873	XX	8185,277
WYOMING							
Clays[2]	metric tons	1,930,169	$62,031	2,138,796	$72,174	2,166,497	$74,697
Gem stones		NA	150	NA	150	NA	157
Lime	thousand short tons	29	1,560	26	1,640	W	W
Sand and gravel (construction)	do.	e2,600	e9,000	3,413	11,351	e4,500	e15,400
Stone (crushed)	do.	3,171	15,049	e2,500	e11,400	2,990	12,120
Combined value of cement, clays (common), gypsum, helium (Grade-A), sodium carbonate (natural), and value indicated by symbol W		XX	557,265	XX	613,097	XX	724,987
Total		XX	645,055	XX	709,812	XX	827,361
UNDISTRIBUTED							
Delaware, Hawaii, Hew Hampshire, Rhode Island, Wisconsin and Undistributed		XX	$6,553	XX	$7,812	XX	$9,043

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

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

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

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

[4]Recoverable content of ores, etc.

[5]Less than 1/2 unit.

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

[6]Beginning with 1989 data reported in B_2O_3, 1987-88 data converted.

[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]Excludes traprock.

TABLE 6

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

Mineral	1987		1988		1989	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
American Samoa: Stone (crushed) thousand short tons	W	W	—	—	48	$476
Guam: Stone (crushed) do.	354	$2,289	—	—	1,063	11,133
Virgin Islands: Stone (crushed) do.	345	2,741	—	—	312	3,159
Total	XX	5,030	XX	—	XX	14,768

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).

TABLE 7

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

Mineral		1987		1988		1989	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
Cement (portland)	thousand short tons	1,296	$106,185	1,397	$113,966	1,374	$112,318
Clays	metric tons	134,290	318	148,218	365	136,873	311
Lime	thousand short tons	25	3,558	25	3,802	26	3,800
Salt	do.	40	900	40	900	—	—
Sand and gravel (industrial)	do.	67	W	31	624	30	600
Stone (crushed)	do.	8,480	41,299	e9,350	e47,400	8,389	46,648
Total[2]		XX	152,260	XX	167,057	XX	163,677

eEstimated. 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	
		Quantity	Value (thousands)
METALS			
Aluminum:			
Metals and alloys, crude	metric tons	593,048	$1,260,638
Scrap	do.	574,170	767,573
Plates, sheets, bars, etc.	do.	425,609	1,250,090
Castings and forgings	do.	20,480	128,975
Aluminum sulfate	do.	941	1,208
Other aluminum compounds (fluorides and chlorides)	do.	34,317	23,997
Antimony:			
Metal, alloys, crude, waste and scrap	do.	293	694
Oxide	do.	2,229	6,106
Bauxite (dried and calcined)	thousand metric tons	44	9,830
Beryllium, alloys, waste and scrap	kilograms	34,261	3,847
Bismuth metal, alloys, waste, and scrap	do.	122,171	540
Cadmium metal, alloys, dross, flue dust, etc.	metric tons	369	857

TABLE 8—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Chromium (gross weight):			
Chromite ore and concentrate	metric tons	40,445	$5,014
Metal and alloys:			
Chromium metal	do.	196	4,097
Chromium ferroalloys	do.	9,464	11,037
Chemicals	do.	23,303	23,626
Pigments	do.	2,264	7,654
Cobalt:			
Metal (unwrought cobalt, powders, matte, waste and scrap) (estimated cobalt content)	do.	355	9,452
Oxides and hydroxides (est. cobalt content)	do.	434	6,073
Salts and compounds (est. cobalt content)	do.	101	1,724
Wrought cobalt and cobalt articles (gross weight)	do.	171	7,033
Cobalt ores and concentrates (gross weight)	do.	28	253
Copper:			
Ore and concentrate (copper content)	do.	266,831	539,325
Scrap (unalloyed scrap only)	do.	154,935	244,195
Refined copper	do.	130,189	303,013
Semimanufactures, copper and copper alloy	do.	179,028	807,257
Matte and blister (includes precipitates, ash, and residues)	do.	14,949	35,365
Ferroalloys not elsewhere listed:			
Ferrophosphorous	short tons	24,898	3,511
Ferroalloys, n.e.c.	do.	6,642	9,068
Gold:			
Ores and concentrates	kilograms	16	165
Wastes and scrap	do.	44,541	542,150
Dore and precipitates	do.	42,935	242,690
Bullion, refined	do.	123,599	1,490,151
Iron ore (gross weight):			
Nonagglomerated:			
Concentrates	thousand metric tons	353	13,887
Coarse ores	do.	—	—
Fine ores	do.	145	559
Agglomerated:			
Pellets	do.	4,852	177,980
Sinter, briquettes, and miscellaneous agglomerates	do.	14	139
Roasted pyrites	do.	1	117
Iron chemicals (gross weight):			
Chlorides	metric tons	172	202
Sulfates	do.	—	—
Iron and steel:			
Pig iron	short tons	11,747	1,334

See footnote at end of table.

TABLE 8—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Iron and steel products (major):			
Steel mill products	short tons	NA	NA
Other steel products	do.	NA	NA
Iron and steel scrap: Ferrous scrap including rerolling material and ships, boats, and other vessels for scrapping	thousand short tons	12,476	$1,776,738
Lead:			
Ore and concentrate (lead content)	metric tons	57,038	23,516
Pigs, bars, cathodes, sheets, etc. (lead content)	do.	33,877	44,204
Scrap (gross weight)	do.	59,909	26,165
Magnesium, metal and alloys, scrap, semimanufactured forms, n.e.c. (gross weight)	do.	56,631	170,374
Manganese:			
Ore and concentrate	short tons	57,191	5,014
Ferromanganese	do.	9,014	7,310
Silicomanganese	do.	5,858	4,068
Metal	do.	5,667	10,632
Mercury: metal	metric tons	221	1,874
Molybdenum:			
Ore and concentrate (molybdenum content)	thousand pounds	112,946	283,371
Molybdates (gross weight)	do.	3,067	16,947
Molybdenum, unwrought (gross weight)	do.	558	3,216
Molybdenum, wrought (gross weight)	do.	743	8,219
Wire (gross weight)	do.	751	10,868
Powder (gross weight)	do.	1,399	3,846
Ferromolybdenum (gross weight)	do.	165	615
Nickel:			
Primary (unwrought commercially pure, cathodes, ferronickel, pellets, briquettes, shot, powder and flakes)	short tons	2,327	XX
Wrought (bars, rods, angles, shapes, sections, plates, sheets, strip; tubes, pipes, blanks, fittings, hollow bar; wire)			
Stainless steel scrap (nickel content)	do.	21,871	XX
Compound catalysts and waste and scrap	do.	6,736	34,875
Platinum-group metals:			
Platinum	kilograms	8,414	135,469
Palladium	do.	13,005	72,849
Rhodium	do.	1,156	28,519
Iridium, ruthenium, and osmium	do.	507	4,232
Waste and scrap	do.	15,046	157,040
Rare-earth metals:			
Rare-earth metals, including scandium and yttrium	do.	424,837	4,801
Ores and concentrates	metric tons	776	560
Cerium compounds	kilograms	1,432,672	7,026
Selenium	do.	372,126	3,429
Silicon:			
Silicon metal	short tons	5,561	84,074
Ferrosilicon	do.	54,056	40,842

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Silver:			
Ores and concentrates	kilograms	607	$166
Waste and scrap	do.	770,788	145,340
Dore and precipitates	do.	78,664	15,478
Bullion, refined	do.	430,110	77,812
Tantalum:			
Ore, metal, other forms (gross weight)	thousand pounds	366	$26,315
Powder (tantalum content)	do.	211	21,451
Tin:			
Ingots, pigs, bars, etc.	metric tons	904	8,915
Tinplate and terneplate	do.	178,884	101,279
Titanium:			
Ore and concentrates	do.	19,832	5,900
Sponge	do.	136	910
Scrap	do.	5,474	22,909
Ingot, slab, sheet bar, etc.	do.	3,875	63,772
Other articles of titanium	do.	3,857	110,511
Pigments and oxides	do.	212,197	437,645
Tungsten (tungsten content):			
Ore and concentrate	do.	203	1,539
Carbide powder	do.	1,360	27,209
Metal powder	do.	762	15,554
Vanadium:			
Pentoxide, anhydride (gross weight)	thousand pounds	8,248	35,204
Ferrovanadium (gross weight)	do.	1,087	5,299
Zinc:			
Slabs, pigs, or blocks	metric tons	7,955	14,433
Waste and scrap (zinc content)	do.	108,086	75,947
Powders and flakes (zinc content)	do.	8,137	13,861
Ore and concentrate (zinc content)	do.	78,877	64,224
Zirconium:			
Ore and concentrates	do.	48,176	33,159
Metal and scrap	do.	242	5,997
INDUSTRIAL MINERALS			
Abrasives (includes reexports):			
Industrial diamond, natural or synthetic:			
Powder or dust	thousand carats	78,235	124,180
Other	do.	2,755	33,248
Diamond grinding wheels	thousand wheels	761	9,896
Other natural and artificial metallic abrasives and products		XX	126,810
Asbestos:			
Exports (includes reexports):			
Unmanufactured	metric tons	27,004	7,690
Products		NA	153,081
Barite: Natural barium sulfate	metric tons	9,709	1,622
Boron:			
Boric acid	thousand metric tons	42	32,613
Sodium borates	do.	646	$361,000

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
INDUSTRIAL MINERALS—Continued			
Bromine:			
Compounds (contained bromine)	thousand kilograms	28,998	$24,093
Elemental	do.	3,557	3,165
Calcium chloride	metric tons	20,316	5,695
Cement: Hydraulic and clinker	thousand short tons	512	25,561
Clays:			
Kaolin and china clay	thousand metric tons	2,337	370,919
Bentonite	do.	671	52,946
Other	do.	748	126,478
Diatomite	do.	137	41,290
Feldspar, leucite, nepheline syenite	short tons	10,283	829
Fluorspar	metric tons	5,134	694
Gem stones (including reexports):			
Diamonds	thousand carats	1,050	1,243,700
Pearls		NA	7,300
Other		NA	222,200
Graphite, natural	metric tons	11,452	7,421
Gypsum:			
Crude	thousand short tons	108	2,286
Plasters	do.	106	15,914
Boards	do.	97	25,140
Other	do.	NA	16,972
Helium	million cubic feet	796	33,830
Lime	short tons	32,241	3,893
Lithium compounds:			
Lithium carbonate	kilograms	9,045,732	28,214
Lithium hydroxide	do.	4,691,991	17,914
Lithium metal	do.	537,557	NA
Magnesium compounds:			
Caustic-calcined and unspecified magnesia	metric tons	20,218	11,476
Compounds, includes magnesium hydroxide, magnesium peroxide, magnesium chloride, and magnesium sulfate	do.	14,851	6,100
Crude magnesite	do.	10,380	8,299
Refractory and fused magnesia	do.	22,525	10,685
Mica:			
Powder	do.	3,628	1,634
Waste	do.	1,224	555
Unworked	do.	60	156
Worked	do.	415	7,227
Mineral-earth pigments, iron oxide, natuural, and synthetic	do.	9,966	15,700
Nitrogen compounds (major):			
Fertilizer materials	thousand short tons	13,569	NA
Industrial chemicals	do.	192	150,813
Phosphate rock (ground and unground)	thousand metric tons	8,323	288,990

See footnote at end of table.

TABLE 8—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
INDUSTRIAL MINERALS—Continued			
Phosphatic fertilizers:			
Phosphoric acid	thousand metric tons	703	$124,074
Superphosphates	do.	534	151,861
Diammonium and monoammonium phosphates	do.	9,102	1,608,264
Elemental phosphorous	metric tons	19,934	28,294
Pigments and compounds: Zinc oxide (metal content)	do.	13,989	19,946
Potash:			
Potassium chloride	metric tons	496,575	NA
Potassium sulfate, all grades	do.	448,880	NA
Quartz crystal:			
Cultured	thousand kilograms	57	2,600
Natural	do.	NA	NA
Salt, crude and refined	thousand short tons	1,567	20,211
Sand and gravel:			
Construction:			
Sand	do.	273	5,888
Gravel	do.	852	7,703
Industrial sand	do.	2,060	78,308
Sodium compounds:			
Soda ash	do.	2,919	365,469
Sodium sulfate	do.	68	6,241
Stone:			
Crushed	do.	3,900	23,345
Dimension		NA	34,610
Sulfur, elemental	thousand metric tons	1,024	107,126
Talc, crude and ground	do.	319	28,949
Total		XX	18,496,017

NA Not available. XX Not applicable.

TABLE 9

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS			
Aluminum:			
Metals and alloys, crude	metric tons	923,030	$1,898,132
Scrap	do.	206,610	309,122
Plates, sheets, bars, etc.	do.	340,384	950,916
Aluminium oxide (alumina)	thousand metric tons	4,311	1,228,123
Antimony:			
Ore and concentrate (antimony content)	metric tons	4,550	8,462

TABLE 9—Continued

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

Mineral		1989	
		Quantity	Value (thousands)
METALS—Continued			
Antimony—Continued			
Antimony and articles thereof, including waste and scrap	metric tons	10,621	$21,143
Antimony oxides	do.	12,041	19,770
Arsenic:			
Arsenic trioxide	do.	28,348	13,526
Acid	do.	48	67
Sulfides	do.	2	19
Metallic	do.	928	2,150
Bauxite, crude	thousand metric tons	10,666	NA
Beryllium ore	metric tons	601	$655
Bismuth, metals and alloys (gross weight)	kilograms	1,880,321	21,586
Cadmium metal	metric tons	2,787	30,161
Chromium (gross weight):			
Chromite ore and concentrate	do.	525,044	43,949
Metals and alloys:			
Chromium metal	do.	4,202	27,590
Chromium ferroalloys	do.	343,732	330,427
Chemicals	do.	12,895	23,677
Pigments	do.	5,963	13,355
Cobalt:			
Metal (estimated cobalt content)	do.	5,444	91,960
Oxide and hydroxides (estimated cobalt content)	do.	273	6,598
Salts and compounds (estimated cobalt content)	do.	75	1,426
Unwrought cobalt alloys (gross weight)	do.	90	3,301
Other cobalt: Matte, waste, and scrap (gross weight)	do.	364	5,054
Wrought cobalt and cobalt articles (gross weight)	do.	84	3,627
Columbium ore (gross weight)	thousand pounds	4,891	7,649
Copper (copper content):			
Ore and concentrate	metric tons	46,515	50,744
Matte	do.	2,252	5,232
Blister	do.	77,217	236,129
Refined copper	do.	300,110	846,609
Semimanufactures, copper and copper alloy	do.	100,254	398,605
Scrap	do.	31,578	87,253
Ferroalloys not elsewhere listed, including spiegeleisen	short tons	2,578	7,737
Gallium	kilograms	15,284	5,665
Germanium	do.	40,105	23,789
Gold:			
Ore and concentrates	do.	2,426	7,103
Wastes and scrap	do.	39,952	115,685
Dore and precipitates	do.	13,159	157,952
Bullion, refined	do.	96,967	1,198,734
Hafnium: Waste and scrap	metric tons	4	976

See footnote at end of table.

TABLE 9—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Indium	kilograms	26,813	$8,944
Iron ore (gross weight):			
Nonagglomerated:			
Concentrates	thousand metric tons	371	7,760
Coarse ores	do.	662	15,566
Fine ores	do.	11,629	297,913
Agglomerated:			
Pellets	do.	5,628	175,728
Sinter, briquettes, and miscellaneous agglomerates	do.	1,186	23,251
Roasted iron pyrites	do.	121	2,045
Iron chemicals (gross weight):			
Chlorides	metric tons	1,116	494
Sulfates	do.	7,554	1,429
Iron and steel:			
Direct reduced iron	short tons	188,038	22,621
Pig iron	do.	488,175	73,184
Iron and steel products (major):			
Steel mill products	thousands	17,333	7,590,841
Other products	do.	2,378	2,884,328
Scrap, including tinplate and terneplate	thousand short tons	1,120	149,109
Lead:			
Ore and concentrates (lead content)	metric tons	5,122	1,975
Base bullion (lead content)	do.	5,782	4,538
Pigs and bars (lead content)	do.	115,681	79,863
Reclaimed scrap, including ash and residues (lead content)	do.	677	286
Wrought lead, all forms, including wire and powders (gross weight)	do.	6,068	9,076
Magnesium:			
Metal and scrap	do.	7,652	20,229
Alloys (magnesium content)	do.	3,829	14,702
Sheets, tubing, ribbons, wire, other forms (magnesium content)	do.	808	2,928
Manganese:			
Ore (20% or more contained manganese)	do.	638,524	43,794
Ferromanganese	do.	476,063	246,540
Ferrosilicon-manganese	do.	255,391	151,241
Metal	do.	16,147	22,283
Mercury: Metal, waste and scrap	do.	131	1,247
Molybdenum:			
Ore and concentrate (molybdenum content)	thousand pounds	—	—
Waste and scrap (gross weight)	do.	386	1,701
Metal:			
Unwrought (molybdenum content)	do.	102	2,391
Wrought (gross weight)	do.	111	3,311
Ferromolybdenum (gross weight)	do.	3,108	9,062

TABLE 9—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Material in chief value molybdenum (molybdenum content)	thousand pounds	524	$1,791
Compounds (gross weight)	do.	4,976	12,106
Nickel:			
Cathodes, pellets, briquets, and shot	short tons	100,448	114,861
Plates, bars, etc.	do.	911	16,511
Powder and flakes	do.	11,572	127,118
Ferronickel	do.	12,650	117,630
Oxide	do.	5,550	3,052
Platinum-group metals:			
Platinum	kilograms	49,238	801,728
Palladium	do.	51,135	263,790
Rhodium	do.	7,105	270,466
Ruthenium	do.	2,883	7,512
Iridium	do.	688	6,565
Osmium	do.	58	605
Waste and scrap	do.	2,159	30,944
Ores	do.	12	83
Rare-earth metals:			
Monazite	metric tons	974	674
Metals, intermixed or interalloyed	kilograms	294,236	4,181
Cerium compounds	do.	250,806	1,940
Rare-earth oxides, except cerium oxide	do.	501,898	6,986
Other rare-earth compounds or mixtures	do.	1,402,448	8,086
Other rare-earth oxides or other rare-earth chlorides	do.	7,390,689	30,709
Ferrocerium and other pyrophoric alloys	do.	244,271	1,690
Rhenium:			
Metal including scrap	pounds	8,345	4,197
Ammonium perrhenate (rhenium content)	do.	2,089	949
Selenium and selenium dioxide (selenium content)	kilograms	417,095	8,934
Silicon:			
Silicon metal	short tons	47,615	80,388
Ferrosilicon	do.	196,096	131,631
Silver:			
Ore and concentrates	kilograms	7,013	2,301
Waste and scrap	do.	90,753	96,254
Dore and precipitates	do.	142,739	27,943
Bullion,refined	do.	3,061,548	578,781
Tantalum ore (gross weight)	thousand pounds	3,850	52,762
Tellurium (gross weight)	kilograms	42,871	3,249
Thallium	do.	1,173	123
Tin:			
Tin ores and concentrates, containing by weight less than 5% lead (tin content)	metric tons	216	1,938
Metal	do.	33,988	288,118

TABLE 9—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
METALS—Continued			
Dross, skimmings, scrap,residues, tin alloys, n.s.p.f.	metric tons	10,270	$34,695
Tinfoil, powder, flitters, etc.	do.	XX	4,570
Tin compounds	do.	314	2,720
Titanium:			
Ilmenite[1]	do.	797,897	110,611
Rutile, natural and synthetic	do.	264,895	119,928
Sponge	do.	903	8,181
Scrap	do.	5,308	41,898
Other unwrought	do.	309	8,336
Other articles of titanium	do.	1,250	34,085
Pigments	do.	166,346	277,140
Tungsten ore and concentrate (tungsten content)	do.	7,896	45,077
Vanadium:			
Ferrovanadium (vanadium content)	thousand pounds	1,073	13,493
Pentoxide (vanadium content)	do.	203	1,911
Vanadium-bearing materials (slags and dross) (pentoxide content)	do.	8,979	18,762
Vanadim-bearing ash and residues (pentoxide content)	do.	3,157	5,035
Zinc:			
Ore and concentrates (zinc content)	metric tons	40,974	23,047
Blocks, pigs, slabs	do.	711,554	1,183,523
Sheets, etc.	do.	3,066	5,436
Dross, ashes, and fume (zinc content)	do.	9,031	7,856
Waste and scrap	do.	9,367	6,674
Dust, powder, flakes	do.	7,253	15,123
Zirconium:			
Ore and concentrates	do.	73,196	33,958
Metal, and scrap	do.	268	2,110
INDUSTRIAL MINERALS			
Abrasives:			
Diamond (industrial)	thousand carats	70,343	105,295
Other		XX	315,689
Asbestos	metric tons	55,306	14,031
Barite:			
Crude and ground	thousand metric tons	1,034	44,679
Witherite	metric tons	76	30
Chemicals	do.	32,637	24,041
Boron (contained boric oxide):			
Boric acid	thousand metric tons	3	2,197
Colemanite	do.	15	4,202
Ulexite	do.	27	1,552
Bromine:			
Elemental	thousand kilograms	460	293
Compounds	do.	30,524	55,602
Calcium metal	kilograms	679,603	3,210

See footnote at end of table.

TABLE 9—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
INDUSTRIAL MINERALS—Continued			
Calcium chloride:			
Crude	metric tons	119,296	$20,856
Other	do.	279	587
Cement: Hydraulic and clinker	thousand short tons	15,741	489,523
Clays	metric tons	27,794	10,928
Cryolite, natural and synthetic	do.	8,429	7,647
Diatomite	thousand short tons	187	41,290
Feldspar, crude, ground and crushed	metric tons	334,000	12,273
Fluorspar	do.	655,590	79,875
Hydrofluoric acid	do.	114,676	117,920
Gem stones:			
Diamond	thousand carats	10,689	4,358,147
Emeralds	do.	3,402	207,546
Rubies and sapphires	do.	6,666	183,344
Pearls (natural, cultured, and imitation)	do.	NA	154,173
Other		NA	211,339
Graphite, natural and synthetic	metric tons	99,374	83,218
Gypsum:			
Crude	thousand short tons	9,304	59,107
Plasters	do.	3	270
Boards	do.	355	29,355
Other	do.	NA	22,280
Iodine (includes crude, potassium iodide, and resublimed iodine)	thousand kilograms	3,326	58,980
Lime:			
Hydrated	short tons	36,952	2,219
Other lime	do.	180,704	9,749
Lithium:			
Carbonate	metric tons	3,326	6,629
Hydroxide	do.	23	164
Ores	do.	31,660	3,049
Compounds	do.	7,191	7,108
Salt	do.	14	14
Metal	do.	15	31
Magnesium compounds:			
Caustic-calcined and unspecified magnesia	do.	81,458	22,851
Compounds, includes magnesium hydroxide, magnesium peroxide, magnesium chloride, and magnesium sulfate	do.	29,002	6,942
Crude magnesite	do.	8,372	1,354
Refractory and fused magnesia	do.	202,790	38,555
Mica:			
Powder	do.	8,902	4,971
Waste	do.	4,185	1,259
Unworked	do.	1,616	2,054
Worked	do.	1,129	6,711
Mineral-earth pigments, iron oxide:			
Natural earth colors, crude and refined	do.	2,135	999

See footnote at end of table.

TABLE 9—Continued

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

Mineral		1989 Quantity	1989 Value (thousands)
INDUSTRIAL MINERALS—Continued			
Mineral-earth pigments, iron oxide—Continued			
Natural micaceous, crude and refined	metric tons	2,826	$355
Synthetic	do.	31,708	29,186
Nepheline syenite, crude, ground, crushed, etc.	short tons	—	—
Nitrogen compounds (major):			
Fertilizer materials	thousand short tons	8,325	920,785
Industrial chemicals	do.	138	108,392
Peat moss (poultry and fertilizer grade)	short tons	529,706	69,931
Phosphate rock and phosphatic materials	thousand metric tons	814	80,284
Pigments and salts:			
Lead pigments and compounds	metric tons	20,770	27,030
Zinc pigments and compounds	do.	71,825	105,089
Potash (includes potassium chloride, postassium sulfate, potassium nitrate, and sodium nitrate)	do.	5,618,300	501,300
Pumice:			
Crude or crushed	do.	273,464	12,483
Wholly or partially manufactured	do.	23,691	3,649
Salt	thousand short tons	6,084	74,474
Sand and gravel:			
Industrial sand	do.	35	2,057
Other sand and gravel	do.	427	6,618
Sodium compounds:			
Soda ash	do.	141,967	17,396
Sodium sulfate	do.	190	13,900
Stone:			
Crushed	do.	4,352	35,631
Dimension		NA	525,052
Calcium carbonate fines	thousand short tons	4	1,234
Strontium:			
Celestite (strontium sulfate)	metric tons	25,640	1,956
Compounds and metal	do.	19,129	11,072
Sulfur, crude, other, colloidal-precipitated or sublimed	thousand metric tons	2,260	209,465
Talc, unmanufactured	thousand short tons	77,716	12,128
Total[2]		XX	34,787,000

NA Not available. XX Not applicable.

[1]Includes titanium slag averaging about 70% TiO_2. For details, see "Titanium" chapter.

[2]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		1988			1989[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	67,992	W	NA	68,362	W	NA
Arsenic trioxide[3]	do.	52,047	—	—	52,390	—	—
Bauxite[4]	thousand metric tons	97,946	588	1	105,029	W	NA
Beryllium concentrates (gross weight)	metric tons	8,302	[5]5,313	64	7,586	[5]4,592	61
Bismuth	do.	3,567	W	NA	3,595	W	NA
Chromite	thousand metric tons	12,167	—	—	11,901	—	—
Cobalt[2]	metric tons	47,205	—	—	47,360	—	—
Columbium-tantalum concentrates (gross weight)	thousand pounds	88,641	—	—	73,306	—	—
Copper[2]	thousand metric tons	8,536	1,420	17	8,887	1,497	17
Gold[2]	kilograms	1,847,840	200,914	11	1,971,004	265,541	13
Iron ore (gross weight)	thousand metric tons	906,293	57,515	6	923,632	59,032	6
Lead[2]	do.	3,414	394	12	3,395	419	12
Manganese ore (gross weight)	thousand short tons	26,300	—	—	26,483	—	—
Mercury	metric tons	5,890	W	NA	5,840	W	NA
Molybdenum[2]	thousand pounds	208,209	94,911	46	256,658	139,123	54
Nickel[2]	thousand short tons	961	—	—	1,027	—	—
Platinum-group metals[3]	kilograms	281,854	[e]4,970	2	283,643	[e]6,280	2
Silver[2]	metric tons	14,167	1,661	12	14,452	2,007	14
Tin[2]	do.	200,150	W	NA	216,457	W	NA
Titanium concentrates (gross weight):							
Ilmenite	thousand metric tons	4,002	W	NA	4,213	W	NA
Rutile	do.	434	W	NA	476	W	NA
Tungsten[2]	metric tons	42,604	W	NA	43,280	W	NA
Vanadium[2]	short tons	33,660	W	NA	33,800	W	NA
Zinc[2]	thousand metric tons	7,015	256	4	7,062	288	4
METALS, SMELTER BASIS							
Aluminum (primary)	do.	17,608	3,944	22	17,980	4,030	22
Cadmium	metric tons	21,899	1,885	9	21,002	1,550	7
Cobalt	do.	27,166	—	—	26,319	—	—
Copper (primary and secondary)[6]	thousand metric tons	9,285	1,363	15	9,535	1,480	16
Iron, pig	thousand short tons	606,030	55,745	9	617,300	55,873	9
Lead (primary and secondary)[7]	thousand metric tons	5,810	1,129	19	5,866	1,205	21
Magnesium (primary)	metric tons	334,372	141,983	42	343,548	152,066	44
Nickel[8]	short tons	947,662	—	—	952,834	382	([9])
Selenium[10]	kilograms	1,540,381	285,600	19	1,553,285	253,427	16
Steel, raw	thousand short tons	857,941	99,924	12	863,064	97,943	11
Tellurium[10]	kilograms	78,259	W	NA	65,031	W	NA
Tin (primary and secondary)	metric tons	234,624	[11]2,045	1	241,828	[11]1,569	1
Zinc (primary and secondary)	thousand metric tons	7,115	330	5	7,186	358	5
INDUSTRIAL MINERALS							
Asbestos	do.	4,323	18	([8])	4,325	17	([8])
Barite	do.	5,481	[12]404	7	5,712	[12]290	5
Boron minerals	do.	2,880	1,149	40	2,989	1,114	37
Bromine	kilograms	408,792	[12]163,300	40	422,900	[12]174,600	41
Cement, hydraulic	thousand short tons	1,215,498	[13]78,252	6	1,235,613	[13]78,559	6

See footnotes at end of table.

TABLE 10—Continued

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

Mineral		1988			1989[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							
Clays:							
Bentonite[3]	thousand metric tons	9,586	[12]2,871	30	9,794	[12]3,112	32
Fuller's earth[10]	do.	3,178	[12]1,973	62	3,079	[12]1,882	61
Kaolin[3]	do.	24,818	[12]8,973	36	25,669	[12]8,974	35
Diamond, natural	thousand carats	93,346	—	—	94,837	—	—
Diatomite	thousand metric tons	1,872	629	34	1,838	617	34
Feldspar	thousand short tons	5,150	715	14	5,155	720	14
Fluorspar	thousand metric tons	5,292	[e]64	1	5,731	[e]66	1
Graphite, natural	metric tons	643,938	W	NA	631,213	W	NA
Gypsum	thousand short tons	105,776	16,390	15	108,624	17,624	16
Iodine, crude	metric tons	14,994	998	7	15,622	1,508	10
Lime	thousand short tons	146,308	[12 13]17,077	12	149,184	[12 13]17,178	12
Magnesite, crude	thousand metric tons	11,936	W	NA	12,003	W	NA
Mica (including scrap and ground)	metric tons	274,585	129,900	47	265,387	119,142	45
Nitrogen (N content of ammonia)	thousand short tons	108,448	13,827	13	109,720	13,830	13
Peat	do.	214,864	844	([8])	213,931	755	([8])
Perlite	do.	2,062	[12]576	28	2,109	[12]601	28
Phosphate rock (gross weight)	thousand metric tons	160,375	45,389	28	162,268	48,866	30
Potash (K_2O equivalent)	do.	32,108	1,521	5	29,789	1,595	5
Pumice[10]	do.	12,636	[12]353	3	12,312	[e 12]424	3
Salt	thousand short tons	202,785	[12 13]38,368	19	209,988	[12 13]38,901	19
Sodium compounds, n.e.s. (natural and manufactured):							
Soda ash	do.	34,234	9,632	28	34,910	9,915	28
Sulfate	do.	5,182	788	15	5,217	777	15
Strontium[10]	metric tons	231,013	—	—	244,300	—	—
Sulfur, all forms	thousand metric tons	58,096	10,746	18	58,348	11,592	20
Talc and pyrophyllite	do.	7,991	1,237	15	7,980	1,253	16
Vermiculite[10]	short tons	599,834	[12]304,000	51	604,300	[e 12]290,000	48

[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. percentage 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 equivalent basis, but for some countries available data are insufficient to permit this adjustment.

[5]Shipments.

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

[7]Includes bullion.

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

[9]Less than 0.5%.

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

[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 Arnold O. Tanner

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The domestic mining industry continued to be strengthened and revitalized in 1989. The healthy conditions and the industry comeback that began in 1987 continued to spread and became more established for many commodities. Relatively comfortable and stable commodity prices, still found predominantly in the metals sector, reinforced other operational factors in bringing vitality to the mining and mineral processing industries. New streamlined business practices, mine and plant modernizations, and the progressive use of new technologies successfully helped lower operating costs and increase efficiency during the past 5 to 7 years. An element common to these three factors of industry renewal and growth was the ever-increasing infusion of and growing dependence on constantly advancing computer technology applications. This trend of increasing computerization was occurring throughout the mining and mineral processing business while it similarly was in most facets of modern business and culture. Some commodities and companies still struggled to outlive sluggish prices and other unstable market conditions or to modernize their businesses, but increases in productivity and profits were more common. A trend toward increased mechanical excavation in nonsoil materials was beginning to surface as a substitute for standard cyclic mine development techniques, such as drill-and-blast and surface shovel-and-truck routines. More continuous mechanical excavation offered the potential for increased production, fewer people at the working face, better ground control, and generally improved safety. The main limitation was rock hardness. The construction industry had already recognized the benefits of tunnel-boring machines for long underground drives and mechanical planers for pavement removal. The Colorado School of Mines held a short course during the year entitled, "Mechanical Excavation Techniques in Mine Development and Production," which was attended by nearly 100 engineers from 12 countries. The consensus of attendees was that for the most efficient use of these machines and techniques, new mining plans needed to be developed beyond the simple adaptation of those excavators to existing mine plans.[1]

MINING HIGHLIGHTS

Production Overview

Raw nonfuel minerals produced in the United States during 1989 had an estimated value of about $31.8 billion, an increase of about $1.8 billion over the final 1988 value. This was the seventh consecutive year that the value had increased. Except for a decrease in 1982, the value had increased each year since 1971. The estimated value of raw metals production increased a healthy 14% from $10.2 billion in 1988 to $11.6 billion in 1989. Growth in this sector was slower than in recent years but still followed the same positive trend. The same value increased 38% in 1988 and 28% in 1987, the year that industry rebounded from the depressed post-1981 years. Industrial minerals value also increased, but at a flatter 2% rise to $20.2 billion, following a 5% increase in value in 1988. Overall, the value of materials produced from these domestically mined, raw nonfuel minerals rose to an estimated $315 billion, a 5% increase over that of 1988.

Trends in domestic metal mine production showed significant increases for gold, molybdenum, certain rare earths (the lanthanides), and silver. Moderate increases occurred for copper, magnesium, platinum-group metals, titanium, tungsten, and zinc, with smaller increases for bauxite, iron ore, lead, and silicon. Production of cadmium, germanium, and selenium decreased a small amount while beryllium experienced a moderate decrease. Industrial minerals with significantly increased production included iodine and sulfur, while moderate increases occurred in bromine, phosphate rock, pumice, and quartz crystal production. More modest increases occurred for calcium chloride, fluorspar, gypsum, perlite, and potash, and small gains were made in clays, feldspar, dimension stone, gem stones, lime, lithium, industrial sand and gravel, salt, soda ash, and talc. Cement, crushed stone, diatomite, fixed nitrogen, vermiculite, and zircon held fairly even. Small decreases occurred for asbestos, boron, magnesium compounds, mica, construction sand and gravel, and sodium sulfate, and production of barite and peat dropped off moderately.

Because of the increased competitiveness of many companies and more profitable prices, many of the base metal markets continued to be very active, as they had been in 1988, following many years of lackluster performance. The generally strong commodity prices in 1989 provided incentive for increased production of most major metals. Copper maintained its position as the metal with the highest production value, followed by gold. But gold continued to be the strongest and most aggressively sought commodity overall in both domestic and international mining, as had been the case for a number of years. The main change for gold in 1989 was that softer prices moderated new growth somewhat, compared to the boom of the previous several years. Gold production continued to increase and was substantially the result of new and expanded mining operations where heap leaching was instrumental in developing low-grade ore deposits. An estimated 37% of total U.S. gold production was the result of heap leaching, and in Nevada, the largest gold-producing

State, it accounted for about 42% of the output. An increasing number of companies were processing their sulfide and refractory ores using new, expensive autoclaves, or by employing roasting methods or other newly developing processes. A few operations continued the development and adaptation of bioleaching methods to preoxidize their sulfide gold ores, which were previously often labeled "waste" by some operations. Until recently, commercial applications of bacterial leaching had been mostly limited to copper and uranium.

Gold output in the United States increased from about 6.46 million troy ounces in 1988 to almost 8.6 million troy ounces in 1989, about a 33% increase. This followed 1988's 31% rise, 1987's similar 33% rise, and 1986's 45-year record increase of 54%. Nevada was responsible for much of this increase. In 1989, Nevada produced just under 5 million troy ounces, slightly more than 58% of total U.S. gold production. Since overtaking Canada in 1986, the United States remained the third largest primary gold producer in the world, behind the Republic of South Africa and the U.S.S.R. Gold bullion imports, following a fall of 25% to 1.8 million troy ounces in 1988, rose 73% to 3.12 million in 1989. Exports of bullion increased 364% to 8.44 million troy ounces in 1988 over 1987 totals because of large sales from company inventories. In 1989, U.S. gold bullion exports moderated, totaling 3.97 million troy ounces, less than one-half that of 1988. However, the current increasing trend, which followed a large drop in 1982, continued. This was a 93% increase over that of 1987 and an 11% increase over that of 1986, the year closest in bullion export total. Interest in precious metals as bullion and commemorative coins remained strong but slower in the United States when compared with that of recent years. Interest in platinum and palladium coins increased in several countries.

Preliminary estimates showed that the United States surpassed world-leading Mexico in silver production in 1989, and the Washington, DC-based Silver Institute projected that this would likely continue through 1992. U.S. production totaled more than 64.6 million troy ounces versus preliminary estimates of 63.5 million troy ounces for Mexico and almost 56 million troy ounces for Peru, the other world leader. The pickup in U.S. production and optimistic future projections were largely the result of increased silver production as a coproduct with gold and copper production and the opening of several major silver and zinc-lead-silver U.S. mining operations. The Institute reported that lower production from Mexico and Peru was in part the consequence of labor problems.

Equipment Sales

The value of shipments by the U.S. mining machinery industry, measured in constant dollars, rose an estimated 2.8% in 1989, relatively the same as the 3% increase of 1988. Comparatively high levels of industrial production and of investment in capital equipment in the United States continued to stimulate both mine production and sales of mining machinery. Many U.S mines continued to make new investments in plant and other equipment to be more competitive in world markets. These purchases included equipment for in-pit crushing and high-capacity conveyor systems to replace costly vehicle haulage systems. New electrochemical mineral processing equipment was employed to economically exploit lower grade ore deposits. Computers were increasingly used to track equipment and machinery maintenance requirements to extend equipment operating life and reduce costs. Nevertheless, about one-half of the total demand was projected to be for parts and attachments. U.S. exports of mining machinery were valued at about $430 million, a 3% increase over a revised 1988 level of $418 million. The International Trade Administration estimated that U.S. imports of mining machinery grew to about $380 million in 1989, almost a 50% increase over the 1988 level. In 1988, these imports rose only 6.4% following a 26% increase in 1987.[2]

East-West Technology Venture

Signs of cooperation between the Communist and the non-Communist world had been on the increase for a number of years. This was partly evidenced by a growing number of scientific and educational information exchanges and cooperative ventures of various sorts. A radical softening of past highly structured political and societal policies in the U.S.S.R., both toward its own people and especially toward the Eastern European bloc nations, provided a setting for further and more relaxed future exchanges. One concrete example of this in the mining industry was a joint venture that was officially formed late in the year between a very large Soviet gold mining association and an Alaskan company. The two, Severovostokzoloto (Russian for "Northeast Gold"), the largest gold mining association in the Soviet Far East, and Bering Straits Trading Company of Anchorage, AK, joined together to combine and market mining technology developed on both sides of the Bering Strait. The partners' new organization, SVZAL, planned to combine the best aspects of their distinctive technologies in developing safer and more efficient mines in both countries. The Soviets were reported to have more advanced permafrost technology and specialized techniques and equipment for large-scale placer operations. The U.S. company had more extensive automation technology and a different management style that was of interest to its Soviet counterpart.[3]

LEGISLATION AND GOVERNMENT ACTIONS

Issues important to the mining and mineral processing industries were the subjects of many often strongly debated bills prepared by both the House of Representatives and the Senate of the U.S. Congress. Revision of the Mining Law of 1872, amendments to the Clean Air Act of 1970, proper controls on mine and mineral processing waste, and a number of wilderness, environmental, and public land bills were frequently on Congressional agendas. Mining law issues drew considerable attention. A mineral leasing system for mining on public lands was proposed in lieu of the current claim and patent system in conjunction with stricter environmental protection and land reclamation requirements for those companies seeking to mine on Federal lands. The Western Governors' Association (WGA) at yearend approved a resolution endorsing the Mining Law of 1872. At the same time, it recognized problems with the present system and directed its staff to review allegations of reported abuses. WGA stated that abuses such as nonmining uses of public lands could not be tolerated and should be prohibited by

Western State laws if they were not subject to administrative solutions.[4] The clean air laws and conflicting information on acid rain also drew much active investigation and debate while major proposals containing an environmental emphasis were presented by the Administration. Substantial wilderness areas in Nevada were protected by one bill's passage, but in terms of legislation that completed the entire circuit through to the President's signature, the year was relatively quiet. Active continuation of most of this legislation was anticipated for the upcoming 1990 session. Legislation to order eventual replacement of the $1 bill with a copper coin and a palladium bullion coin bill were among coin bills proposed but not completed by yearend.

Statutory Changes

National Defense Stockpile.—The National Defense Authorization Act for Fiscal Years 1990 and 1991 (Public Law 101-189) included amendments to the in-place National Defense Stock Piling Act. The stockpile manager was authorized to dispose of stated quantities of 11 specified stockpile materials during the 2 years, with the disposal limited to $180 million each year. In turn, $180 million was to be spent each year for acquisitions and upgrades of stockpile materials, with at least $30 million yearly to be obligated for new upgrade programs not already required by law. Another provision of the law instructed the President to encourage the development of domestic sources for appropriate strategic and critical materials. This was to be done to the extent that the President determined such action was required for the national defense.

Strategic and Critical Material Availability.—The Defense Production Act (DPA) was extended until August 10, 1990, as Public Law 101-137. The DPA was designed to place heavy emphasis on maintaining a continuing level of industrial and economic preparedness in the eventuality of a national defense emergency. The DPA previously had an exclusive emphasis on mobilization preparedness. In recent years, it had been oriented more toward providing a way to respond to adverse actions occurring outside the country. Such actions included those that could result in nonavailability or serious shortages of strategic and critical materials with serious effect on the national defense preparedness of the United States. The U.S. Department of the Interior is charged under DPA with responsibility for emergency readiness plans and programs for all nonfuel mineral materials. Under the Act, the Bureau of Mines, as a result of its continual monitoring of mineral supply and demand and its technological competence, has the organizational framework needed to discharge priorities, allocations, and supply expansion responsibilities. To facilitate coordinated Government action in the event of an emergency, the Bureau maintains 96 standby interagency mineral commodity committees, which would be called upon as needed in an emergency, as well as a unit of the National Defense Executive Reserve.

Wilderness Protection.—In December, the President signed into law the Nevada Wilderness Protection Act of 1989 (Public Law 101-95), which established 733,400 acres of wilderness in 13 areas on national forest lands in Nevada to be administered by the Secretary of Agriculture. In addition to setting aside wilderness areas, the bill's passage released about 2.4 million acres of land back into multiple-use status. This land had been tied up for years in wilderness study areas pending passage of a wilderness bill.[5]

Deep Seabed Funding.—The Deep Seabed Hard Mineral Resources Act (Public Law 101-178) was reauthorized and funded through 1994 with an annual funding level set at $1.5 million. Exclusive exploration licenses could be issued to applicants on a first-come-first-served basis, with the potential for future conversion to a permit for commercial recovery in the area covered. This law was renewed partly in anticipation of more comprehensive future legislation.

State Tax Legislation.—According to a survey of 24 mining States by the Mining Cost Service of Spokane, WA, tax legislation specifically favorable to the mining industry was passed only by Montana. Two States, Kentucky and Nevada, passed legislation increasing taxation of the mining industry, while four others—California, Minnesota, Missouri, and North Dakota—passed tax laws that impacted mining but were not specifically directed at mining. Montana reduced its personal property tax rates for mining equipment and passed a local government severance tax to replace property taxes on coal mine proceeds. Under State supreme court order, Kentucky raised its property tax rate on unmined coal. The court deemed the then-current rate to be so low that it amounted to an unconstitutional exemption from taxation. Nevada completed passage of a constitutional amendment that effectively raised the tax on the net proceeds of its mines.[6] In another State action, the New York State government encouraged investment in precious metals by exempting precious-metal bars and bullion coins from New York State sales tax effective September 1, 1989. Platinum products, which were often previously too expensive to purchase; gold and silver bars; and low-premium bullion coin sales of $1,000 or more became exempt. Exceptions to this exemption included coins from the Republic of South Africa and those being manufactured, processed, assembled, fabricated, or used for an industrial, professional, esthetic, or artistic purpose.[7]

Court Rulings

Increased Arizona Mining Royalties.—The U.S. Supreme Court upheld a 1987 Arizona supreme court ruling that invalidated a State law that allowed the Land Department to charge a maximum 5% royalty for mineral development on the State's 9.6 million acres of trust land. Under the Enabling Act of 1910, the Federal law under which Arizona became a State, mineral lease royalties from State trust lands were to go into a fund for schools with the interest used to pay for education in Arizona. This Act also required the legislature to obtain the highest possible worth for trust lands it chose to lease. The Federal Court ruled that the 5% cap deprived the State of its fair share of the minerals' value, but stopped short of invalidating current mineral leases. If that had been done, Arizona would have stopped receiving royalties while the issue awaited resolution. The Court added that the leases' validity was on shaky ground, having been issued under a mineral leasing law now considered invalid. An Arizona trial court was ordered to resolve the question of current lease validity and decide whether retroactive royalties to the State were to be collected. The specific case, *Asarco* v. *Kadish*, was initiated by State

education groups and involved royalties received from such operations as Asarco's Mission Mine, south of Tucson, AZ. The copper and molybdenum mine was situated on both Indian territory and Arizona "trust land."[8]

States Allowed Development Taxes on Indian Lands.—Several weeks previous to the Asarco case, the U.S. Supreme Court had ruled in favor of a State's right to tax mineral development on Indian lands in two separate State cases. In the case of *Cotton Petroleum* v. *New Mexico,* the Court ruled that tribal sovreignty did not prohibit States from imposing taxes on mineral production (in this case oil and gas) from reservations or tribal lands. The decision applied to non-Indian lessees of tribal resources.[9] In a case brought by Peabody Coal Co. against the State of Arizona, the Court upheld, without comment, a decision by Arizona courts that State "transition privilege" taxes must be paid by Peabody Coal for coal mines it operated on Navajo and Hopi reservations in Arizona. Peabody had been paying taxes under protest since 1980. Of concern to Indian tribes and companies alike was double taxation, by State and tribes, on the same property. Both claimed that mineral extraction should be exempt from State tax levies because of tribal sovreignty. Indian officials contended that double taxation was unfair and that economic development programs on reservations would be hurt by continued State taxation privileges on their lands. Indian tribes from other States, including Colorado, Utah, and Wyoming, expressed concern to the U.S. Senate following the rulings. Tribal representatives stated that the double taxation placed reservations at a disadvantage in trying to attract new oil and gas and other mineral development and was at present threatening the continued operation of some existing facilities. Mineral production tax revenues were necessary to the tribal economies, the tribal representatives insisted.[10]

Workplace Health and Safety.—In another U.S. Supreme Court case, the Court let stand a unanimous decision made by the Illinois supreme court earlier in the year that allowed States to file criminal charges against employers accused of neglecting the health and safety of workers. It agreed with Illinois that Federal workplace regulations did not bar State prosecutions. Corporate officials could be prosecuted for knowingly exposing their employees to hazardous chemicals and unsafe conditions. Defendants argued that criminal charges brought by the State should not be valid because the Federal Government preempted State prosecutions when it enacted the Occupational Safety and Health Act of 1970. They argued that Federal officials were more experienced and knowledgeable and would use more uniform and national workplace safety standards than some local prosecutors and juries which could be less informed and less consistent.[11]

Federal and State Placer Claim Dispute.—In a case before the Alaska supreme court involving conflicting State and Federal claims to the same placer deposits, holders of several unpatented Federal placer claims lost to State claimants. The problem was caused by (1) Federal Public Land Orders in 1972 and 1981, which withdrew selected public lands from mineral entry, giving their elective control to the State of Alaska, and (2) complicated claim histories, which included some gaps in the mandatory annual labor requirements for the properties. The supreme court affirmed one previous lower court judgment and reversed another, holding that a successor-in-interest to Federal mining claims could not cure his predecessor's failure to perform annual labor after land encompassing claims were withdrawn from mineral entry.[12]

EXPLORATION

The 28th International Geological Congress, with participants from 107 countries, was held in the early summer in Washington, DC. The world supply of minerals was a major focal point of discussion. Money and motivation available for mine development and exploration was of more concern than the size of the world's supply. This was less the case for developed countries such as the United States than for developing countries. They were supplying much of the world's minerals with too little of their own money to invest in such work. On the other hand, these Governments were viewed as becoming less hostile to foreign investors and private mining operations, thereby opening the door to a new and potentially lucrative style of mine development.[13]

Overview

Mineral exploration in the United States continued to show signs of renewed interest. The pursuit of gold, and less so other precious metals, remained strong in 1989, but with slightly less intensity than in 1988 because of relatively low and somewhat prolonged, soft gold prices. Some companies were reported to be diversifying away from a singular emphasis on gold. Geochemistry plays an important role in gold exploration because gold often occurs in submicron-size grains, especially in hydrothermal deposits. In geochemical surveys, gold remained as the most actively sought commodity, but modest exploration projects were undertaken for other commodities, such as copper, lead-zinc, platinum-group elements, and rare-earth elements (the lanthanides). Generally strong base metal prices helped fuel some increased interest in these materials, but base metals were largely sought in conjunction with precious metal-enriched massive sulfide or porphyry-type deposits.[14] Exploration activity for gold (with some interest in copper and zinc) increased in the States of Idaho, Montana, both North and South Carolina, Oregon, and Washington. Titanium was actively pursued in North Carolina and southeastern Virginia, especially by foreign companies, as well as in southern California. Exploration activity for some industrial minerals was also reported. Among these were sulfur in Texas and the Gulf of Mexico, kaolin in Minnesota, high-grade lime and boron in California, and a diamond deposit in Arkansas. While exploring for gold in southern Nevada, one company discovered a high-grade wollastonite deposit, after which it shifted emphasis to defining and testing the quantity and quality of its wollastonite showings. Wollastonite had an increasing potential for use as an asbestos replacement and as reinforcement fillers in plastics and resin systems.

With support from the Bureau of Mines and the U.S. Geological Survey (USGS), the Society of Economic Geologists (SEG) conducted its annual Mineral Exploration Statistics Survey to gauge the levels of current nonfuel mineral exploration in the United States and Canada. SEG results indicated a definite

need for more investment in base metal exploration in both countries, although more so in the United States. The Society noted a lack of adequate exploration for lead-zinc resources conducted in the United States through early 1989. Because of this, the U.S. ore reserve base was diminishing, with little replacement reserve base being added through exploration. SEG reported copper exploration to be sluggish, but it stated that the lead-zinc situation was more serious because of the geological setting in which the deposits occur. Copper deposits generally have low-grade mineralization adjacent to presently mined ores. However, lead-zinc deposits generally have distinct geologic cutoffs, with little adjacent low-grade mineralization to process when more economically desireable, higher grade reserves are depleted.

Some areas of interest to those exploring in the United States were (1) several areas in Kansas, Missouri, Oklahoma, and Wisconsin for copper, gold, iron, lanthanide, silver, and uranium ores; (2) northern Minnesota for deposits of gold, platinum, and silver; (3) Alaska for gold and rare-earth deposits; and (4) placer gold occurrences along the Georgia-Alabama Fall Line. Minnesota's State Executive Council encouraged metallic-mineral exploration with a lease sale in October. It awarded 65 leases, covering 25,775 acres, to 9 companies primarily interested in gold and platinum-group metals.

Convenient Position Fixing

A handheld Global Positioning System (GPS) receiver called the Magellan GPS Pro[15] was developed through the cooperative efforts of a number of Australian companies and subsequently manufactured at Magellan Systems Corp. of Monrovia, CA. The unit was designed to enable field exploration personnel to precisely fix their position to within 5 to 7 meters (m), by latitude and longitude or specified map grid. The Pro model reportedly incorporated features initially requested by the Australian minerals industry, including standard and user definable datums, computer interface, and navigation features. The GPS used a network of 21 satellites plus three optional backups, circling the earth twice daily in 6 fixed planar orbits. The company claimed that in a country such as Australia, which has a high level of satellite availability, the unit could be operated virtually without time restriction in most parts of the country in daylight hours. The mineral exploration industry model incorporated a communications package that allowed survey information to be processed by a data logger or personal computer.[16]

Airborne Data Collection

Remote Sensing.—The use of remote sensing as an exploration tool has steadily grown. Not only were technologies emerging to identify rock types and the location of minerals and ore deposits, but the location of structural features evident on some processed images were used to assist in determining the safest approach to mining an ore body. A property under consideration could be evaluated for the likelihood of mining difficulties attributable to geologic structural weaknesses, thereby lessening an adverse economic impact on the project and increasing the safety factor. Satellite imagery was useful in detecting special spectral signatures in vegetated areas. A large body of evidence was accumulating indicating that metal anomalies in soils are expressed as anomalies in the overlying vegetation. Such data could be useful as an aid to prospecting and to environmental monitoring of soil chemistry.

Numerous systems were undergoing development for conventional airspace and earth orbital applications, but the workhorse of the geological remote sensing industry remained the Landsat satellite. Federal Government Agencies' support of the two existing Landsat earth-watching satellites 4 and 5 was continued when the President approved funding through fiscal year (FY) 1991. Included in the approved plan was the launching of Landsat 6, tentatively scheduled for mid-1991. Landsat 6 was planned to provide an updating of technology, some of which was as much as 15 years old. Landsat imagery was costly, but it was the least expensive method that was available for conducting regional surveys.[17] The State of Oklahoma used satellite scanning to detect erosion, and single images cost more than $3,000 each. Nevertheless, scientists expected remote sensing to become increasingly popular, especially if environmental problems and the need to more closely monitor them continued current increasing trends.[18] In addition to the Landsat program, sensor systems for satellites were being developed by other countries with a variety of spatial and spectral characteristics. On the international scene, remote sensor systems included the French SPOT satellites, Soviet Soyuzkarta, Europe's ERS-1, Japan's JERS-1, Canada's Radarsat, and the international polar platform.

Following the discovery via satellite imagery of a zone of silicate minerals containing ammonium, a scientist from the USGS postulated a substantial potential for gold and silver deposits in the Cedar Mountains in southern Utah. The large size of the ammonium-bearing zone—up to 100 times the size of other known occurrences—made the Cedar Mountain locality unique. Ammonium-bearing minerals had been found at major gold-producing areas in the United States, including the McLaughlin gold mine in California and in gold deposits along the Carlin Trend in Nevada.[19] In Brazil, the use of Landsat imagery and side-looking airborne radar preceded the finding of cobalt, copper, lead, nickel, and zinc mineralization and high bismuth, gold, and silver mineralization. Other areas in Brazil revealed the occurrence of colored granites useful as ornamental stone. In these studies, costs of remote sensing exploration were estimated at about 1% of conventional black and white aerial photography and field mapping at a 1:100,000 scale.[20]

Economical Geophysical Survey.—Before 1989, the Dinguiraye Gold Mine Ltd. (DGM) mining concession in the Republic of Guinea in western Africa began comprehensive geophysical mapping of a small African bush area with high gold mineralization potential. Outcrops on the heavily laterized landscape could not be used to support any geological model or reasoning for the selection of worksites, and DGM wanted to find more targets. A standard aircraft and crew were too costly because of the small size and remoteness of the exploration area. The company used a microlight aircraft configured with modern sensing equipment and on-the-spot data processing with microcomputers. The location and mapping of a shear zone, a known major tectonic feature, was essential to interpreting the area and selecting further geochemical testing sites. This zone was a site of magma rise, where deepwater convection had redistributed various

elements, including gold. The survey also revealed smaller structures, such as faulted mafic dikes and certain specific faulting patterns, which were especially important for the location of stockwork and placer deposits. DGM's success with this low-level airborne geophysical survey suggested its potential as a future exploration tool in remote areas. This exploration project led to a 50-50 partnership between DGM and the Guinean Government for mineral exploitation and continued exploration programs in 1989.[21]

Drilling Technologies

Diamond Drill Bits.—Two new matrix-diamond impregnated drill bits with differing methods of improving performance were produced, one by Boart Exploration Services of South Africa and the other by Christensen Mining Products, based in Salt Lake City, UT. Boart launched its new "Series 9" core bit, which utilized a new reactive matrix. The matrix reportedly provided improved diamond retention and hence more effective utilization of the diamond in service. The innovative matrix technology necessitated the development of a new manufacturing process, which included further development and use of a sophisticated vacuum furnace. Boart claimed that this addition allowed better process control and consistent product quality, a wider range of processing conditions, and the evaluation of more exotic materials and different production methods. The. bit was said to have given impressive results in exploratory underground drilling in a variety of quartzites, providing longer life and improved productivity, particularly on high-speed, medium- to high-powered hydraulic machines.[22]

Christensen Mining developed its new "Gold" bit. The new bit combined friable diamonds with a new matrix, which was designed to continually expose the diamonds so that they sharpened but did not polish themselves as they slowly broke down. Christensen claimed a more consistent cutting surface along with more consistent penetration rates, and minimal polishing. In ultrahard, dense, consolidated formations, typical of many gold deposits in the Western United States, other comparable bits could become polished and penetration rates eventually fall off to zero. The new Gold bit was designed to cope more effectively with these conditions. Tests were conducted on many demanding formations throughout the United States and reportedly demonstrated an overall average increase in hard-rock drilling production of between 15% and 20% and an almost 20% increase in bit life.[23]

Hammer Drill.—Entec Industries Ltd., based in Northern Ireland, United Kingdom, developed a new down-the-hole (DTH) reverse circulation hammer specifically for geologic sampling. The Samplex drilling system incorporated independent internal flushing. The patented design created suction at the bit face to promote high-volume recoveries, which Entec claimed contained no contamination, a common DTH drill sampling problem. A continuous airflow was passed through the flushing jet into the sample tube, maintaining flushing whether the drill piston was in operation or not. Sample recovery started immediately when drilling commenced, and the penetration speeds were equivalent to conventional standard DTH hammers. The bit could produce large chip sizes suitable for rock identification in the field and laboratory thin-section analysis. There reportedly was no loss of circulation in voids and fractures with continuous sampling through varying geologic conditions.[24]

Reduced Drilling Downtime.—Because of the harsh conditions under which drill pipe is required to operate, including the presence of water and highly abrasive particles, difficulties in breaking down the drill stem occur. A South African exploration company approached this problem by having the screw pieces on its drill pipe treated with a coating of nickel phosphorous, chosen for its friction-reducing capabilities. Reportedly, the compound eased pipe detachment and benefitted the tightening process as well and attracted interest from, among others, Australian and Canadian mining firms. Equipment longevity increased, and there was also a significant reduction in downtime during exploration drilling operations. A nickel teflon compound was used on swage lock-type fittings to allow for their reuse after detachment.[25]

DEVELOPMENT

The rate of development of new mining properties other than those for gold remained moderately slow in 1989. As in recent years, gold mine openings headed the list. Most were low-grade ore gold mines using heap leaching to recover precious metals. Though not harshly affecting the industry, the relatively low and fairly consistent soft gold prices contributed to the suspension of operations of some marginal gold-mining operations and relegated some other operations to marginal status. As has been the recent pattern, expanded operations and modernization of existing properties, reopening of mines closed during the past several years, and redevelopment of previously mined properties took precedence over the development of new mining ventures. Gold again was the commodity that had the highest number of mine projects to come on-line. More than two dozen new gold mines began production in 1989, while the capacities of many other gold mines were expanded. Six new and reopened zinc-producing mines, several producing significant amounts of lead, began production in 1989. A gold and industrial sand operation in North Carolina commenced production of a mixed heavy-mineral sands concentrate consisting primarily of monazite, a principal ore of the rare earths, with lesser amounts of zircon and the yttrium-rich mineral xenotime. The deposit was the first domestic source known to have produced commercial quantities of xenotime.

Alaskan Production Commences

Largest U.S. Silver Producer.—The Greens Creek lode-silver-gold underground mine on Admiralty Island, 18 miles southwest of the capital city of Juneau, began operations in February. In its first year, it became the largest silver-producing mine in the United States, extracting 6.4 million troy ounces [198,066 kilograms (kg)], and the second largest lode-gold mine in Alaska. Significant quantities of zinc and lead, almost 10% and 4% of the ore, respectively, also were produced. Following milling and flotation, all concentrates were shipped to smelters in western Europe, Japan, and South Korea. Preliminary figures showed that the overall value of mineral production in Alaska increased 27% in 1989, and this was mainly attributed to the metal concentrate production at Greens Creek. Mine development costs amounted to about 40% more than original 1986 estimates, and that rise was attributed to poor weather, safety investigations, breakdowns, and equipment adjustment. In the spring, secondary

explosions hot enough to melt ventilation tubes occurred within seconds of blasting on two separate occasions. Fortunately, no serious injury occurred, but the high-grade ore zones were closed for 6 weeks to solve the problem. Use of a sprinkler system to saturate the mine walls and the ambient air during blasting operations apparently solved this unusual problem not reported in a U.S. mine since 1941. The puzzling explosions were determined to be caused by the buildup of fine-grained sulfide dust after blasting in the massive sulfide ores. The primary ore extraction method was drift-and-fill, and cut-and-fill techniques were used in steeply dipping areas. Mine life based on proven reserves was estimated to exceed 10 years.[26]

Red Dog Gearing Up.—The Red Dog open pit mine in remote northwest Alaska began somewhat abbreviated production in late November. The zinc-lead-silver deposit was the largest known zinc reserve in the United States and, according to Cominco, was the third largest zinc deposit ever discovered. The milling complex was completed, and the first concentrate was produced on schedule. However, some plant deficiencies, including a concentrator operating at one-half of capacity, and work slowdowns at the mine owing to early winter weather slowed down the anticipated startup pace. Mine development was on schedule with full operation expected by the end of March 1990. Production was expected to reach full capacities of 560,000 tons [508,000 metric tons (mt)] of zinc and 120,150 tons (109,000 mt) of lead concentrate per year in 1992. Development costs were relatively high, totaling about $420 million, but that was considered worthwhile because of (1) the high ore grade, 17% zinc and 5% lead; (2) a very low average overburden-to-ore strip ratio, 1:1 or less; and (3) known reserves indicating a mine life of 50 years at about 6,600 tons (6,000 mt) per day. Greens Creek and Red Dog were the first major base metal mines to be developed in Alaska since the 1930's.[27]

Low Budget and Efficient

Amax Gold Inc. commenced production at its Wind Mountain gold-silver heap-leach project in western Nevada in the spring. The low-grade, abrasive (highly silicious) gold deposit, passed up by several companies because of ore grade and location, was developed with a minimum of contractors. The company chose to use its own personnel from such projects as its productive Sleeper surface gold mine to the north and completed construction of Wind Mountain in about 4 months. Much attention was paid to detail, planning, cautious selection of a significant amount of used equipment, and selection of skilled, industrious personnel in making the marginal near-surface project profitable. The total size of two equal heap-leach pad areas was about 3 million square feet, the majority of which was leached by the increasingly popular drip method. Cash production costs for 1989 were in the range of $265 per troy ounce of gold and silver combined. Wind Mountain had an anticipated 4.5-year mine life with an annual output of 42,000 troy ounces (1,300 kg) of gold and 7.5 times as much silver. Close to 70% of the gold was sold up to 4 years ahead of time to add some security to the $17 million project. The Wind Mountain property was close to the prehistoric Lake Range Quarries, where early human beings mined materials to make tools. Amax funded an archeological study of the area from which a Bureau of Land Management archeological team acquired significant amounts of data as well as some artifacts.[28]

Return to Historic Mining District

The last major gold rush in Nevada and the first made by automobile occurred partly in southern Nevada's Bullfrog Mining District. Substantial precious-metal development returned to the area with the opening of the Bullfrog open pit gold mine. Bond International Gold, Inc. expected average yearly gold production to be 220,000 troy ounces (6,800 kg) with almost as much silver during its first 2 full years of operation. Greater annual production was anticipated thereafter during a 5- to 7-year mine life from approximately 1.8 million troy ounces (55,700 kg) of proven and probable reserves of gold. The company completed construction of the mine and conventional processing complex in 11 months and commenced production on September 1st. Unlike Amax, Bond hired a contractor to do the mining, freeing the company from purchasing its own equipment. Bond personnel did all ore beneficiation, electrowinning, and electrorefining to produce doré and neared full production levels by yearend. Ongoing exploration indicated more reserves and a potential for future underground mining.

Bond paid close attention to the mine's impact on the environment and the local community. The Bullfrog Mine was near the historic Nevada mining camp of Beatty, and it was directly adjacent to the remains of the old gold-mining boom town of Rhyolite, where one-half dozen people still lived in a few remaining buildings. A major local highway leading to Death Valley National Monument, CA, strategically separated the mine and processing complex from the tailings pond area. If a heap-leach pad was ever to be built, it would probably be constructed next to the pond because of the perfect slope, size, and lay of the land. Also, Bullfrog was situated close to the tourist town of Beatty, NV. Among other projects, Bond increased the quantity and quality of the town's water supply by drilling a new well, and it provided funds for expansion of the Beatty school system. Bond drew from the valuable past experience of developing the Colosseum gold mine in an environmentally sensitive area of California. (See Mining and Quarrying Trends chapter in the 1988 Minerals Yearbook.) Control of dust was crucial at Bullfrog. The company controlled dust by continuously spraying water at the mine, on the haulage roads, and in the covered ore conveyors. All ore, even low-grade ore not economical for conventional processing at then-current prices, was stored in buildings to control the dust. These buildings were painted in appropriate colors to blend in with the desert landscape as naturally as possible.[29]

Instrumentation

Microcomputers and Modeling.—Since about 1984 mining industry professionals, such as geologists, mining engineers, and metallurgists, progressively increased their use of the microcomputer in their day-to-day work. Besides speeding up general office duties, this relatively new tool of the trade was used to store drill-hole data and equipment and flowsheet information as well as perform calculations on this same data. With specialized software, a computer can generate maps and other graphics, such as three-dimensional views and interactive design of mine plans and flowsheets. Another use was that of modeling geological and geophysical data throughout the entire life of a mine from exploration

and development through reclamation of the land. Modern microcomputers were powerful enough to handle the vast numbers of calculations and cross calculations between different sets and types of data that only larger computers could handle not too many years before. Three-dimensional descriptions of a deposit were routinely generated. Mining and mineral processing methods could be tested or computer-simulated and optimized. The performance of many mining and metallurgical operations could be "optimized" in a variety of ways, such as in the selection of the best pit scheduling, the best maintenance plan, or the best size plant equipment. A growing number of methods were being adapted to deal with such factors. Microcomputer simulations of a process or method were similar to conducting a pilot project, but at much lower cost. In mining, simulations consisted of testing alternative equipment and methods on models that represented the ore body or the operation of the mine or mill. Another example of the application of modeling was found in inversion methods. If looking for an ore body with a density of at least 3.2, inversion methods could be applied to gravity data to determine if this was possible, and if so, what was the shallowest possible depth.[30]

Vibration Measurement and Control.—Microchips and microcomputers have contributed many sophisticated advancements in the blasting industry in the form of electronic timers, accurate caps, complicated blast delay timing schemes, laser face measurements, and nonelectric firing systems, among others. A new technique using miniature computerized seismographs, called the Iso-Seismic System, was developed by Geosonics Inc. of Warrendale, PA, to measure vibration transmission through the subsurface in much greater detail than had previously been practical to do. All vibration data was collected with 100 or more miniature seismographs, called micro-seis units, each of which was a self-contained computer recording device. Following proper operational programming of all units while plugged into a large main board, the units were removed and distributed from 100 to 1,000 feet (30 to 305 m) from the blast site. After recording 1 to 20 separate detonations, this information from the units was downloaded through the main board to a master computer. Specialized software was used to analyze recorded data and the units' exact locations along with appropriate local data, such as the locations of local significant structures and the mining operation perimeter on a preestablished coordinate grid. Results were displayed on a series of two- and three-dimensional topographs, similar to geologic, equal-elevation, contour maps. The vibration topographs represented areas of equal particle velocity or frequency, vibration intensity differences between two separate blasts, or the percentage of the Bureau of Mines recommended vibration limits that were encountered.

Geosonics noted several potential benefits of the system. With the knowledge gained from each analyzed blast, mine operators could map and understand subsurface anomalies that amplified or attenuated vibrations in specific directions to assist in planning future blasts. Presentation of this scientific information to zoning boards, regulatory agencies, and planning commissions could help to illustrate the effect blasting was having or would have on a community. Often such assessments had previously been dependent on individual seismograph readings and/or the subjective perceptions of various observers or local property owners. Greater control over the vibration effects during blasting could reduce a variety of problems and improve relations with neighbors.[31]

Vertical Borehole Direction Control.—An automatic steering device that gave a reported ±0.1% accuracy during field testing was developed in a joint project between Bergbau-Forschung and Schwing Hydraulik Elektronik GmbH & Co. of the Federal Republic of Germany. The ZBE 3000 directional drilling device utilized concurrent rotary drill stem action to provide power for its built-in generator. The internal inclinometer was designed to detect deviations down to 1 minute of arc from the vertical, and the device was claimed to be effective to a depth of 600 m. The inclinometer generated an automatic correction signal in its control circuitry which, in turn, activated hydraulic clamping cylinders. The cylinders pushed steering runners against the side of the borehole until true vertical direction was restored. To monitor the system's position and log data, the ZBE 3000 utilized the drilling fluid as the data transmission medium. At 5-minute intervals, information was transmitted as pressure pulses by means of an electronic transmitter. Resultant pulses were fed into a differential pressure receiver, converted back into electronic signals, and sent to a data terminal for decoding, logging, and visual display. Among other applications, the company claimed that the device was particularly useful for pilot-holes before shaft boring where truly vertical holes were essential. Geosonics continued work on the development of a multidirectional version of the device for straight hole drilling at an inclination to the vertical or in the horizontal plane.[32]

UNDERGROUND MINING

Mechanized Tunneling

The National Research Council of Canada provided partial funding for a joint venture headed by the Canadian mining company Falconbridge Ltd. to design a new, fast and efficient tunnel boring machine (TBM) specifically for the mining applications. The Compact Underground Borer (CUB) machine was the result. The CUB's initial customer was Falconbridge's Fraser nickel-copper mine, near Sudbury, Ontario, where it was needed to economically speed up the advance rates of the mine's underground drifting. The other design requirement for the CUB was that it be capable of rapid assembly and disassembly to enable quick movement from one job to the next. Disassembled, its components were small enough to traverse shafts and openings of less than 6 feet (2 m) in width. In operation, the machine's overall compactness allowed it to bore curves down to a radius of 85 feet (25 m). In its first application, the 8-foot (2.5 m) diameter cutter head, including 20 special 18-inch [450 millimeter (mm)] diameter rock disc cutters, was to be used to bore through hard rocks of up to 45,000 pounds per square inch uniaxial compressive strength, as are found in many Canadian mines. The high density of the cutter arrangements was combined with a thrust of reportedly more than 1.1 million pounds (1/2 million kg). With the addition of a second gripper module behind the standard cutter module, the CUB was said to be capable of performing as a boxhole or raise borer. It could cut steep raises such as inclined ventilation openings, decline ramps, and inclined conveyor drifts. The designers projected a normal advance rate of a little more than 3 feet per hour (1 m) and anticipated that it would prove to be well suited to many civil engineering applications.[33]

The Stillwater Mining Co. (SMC) also decided to use a TBM to speed up the development of footwall drifts at its platinum-group metals mine in the Beartooth Mountains near Nye, MT. In 1986, mining commenced at this mine, the first and only primary platinum-palladium producer in the Western Hemisphere. To fulfill recent ambitious expansion plans, the mining company chose mechanized tunneling for developmental drifts over the slower conventional drill-and-blast method previously used. A used 4-m diameter Robbins TBM with its original cutterhead was selected. After cutting two successful drifts while the mine personnel were learning the use of the new equipment, a third drift was cut using a new cutterhead designed more specifically for the hard, mafic gabbro, norite, and anorthosite rocks of the mine. The fairly good performance already achieved improved considerably. A new development drive by a second TBM on the opposite end of the mine was soon to open up a larger mine section with 2,000-ton-per-day (1814 mt) ore production, double that of the present mine. Stillwater professed many advantages of its choice of TBM's. The mechanical underground tunneling of footwall laterals was costing one-third less than traditional drill-and-blast methods. Less rockbolting was necessary on the smoother surfaces of machine-bored tunnels. The round smooth-surfaced tunnel profile improved tunnel ventilation. Even more important to Stillwater, the overall development of the mine was taking much less time than similar work had previously taken them. The second tunnel, 5,000 feet long (1,524 m), was driven in 3 month's time.[34]

Computerized Equipment Dispatching

During the past decade, Modular Mining Systems Inc. of Tucson, AZ, had been a major developer of computerized dispatching systems for surface mining operations. Acceptance of this type of technology was growing. Modular had completed one-half of its total of 25 system installations in the past 2 to 3 years. With complete real-time knowledge processed through a central computer, appropriate mining equipment, such as excavators, loading shovels, haul trucks, and crushers, could be monitored and controlled. Work duration times for individual tasks and current equipment locations were communicated and proper scheduling executed via digital data radio. The result reportedly was completion of the normal tasks at hand in a most efficient and safe manner. The company claimed that its surface systems were responsible for mine production increases ranging from 10% to 23%. Recently, Modular completed development of a computerized dispatching system for underground mining applications. The system was designed to allow the mine manager to control ore-mining and ore-hauling equipment from a control console on the surface. The company planned installation of what it said was the world's first underground computerized dispatching system at the Finch Mine in the Republic of South Africa during 1990. Political difficulties had slowed down the contracting process, and arrangements were made through an intermediary company instead of the mine owner, DeBeers Consolidated Mines Ltd.

Continuous Haulage

Finding a continuous automated alternative to the traditional drill-and-blast mining methods has been an ongoing area of research and development efforts for many years. The softer, flatter, and more uniform the material, the easier the mechanization of mineral extraction machines becomes. Coal is usually a relatively soft and brittle material and can be followed more easily than more typical winding and disjointed mineral ore bodies because coal is relatively flat bedded and of uniform thickness. Hence, coal mining is well suited for the development of such machines as continuous miners and longwall shearers. Other minerals, which for similar reasons may be appropriately recovered by continuous mining technologies, are potash, salt, and trona. Applications of continuous mining equipment for mining these industrial minerals have been continually increasing, supported by the same technological advancements that have occurred in the coal sector. Developing a continuous haulage system to complement the new and innovative machines was as much a challenge as designing the continuous excavation machines themselves. In recent years, a number of mobile and semi-mobile continuous conveyors and haulage systems had been developed and successfully installed at mining operations. Although often costly, these initial developments were helping to bring automated mining closer to the totally continuous ideal.

Mobile-Bridge Conveyors.—New Mexico Potash Co. added a system of bridge and mobile-bridge conveyors to continuous miners at its underground potash operation in New Mexico by linking the conveyor beltheads directly to its mining machines. The Full Dimension Continuous Haulage System was developed by Long-Airdox Engineering Co. of Mount Vernon, KY, and this mine was the first noncoal application of the system in North America. This system did not introduce new technology so much as demonstrate the harmonious adaptation of the equipment to a new mining situation. Long-Airdox had installed a similar system in a bauxite mine in Italy four years before. A train of highly mobile, crawler-mounted chain conveyors replaced New Mexico's fleet of shuttle cars. The chain-type system was chosen over a similar belted system because it was more reliable and sturdy, though noisier, and it could break up jams better in the potash, which was harder and more dense than coal. The new system provided a continuous, uninterrupted flow of material from the face direct to an artery of the main conveyor haulage system, which then flowed to the surge bins at the production shaft.

Although application of this technology was relatively new, the miners found that the continuous miner became more the limiting factor. Initial use of the system reportedly increased productivity 30% to 60% over that of traditional shuttle cars, which forced a halt to face advance with each shuttle car change. Further comparative tests showed that a small continuous miner working with a bridge system would out-produce a larger continuous miner working with diesel shuttle cars. Personnel levels and ventilation requirements for the two different systems were about the same. Elimination of diesel pollutants was compensated for by the added heat generated by the continuous miners working long headings without stopping. Ambient air temperature was 78° F in the underground workings, which were 1,650 feet (503 m) below the surface. New Mexico Potash operated 10 days straight with two production shifts and one maintenance shift per day, followed by 4 days off with no maintenance except major work.[35]

Continuous Trona Production.—Stauffer Chemical Co.'s Big Island trona mine in Wyoming added a continuous haulage system to its continuous mining

faces in 1988. The annual percentage of ore mined by the continuous miners increased from 2.4 % in 1984 to 13.9% in 1988. The company was accelerating its transition to the modernized mining system and was aiming to achieve 100% of its annual ore production with continuous mining methods by 1992. The company claimed that its successful use of continuous miners with the added continuous haulage was the result of well-controlled implementation, supportive equipment manufacturer assistance, and a willingness by mine employees to learn and improve on novel mining methods and technology. This last factor has often been cited by mining professionals in this age of new technologies as one of the most critical yet toughest with which to deal. Although new technology, especially in the form of large fast-moving machinery, can be attractive and challenging to miners, it can be very threatening to the average worker. Stauffer claimed that success with the three factors previously listed had led to constantly rising production standards and a more efficient operation. The company believed that the potential for using continuous mining methods and equipment in similar deposits had been realized in its mining operation.[36]

Longwall Mining of Trona

Longwall shearers also are technological advancements that owe much of their origin to the coal mining industry. Longwall had become the chief mining system used throughout Europe for mining underground coal deposits. It also accounted for about 30% of deep mined coal from almost 100 installations in the United States. FMC Wyoming Corp. in Green River, WY, the largest producer of trona (sodium sesquicarbonate) in the world, continued its innovative approach to mining at its southwestern Wyoming trona operation. Trona ore is the natural material that is processed into soda ash, versus soda ash that is synthetically produced. Soda ash is a raw material of major importance in the manufacture of detergents and glass products. In the spring, FMC reinstituted longwall mining of trona in the Green River basin area. This method was added to the already aggressive use of mechanized, continuous borer and fixed-drum mining machines in its room-and-pillar operation and to FMC's solution mining of some of its deeper ore deposits.

FMC chose the all-electric EDW 450/1100-L double-ended ranging drum shearer. It was supplied by Eickoff Corp., based in Pittsburgh, PA, from the parent manufacturing company in the Federal Republic of Germany, and was the largest and most technically advanced shearer that the company built. The EDW 450 was capable of cutting seams from 7.5 to 11 feet (2.3 to 3.5 m) thick and this permitted FMC to significantly increase production in its high (thick) ore seams. The electric cutting machine rolled along on a 410-foot (125-m) conveyor and was controlled by one miner using a handheld remote radio device. Whereas FMC pioneered the solution mining of trona, FMC engineers were not the first to introduce longwall technology to the Green River area. They were basically reintroducing it and replacing an old and less powerful machine that became uneconomical to operate several years before. That past longwall experience with the tough trona material led the company to obtain the maximum weight and power output combination that they could buy and still receive good service support from the manufacturer in the United States.[37] Longwall equipment was initially a more expensive capital investment than conventional mining machinery, but this was normally offset by higher yields and increased safety. Ore extraction could be more than 80% efficient compared with as low as 50% by room-and-pillar methods.[38]

Underground Safety and Comfort

Among products developed by manufacturers to make mine conditions better and safer for the individual underground miner was a new miner's cap lamp. The lamp, promoted as giving 60% brighter illumination than conventional krypton-filled bulb lamps, was offered by MSA International of Pittsburgh, PA. The Ultralight cap lamp system used a tungsten halogen bulb and a computer designed reflector to maximize light output. More than 90% of the light was focused into an extremely tight prefocused beam. MSA claimed that it consumed less battery power and ensured brighter output over a full shift without any reduction in bulb life, rated at 300 hours service life. Halogen bulbs, which had become common in the everyday nonmining world, had brighter light than conventional bulbs, and MSA claimed that they would provide better illumination of the workplace and reduce the eye strain of the miner.[39]

SURFACE MINING

Novel Electric Detonation

Preferential use of safer nonelectric initiation when blasting continued to be increasingly popular, but electric detonation remained very common because of its significant benefits, such as the ability to check the continuity of the blasting circuit. This benefit helps ensure miners of no or fewer hole misfires but always causes concerns about radio-frequency radiation or stray currents inadvertently causing premature detonations. Nobel Explosives Co. Ltd. of Ayrshire, Scotland, the United Kingdom, developed a new way of stringing together electric initiation systems for multihole blasting. Its Magnadet system, in a modified version, was being used in eight surface mines in the United States, following previous applications in European and South African mines. The system used the electromagnetic property of electric flux, the basis for the functioning of transformers. Any change of current in an electric circuit produces an alteration in the magnetic field around it, and the accompanying change in flux sets up an electromotive force in any circuits nearby. The Magnadet detonators were actually small, frequency-selective transformers, which could only be activated effectively by an alternating current blasting machine set within a specific range of high-frequency currents. The company reported that a standard direct current or the standard 60-hertz alternating current used for main power in the United States would not work. The company also claimed that the detonators were immune to radio frequency radiation and could withstand high electrostatic energy discharges, such as those that could be built up on a poorly grounded ammonium-nitrate-fuel oil explosive truck. Circuit checks were conducted with a standard blasting ohmmeter. According to some of the U.S. users, the Magnadet system was fairly simple to set up, resulting in overall blasting costs being comparable with other systems.[40]

Excavation Equipment

Hydraulic Face Shovels and Excavators.—A Norwegian company, Brown

Engineering (Bryne) A/S, introduced several hydraulic face shovels and excavators, which they redesigned for more efficient and economical operation. Brown used the prior proven superstructure, powerplant, hydraulic systems, and boom arrangements of its wheeled face shovel machines and propelled them on new tracked undercarriages for greater overall stability as well as digging stability. A new speed-sensing power control hydraulic system was the adaptation which, the company claimed, considerably increased the hydraulic efficiency of the newly tracked machines. Also, its dual speed range control system made it possible to change between high- and low-speed ranges while in full operation. Brown claimed that savings of up to 50% had been recorded, compared to machines of a similar production capacity. A tracked backhoe version was offered with hard-rock capabilities, and the new machines followed the current trend toward increased automation with fully automatic centralized lubrication systems for easier and more reliable maintenance.[41]

Largest Shovel Dipper.—An all-cast manganese steel power shovel dipper, believed to be the world's largest, was recently produced by the New Jersey-based Amalloy Corp. The dipper weighed 97,000 pounds (214,000 kg) and had a nominal capacity of 34 cubic yards (26 cubic m). The initial unit was produced by Amalloy's Amsco foundries in Quebec and Manitoba, Canada, and was in use at a southwestern U.S. copper mine. Three more were in production at the Quebec plant. According to the company, new design refinements, including a wider lip, revised lip angle, shorter lip-to-door distance, and a reduced back angle, increased power shovel efficiency. Other features, such as an arched back and an unloading door opening that was larger than the front opening, reportedly increased the effective maximum load capability of the dipper. Amalloy maintained that the new design changes reduced or eliminated empty spots, allowed more rapid emptying, and increased the unit's anticipated wear life.[42]

Steep Incline Conveyor

Several newly developed high-angle and versatile ore conveyance systems were brought on the market in the past few years. In some instances, they were developed to fulfill the demands of steeper open pit operations, more cramped surroundings (land relief or existing buildings), or other situations calling for a curvy and rolling route to the dropoff point. Many mining operations shifted to the increasingly popular and commonly more economical practice of in-pit crushing. Much more finer grained material than before had to be moved to the grinding mill and processing plant, and conveyors, overall, were the least expensive route. Various innovative concepts had been used in their development, such as wide belts progressively enveloped by idlers into an enclosed pipe structure and doubled "sandwich" belt systems that could convey materials at angles of up to 90° vertically.

One of the newest steep-angle conveyor systems, the Hurise system, was developed by Huwood Conveyors of the United Kingdom. The system was designed to operate between a 20° and 70° inclination uphill or downhill and had a rated capacity of 800 metric tons per hour of material sized at one-third belt width. According to the company, the design incorporated two new concepts in material handling of this sort—a moving bed chain elevating conveyor and a torsion bush chain design. The system consisted of a troughed conveyor belt joining in parallel operation with a chain conveyor at the feed section. Scoops or paddles attached to the chain conveyor were profiled to the shape of the troughed belt, and when running in unison the paddles propelled the material up the conveyor or held it in place when running downhill. The main haul section could be lengthened or shortened by adding or removing 5-m modular design structure sections. Before discharge, the two conveyors parted company on a normally flat to shallowly inclined section (up to 18°), after which the main troughed belt section continued to the discharge point. Runback was prevented by using a series of intermediate brakes, and loading could take place on the incline as well as at any place along the system's length. Huwood added the extra touch of fully remote-controlled operation.[43]

The increasing use of remote control by addition to standard machinery, as well as more research into complete remote operation of various mining procedures, were evergrowing trends in efforts to develop new technologies and advanced mining methods. Use of remote control had both production and miner health and safety benefits. In mining as well as in most other vocations, the new science of ergonomics (engineering and design influenced by human factors) was going well beyond the art of designing comfortable office chairs. Ergonomics conscious companies were recognizing the importance of designing sophisticated equipment to fit the cognitive, psychological, and sensory requirements of its users. Removing the miner from the many dangers associated with mining was a priority. These dangers and problems included loud noise, small quantities of respirable dust, and simple tension-producing vibrational discomforts, as well as the more dramatic fire, roof falls, and unsafe mechanical equipment.

Growth of In-Pit Crushing

Approximately 140 mobile and semimobile in-pit crushing units for surface mines and quarries were installed or put on order from 1956 through 1987, and interest in them continued to grow. The first mobile crushers were introduced in the limestone-cement industry in the 1950's in the Federal Republic of Germany, and even in the late 1980's most large-scale, mobile and semimobile crushing plants were designed or built by West German manufacturers. Krupp Industrietechnik and O&K Orenstein & Koppel dominated the market. The vast majority of all installations were in quarries producing limestone for cement or other rock products. Interestingly, some 16 of the total installations had throughput capacities in excess of 3,500 mt per hour, and they were almost exclusively in coal and metal mines for crushing ore and overburden. Most large units were semimobile, only 2 of the 16 largest being fully mobile. In the previous 2 years, many of the important new or soon-to-be-completed installations worldwide were in copper or gold hard-rock open pit mining operations. Crushing units potentially could be gyratory, impact, twin-roll, or jaw crusher systems, but all of the recent installations previously referred to used or would use large gyratory crushers. Gyratory crushers were normally selected for big installations because of an unrivalled capacity for crushing the hardest rock, but, in softer overburden and coal, the increasing use of roll crushers was anticipated.[44]

Sizer-Style Roll Crusher.—New design principles were expected by some experts to play an increasing role in in-pit crushing machines. A size-reduction principle was used in a new roll crusher introduced by Mining Machinery Developments (MMD) of England, United Kingdom. MMD incorporated some functions of a sizer machine into a roll crusher and obtained size reduction by a combination of shear and tensile forces. This resulted by applying more precisely directed breaking forces and fewer indiscriminate forces typical of similar machines. Rock was crushed by means of twin, inwardly rotating shafts. On these were mounted a series of toothed rings fitted with less costly, replacable wear caps. Large-size teeth in special configurations were rotated at low speeds to reduce wear and facilitate the handling of wet and sticky materials without buildup or stalling. The tooth and roller units were designed to require no prescreening of undersized material and to act like a rotating screen to direct passage of that material through the machine. Material to be broken was introduced to the teeth in such a manner as to take advantage of the low tensile strength of rock. The company claimed that higher capacities and reduced power consumption was the result. Roll crushers, because of their relatively small weight and size, were well suited to mobile or semimobile installations, and output from them was considered respectable. After first being introduced in rock quarries, they were also used in several open pits, including coal mines in Australia and in crushing kimberlite in diamond mines in the Republic of South Africa.[45]

Mobile Crushing and Conveying.—Semimobile, cellular constructed, in-pit crushing units, have brought primary crushing stations to the mine site and helped streamline many open pit and quarrying operations. However, as the mine faces advance farther away from the unit, ore haulage distances to the crusher eventually necessitate moving the unit. The smaller the mine the more critical the purchase or relocation of such equipment can be. The execution of such moves, though usually well-planned and kept to a minimum, requires an expensive delay in the running of an operation that includes constructing suitable foundations for new semifixed installations. Lokomo Crusher Works of Finland developed its line of Lokotrack crushers to address this problem. The result was an innovative, self-propelled in-pit crusher, that could be easily moved to the broken ore on its tracked chassis, and after crushing be backed away from the new mine face for subsequent blasting. When linked to a series of mobile conveyors, the need for a fleet of haul trucks was eliminated. One such operation was working successfully in the United Kingdom at ARC Ltd.'s Silverdale stone quarry in Cumbria, England. ARC reached the point of excessive haulage costs with its fixed primary crusher and had related expansion problems resulting from environmental restrictions. Lokomo's local subsidiary, Lokotrack, Nordberg (U.K.) Ltd.; the English mobile conveyor manufacturer, B&W Mechanical Handling Ltd.; and ARC together developed a system that they believed had the potential to cut operating costs by up to 40%. The system comprised a Lokotrack model 125, which was a track-mounted, diesel-powered primary crushing unit with a capacity ranging from 250 to 400 mt per hour. The unit discharged directly to a pair of B&W self-propelled mobile conveyors developed specifically for the Silverdale operation. These were conventional except for their wheel arrangements which, with 270° rotation capability, allowed a high degree of mobility. The wheel technology used in large loading conveyors at shipping ports made this possible. At Silverdale, the total time taken for placement of the crushing and conveying equipment was about 20 minutes in each direction. In the first 9 months of operation, ARC reported operating cost savings of about 8%. Primary units could be equipped with either impact or jaw crushers, and secondary and tertiary gyratory crushers could be added to the system. Since first developed in 1985, Lokomo had supplied more than 100 Lokotrack units to operators in different parts of the world. A fully remote-controlled model was under development that would enable the operator of the loading machine also to supervise the operation of the crusher.[46]

Microwave Remote Control

A microwave communications system was used to tie a programmable logic controller (PLC) to its remote input/output (I/O) modules at the large open pit copper mine of Phelps Dodge Morenci Inc. in Morenci, AZ. The microwave system was needed to permit a centrally located PLC to communicate over rough terrain to the I/O regulating panels. These units controlled mine water distribution from storage sites large distances from each other. Use of this remote-controlled system was claimed to be the first such application of the developing communications technology in a mining situation. Microwave was chosen over cable because of the constantly changing mine contour, the distances which needed to be covered, and past experiences with wireline equipment that was repeatedly damaged by lightning. Additionally, a pole line carrying coaxial cable around the pit would need to be more than 15,000 feet long, and this was beyond the maximum range of the regulating I/O driver regulating equipment. In one segment, a single 5,900-foot-long transmission medium was needed to reach across a corner of the extensive pit. The PLC I/O system automated, in a series arrangement, water distribution from the mine's three storage sites to suit the mine's raw water needs. Communications reliability was essential because of limited water supplies that served the needs of the extensive mining operation. For example, one of the three water storage sites only provided 4 to 6 hours of the normal daily mine consumption, so proper scheduling of water transfers from the three sites was necessary. Phelps Dodge Morenci instrumentation electricians, using available components, designed and installed the system.[47]

REMOTE MINING

Government Research

In Situ Leaching.—The Bureau of Mines proceeded with work on a variety of new and advanced mining methods to make underground mining safer, to make economic those ore bodies that were previously of too low a grade or too deeply buried, and to increase productivity in a time of growing worldwide competitiveness. The Bureau continued work on two methods that offered the most promise for significant success: in situ leaching, and a variation of the same, underground stope leaching. For more detail, see the Mining and Quarrying Trends chapter in the 1988 Minerals Yearbook.

Beyond initial applications to uranium mining, the majority of recent research and pilot project work, both public and private, had been on copper deposits. During 1989, the Bureau initiated a research project to investigate the technical

and economic feasibility of applying in situ leaching technology to the mining of domestic manganese deposits. Laboratory column leaching experiments were conducted using iron-manganese ores in which manganese recoveries ranged from 70% to 90%, while removing only 10% to 30% of the iron. The ores started as 18 to 50 weight percent iron and 5 to 18 weight percent manganese. Experiments were also conducted on several ore types from domestic manganese deposits in Arizona, Minnesota, and Nevada. Better definition of the dissolution and complexation reactions were to be sought for each ore type. These experiments provided input for the development of an in situ mining process for manganese oxide ores. Work was to continue in 1990 with drill cores and site-specific field data from two manganese deposits.[48]

Ongoing Automation Research.—A fully automated continuous miner or other mechanized mining process was believed to be at least 20 years in the future. The removal of the miner from the dangers of the mine concurrently with the development of cost-effective, efficient, and more productive and profitable mining procedures were the ultimate goals. Novel technologies brought into the mine gradually meet with less resistance than quick introductions because of the sometimes slow pace of human acceptance of the new. The similar rate of current technological progress would likely ensure that new technology would not be introduced any more quickly. The Bureau of Mines progressed with projects in computer control and automation of continuous miners and roof bolters, the development and application of expert systems, and the development of various machine guidance systems. Computer systems and software would be the means of emulating the human operator's capabilities. Bureau scientists took a practical approach to advanced automation. A machine operator's tasks were examined to identify the research and development topics critical to the development of an intelligent mining machine. Researchers observed that an operator had to *guide* a cutting *machine* tool *within* an *ore* seam or body following a *plan* that could be *altered* by local conditions and events. Those key words, *guide, machine, within ore, plan,* and *altered* provided guidance for automation development work. Tying all these functions together was the challenge that scientists faced, and this data gathering and information processing would likely be accomplished by a complex computer system.

Continuous miner guidance work was divided into lateral and vertical systems. Lateral referred to positioning the machine laterally within the open space of an entry, and vertical referred to keeping the machine within the coal or ore body. Lateral navigation, most important in the face area, required sensing systems to rapidly provide machine location coordinates, machine heading, and also the location of obstacles, such as ribs, face, and corners. The machine guidance system under development used multiple laser-based scanners for determining position and heading angle. The range of the laser scanner could be increased by using a more powerful laser and more sensitive detectors. The laser system, with gyroscopes and a flux-gate compass, both mounted on the continuous miner, were being individually evaluated for performance and accuracy. Control and analysis software was also being developed. Ultrasonic ranging techniques were being investigated for determination of rib and concave-convex corner positions. A thorough investigation of ultrasonic ranging transponders was completed that indicated response levels to real mine surfaces. Because of known limitations in the individual sensor systems, future sensor-based machine guidance would require data integration between all of a machine's systems and the utilization of the most accurate readings to update references used by other systems. Vertical control developments centered around the detection of fundamental properties of the strata. Sufficient advances had occurred in technologies used to discriminate between differing electrical signals, such as those generated by accelerometers that measure machine vibration or seismic variations between coal or ore body and the adjoining strata. The Bureau was investigating whether the differences in these vibrational signals were significant and consistent enough to allow detection of the adjoining strata and subsequently signal the machine to make adjustments in cutting height.

Another area of active investigation was in the use of an infrared camera that displayed in different colors differences in temperatures at the cutting surface. Recent experiments had shown that there could be a detectable difference in cutting-bit and dust temperature even with the use of water sprays. A system to constantly monitor video images could be used with such a system to control the cutting. Researchers believed that, in the long run, multiple sensor systems would be needed and that data would require computer filtering to indicate the best estimate of either the location of adjoining strata or coal or mineral deposit thickness.[49]

Dredging

Throughout the world, long-established gold alluvials were being reworked, and, in many countries, small-scale miners were using basic, rudimentary methods. Although gold was the most glamorous placer associated with placer mining, it was by no means the only one. All the world's mineral sands came from alluvial deposits as did much of the world's tin. Alluvial material mining methods were also used to mine phosphate, potash, salt, and other industrial minerals. Alluvial mining was essentially a low-grade and high-capacity business, and the dredge was its workhorse.[50]

Dredger Control System.—Among several sophisticated monitoring and control systems for dredgers was the Survey and Dredge Control System (SDC), developed by Meconaut Ltd. of the United Kingdom. The system was designed to fully integrate survey information and resultant positioning and functional control for ore-layer dredging with bucketwheel dredgers. The company maintained that the SDC could accurately and automatically control the dredging of soil layers as defined by the survey system that it incorporated. Meconaut produced four systems of increasing performance range that were designed for cutter dredgers but could be applied to cuttingwheel and bucketwheel machines as well. The system used a standard hardware-software survey package installed on a survey launch to produce bathymetric charts and cross-sections of the underwater area being excavated. Borehole data could be integrated with this data to determine ore layers. When dredging, all necessary data were used by the dredge control computer to guide the cutting wheel over the selected path and dredging profile using the machine's positioning system. One of the most sophisticated versions included the Automatic Wheeldredger Controller (AWC), which could adapt its control to varying soil and other irregular conditions. It monitored all functions, displayed them on a screen with setpoints, and could be manually overridden. System design features

included the capability to calculate the quantity of energy used for each cubic meter of dredged material and the total energy used during a chosen time period.[51]

Deepwater Dredge.—An interesting development in deepwater dredging came from Alluvial Mining Ltd., United Kingdom, in the form of the Tramrod, a remote-controlled seabed dredging vehicle capable of operating at depths of 100 m or more. A prototype was used in 1988 to level the seabed around an oil platform in the North Sea. The company reported that in 1989 the same machine, with modifications, had begun successful experimental trials of seabed mineral mining in the United States. Tramrod was a tracked vehicle that was designed to scour and clean up bedrock in conditions where standard cutter dredges could not operate. It reportedly could negotiate rough terrain and slopes greater than 45°. The vehicle was controlled from the surface, and its progress was monitored by two or three underwater television cameras. The suction head consisted of a special jet pump that sucked material from the seabed and pumped it to the surface. Alluvial claimed that Tramrod could handle solids of up to 250 millimeters in diameter at throughputs from 40 to 200 cubic meters per hour, depending on the materials.[52]

BENEFICIATION

Developments in Comminution

New Technologies-Larger Mills.—In recent years, steady progress had been made in the development of more advanced milling machinery. Technological developments in basic design, adaptations of large wraparound motors, and new manufacturing techniques resulted in the building of ever-larger mills. The world's largest mill, an 11.25-megawatt, 36-foot-diameter by 15-foot-long (10.97-m by 4.57-m), semiautogenous grinding (SAG) unit was being installed in the El Teniente copper processing plant in Chile. Other recent similar installations included three 34-foot-diameter SAG mills of equal length at the Bingham Canyon Copper Mine in Utah and two of the world's largest ball mills at a plant in the U.S.S.R. These new mills were being designed and manufactured to far more stringent reliability standards than those that preceded them. The cost of downtime for such a large mill was significantly greater than that of one of two smaller machines. Some of the benefits of larger mills were lower capital costs per unit of throughput and, in the case of autogenous (AG) and SAG mills, the elimination of secondary and tertiary crushing. Overall, maintenance costs and media consumption were lower, and generally, fewer operators were required. Operating-cost savings were reported to be as high as 30%. AG and SAG milling reportedly was gaining in popularity, both for high-tonnage operations and increasingly for moderately sized plants of 3,000 metric tons per day or less, especially where wet, sticky, high-clay ores were encountered.[53]

There were disadvantages to the large machines. Their enormous size meant that they needed to be optimally (amply) loaded to take full advantage of their economies of scale and produce the most consistent product. Less than optimal loading results in varying throughputs with possible attendant changes in ore hardness and sizing. Variations in throughput and product size could have additional deleterious effects on downstream processing. With AG and SAG mills, far greater adjustment of feed tonnage was necessary to avoid overgrinding of soft ores and undergrinding of hard ores as grindability changed. Proper circuit control was important to managing these problems and crucial to sending the most suitable feed to downstream separation steps. The simplest controls adjusted feed rates and water additions to maintain an optimum throughput, but more sophisticated controls were being designed to calculate economic recoveries. With sophisticated controls, an operator could determine the interaction of throughput, recovery, concentrate grade, and sales relationships to arrive at a combination of throughput and grind sizing within the operating constraints that would maximize revenue.

Development of expert systems was still in its infancy, but some initial systems were making their debut. Unlike their predecessors, "black box" microprocessors, the systems were designed to be interrogated at any time, enabling the operator to follow the decisionmaking process and test and alter the control strategy while this accumulating work experience was being stored into memory. Thus, interaction between operator and machine allowed the control logic to progressively improve at the same time as knowledge did. Expert systems had been implemented at the copper-molybdenum Brenda Mine in British Columbia, Canada, and Outokumpm Oy's Pyhasalmi concentrator in Finland, where they had enhanced efficiency and standardized operating procedures for different operators and shifts. For large mills, controls based on grinding models and expert systems were thought likely to increase in importance. Computer design techniques and gearless wraparound motors were instrumental in dealing with two old constraints over building larger mills: certain restricting mechanical factors and the large amount of power that needed to be applied.[54]

Comminution Symposium.—The Camborne School of Mines of Cornwall, United Kingdom, sponsored the International Comminution Symposium[55] at which some of the field's latest developments and future needs were presented. A variety of new technologies were discussed along with some concerns about the direction in which research was headed. Despite its importance, comminution generally was still regarded as a relatively inefficient process consuming much energy and materials and often generating an abundance of untreatable fines. One of the major aims of current research and development work in this field was to reduce the high operating costs of comminution. The energy needed for the grinding circuits of base metal concentrating plants was estimated to be about 50% of the total cost.

Another concern at the symposium was the limited focus of ongoing research and Development on comminution processes. According to one view, mineral industry research too often sidestepped a most important objective of comminution: to liberate minerals from each other at their boundaries, as well as to reduce ore to the desired particle size with limited fines. Relatively few current efforts were said to be aimed in this direction. Conventional methods separated one mineral from another relatively inefficiently, if at all in many cases, owing to the indiscriminating breakage process. A few notable exceptions were presented in papers, including one called the Snyder process and several other methods involving electric and ultrasonic energy that were attempting to concentrate the breakage energy at the mineral crystal boundaries. The Bureau of Mines had shown

that microwaves could produce thermal stresses in ores, forming microcracks between mineral grains. Microcracking at these interfaces improved the liberation of mineral values from host rock, which could significantly reduce costs, but use of microwaves in processing was not expected to reach commercial application before the turn of the century. Some of these innovative processes had not been accepted by industry because of their high capital and operating costs and the difficulty so far in adapting them to high throughput continuous operation. Inadequate mineral liberation leads to higher energy consumption, because finer grinding is necessary to achieve an adequate degree of liberation. Another undesirable outcome of finer grinding is the production of ultrafine slime particles, which may not be recovered in the downstream concentration process. This was reported to be a particularly serious problem in the hard-rock tin ores, such as those found in Cornwall, United Kingdom, where up to 30% of the mined tin mineral cassiterite was sometimes lost as fines.

Rare-Earths Processing.—Late in the year, the University of Australia, in cooperation with the Australian companies Carr Boyd Minerals and Ashton Mining Ltd., claimed that an innovative process for the refinement of the lanthanides (rare earths) had been developed. Through a university research program, the developers used mechanical means to process high-purity metal oxides as opposed to traditional, expensive treatments using chemicals. The new process reduced oxides directly to metals and alloys without any heating or melting. Metals and alloys were milled from their respective raw oxide state in a high-energy ball mill. According to the university, the process was much cheaper than conventional chemical techniques (which require careful blending and high temperatures), and yielded a purer product. Carr Boyd, with exclusive world licensing rights to the process, owned a majority share in the Western Australia Mount Weld Mine Project, one of the richest rare-earth deposits in the world, with a preliminary resource of 6.2 megatons grading 17% rare earths and yttrium, including 1.7 megatons grading a full 26%.[56]

Computer Simulation.—One of the major advances in comminution was observed to be in the computer control and computer simulation of comminution circuits. Considerable research was being done on the simulation of machines and circuits as an aid to design and optimization, and simulation was viewed as being possibly the most important future use of the computer in mineral processing. Expert systems, as previously noted, were undergoing development in various mineral industry applications, including comminution, although practical applications were still limited.[57] Before actual plant control, expert systems first had to be proven by means of computer simulation runs. An expert supervisory system prototype was developed by one group of scientists to use in simulating the operation of a mineral crushing plant. The "intelligent" supervisor extended the limits of the automatic plant operation in most of the situations where the operator formerly took control of the plant and guided it manually. The supervisor was designed with modular characteristics to allow improvements in future stages of control, including modification of the existing heuristics (a machine's "self-adjusting" problem-solving techniques based on previous decisions or steps), improvements in the knowledge base, and powerful interfacing of alternative information.[58]

Separation

Superconduction Technology.—In 1986, the J.M. Huber kaolin processing plant in Wren, GA, was the first commercial user of superconduction technology in its high-gradient magnetic separator (HGMS) system, installed by Eriez Magnetics of the United Kingdom. Because the production capacity and ease of use exceeded their expectations, Huber had a second machine with double the capacity installed in 1989 and a third one ordered for 1990 delivery. The superconducting HGMS was very efficient because it avoided the incremental energy costs of conventional water-cooled systems and reportedly used no electricity to maintain the magnetic field after startup. The new HGMS superconductor could be powered up to its full 20,000 gauss in 60 seconds, which meant there was less downtime between batches than with similar conventional systems. Eriez continued research efforts to find other successful applications for the new energy-saving technology. Potentially, any process where the removal of paramagnetic impurities was critical could be an application for a similar device.[59]

Sound Wave Separation.—Acoustical methods were being used in the U.S.S.R. to develop a new process for cleaning gravel. Acoustical enclosure devices or "belts" were used to encircle a slurry pipeline using the sound waves to loosen clay particles clinging to the individual gravel bodies.

Flotation

Column Flotation.—The absence of column flotation cells at many mineral concentrating facilities was partly the result of the physical difficulty of accommodating the tall though very efficient columns. Successful trials with a new, small prototype column flotation unit were completed at the Mount Isa lead-zinc-silver mine in Australia. The inventor, a professor from Australia's University of Newcastle, in conjunction with MIM Holdings Ltd., Australia, subsequently completed development of an innovative column flotation unit called the Jameson cell. In addition to marketing the unit, MIM planned installations at several of its lead-zinc mines and a fine coal recovery operation. Although almost twice the height of original design, the new Jameson cell was only 2 m high, and total pulp retention time was reported to be a mere 2 minutes. Because of the small size, installation cost savings were projected for foundation preparation and building height needs. Air was "induced" rather than blown into the pulp, and the total power requirement for the elevation and injection of feed pulps was claimed to be only about 50% of that required for all purposes on tall columns. MIM professed that the Jameson cell had significantly lowered cleaning cell flotation costs more than any other cell they had found available.[60]

Spray Flotation.—Application of a spray flotation system from AFT Inc. of Cleveland, OH, was expanded beyond its initial use with coal recovery from coal waste into other mineral separations where selectivity and recovery of fine minerals was important. The Sprayfloat cell system was an alternative to conventional subaeration flotation cells and, according to the company, required less than one-half the plant floor space of an equivalent capacity subaeration system at about one-half the horsepower. The process began with the primary feed being sprayed onto the surface area of the primary product recovery section of the

cell. Particles that did not float initially were drawn out and sent back to a second recycle spray, which created secondary bubble generation and provided a second chance for product flotation. Particles that did not float were directed to the tailings discharge as waste or on to a rougher cell, and the cleaned product was directed to a froth collection tank. The system could be operated with companies' existing chemistry packages and feed solid streams. It was initially tested in the laboratory with success on minerals such as copper, gold, molybdenum, nickel, and phosphates. Further development and field testing indicated that the system was applicable to a variety of other minerals. A Sprayfloat mobile pilot plant was being transported to various existing concentrators, such as a placer gold operation in British Columbia, Canada, to determine potential applicability to commercial concentrate streams. Significant success was claimed when AFT's system was applied to feed streams that contained very fine particles or agglomerated materials.[61]

Modular Design

On-Site Cyanide Production.—By some latest estimates, Nevada accounted for about 55% of U.S. sodium cyanide consumption, about 100 million pounds (45,359,240 kg). Though not yet disruptive, a progressively growing supply shortage had considerably escalated the price of cyanide. Much of this need was the result of extensive growth in the mining of surficial low-grade gold ore deposits, brought on by advances in heap-leaching technologies and fair to good gold prices. A process designed to lower costs was developed by the firm Kappes, Cassiday, & Associates (KCA), of Sparks, NV. The company claimed that the process would allow end users to manufacture their own cyanide on-site as required at a substantially lower cost than manufacturers were charging. KCA's first new modular cyanide-producing plant was completed near Reno, NV, before year-end and was reportedly capable of producing 1,000 pounds (455 kg) of sodium cyanide daily for use in heap leaching in the recovery of precious metals. Another similar but larger plant was undergoing construction by other companies in the active gold-mining area near Winnemucca, NV, with the expectation that the new plants would lessen the supply shortage.

Portable Processing.—KCA was not new to modular plant design. It was one of several companies worldwide that produced small "self-contained" gold processing plants. KCA had introduced a line of portable carbon adsorption recovery plants for the processing of gold-bearing solutions, incorporating the most recent process technology, 2 years previously. These plants were trailer-installed and could be made operational in a short time. Additionally, these modular units could be joined together to handle larger flow rates. This type of plant was advantageous for short-term, low-capital projects and would possibly retain value because of portability. Additionally, KCA designed its plants to be operated in remote areas.[62]

HEALTH AND SAFETY

Safety Data

Preliminary injury and employment statistics compiled by the Mine Safety and Health Administration (MSHA) for 1989 showed that mine fatalities in the Nation's metal and industrial mineral mines hit a historic low of 48 deaths. This was 1 less than the previous record low of 49 that occurred in both 1986 and 1988. All pre-1989 numbers are final tabulations. The same data showed that the average number of employees increased by about 3.55%, less than the 5.57% average increase in 1988, but almost twice that of the 1.86% increase of 1987. In another preliminary survey, respectable gains in metal mining employment was shown to be partly offset by a slight decline in the industrial minerals mining sector. From the MSHA data, employee hours were shown to increase by an early estimate of 1.5% after 1988's strong upward turn of 6.42%. Total reported injuries increased for the fourth consecutive year, climbing to about 7.76 per 200,000 employee hours, up from a 7.57 rate for 1988 and 6.32 in 1987. The rate of nonfatal injuries requiring lost worktime was virtually the same. Almost 4.35 of such injuries occurred per 200,000 employee hours in 1989 versus 4.33 for 1988. All figures include independent contractors.

Microseismic Activity Monitoring

A new monitoring system, the Automated Microseismic Monitoring System (AMMS), was developed by the Bureau of Mines Denver Research Center. It was designed to concurrently detect, record, and locate energy release relative to longwall mining operations. Following more extensive use in the field and the accumulation of data and inherent resulting data patterns, the system had the potential to be used to provide a warning to miners at the face of imminent rock bumping or bursts before they could occur. The AMMS continuously monitored signals received via cable from up to 16 geophones. These were mounted along the headgate and tailgate entries of the longwall panel and continuously moved with the advancing face. The system evaluated regions of intense microseismic activity to quickly locate or anticipate bumps and bursts. The system was installed at a western coal mine and was undergoing field evaluation and further development aimed at functionally improving it. A real-time graphical display for overlaying sources of microseismic activity on mine maps was being programmed, and a method of generating graphical hardcopy from more accurate digital geophones was being developed. Waveforms captured during monitoring were to be analyzed for indications of the type of physical action creating the seismic source. Also, intentionally generated active seismic sources would be used in conjunction with tomographic analysis to try to delineate anomalous ground structures and stress concentrations in and surrounding the active mining areas.[63] Overall, the Bureau's microseismic research program had three goals: (1) to acquire a basic understanding of burst mechanisms and precursors to events; (2) to improve failure forecasting prevention and control capability; and (3) to archive and interpret microseismic data.

Safe Air Underground

Innovative Ventilation Control.—Sometimes a relatively simple and practical solution can be most effective when dealing with a serious problem. A simple air control device based on fundamental pressure principles was developed by research scientists at the Bureau of Mines Pittsburgh Research Center for maintaining adequate escapeway ventilation during mine fire evacuation. During a fire that occurs by the working sections, such as in a beltway, air intake escapeways can quickly become contaminated with smoke and fumes and endanger human

life. There is little to stop significant amounts of air from leaking back into the stopings, especially with erratic air currents that the fire's heat can help to generate. Scientists compared this to water running through a hose with small cuts in it. Relatively low water pressure occurred at the leaking holes until the end was capped. If in a similar manner fresh intake air could be strategically blocked, air pressure might be raised high enough at the ends of adjacent drifts to "deflect" contaminated air down the return airway. Researchers took a specially sewn 20-foot-diameter parachute and attached it to the roof of a mine air intake tunnel. The parachute was rolled out of its pack downwind to let the incoming air inflate the chute. The chute became a quick-erect check curtain that leaked much less than conventional curtains. Air pressure in the intake quickly climbed, and it was sufficient in the adjacent airways to stop or greatly reduce migration of smoke and fumes into the air intake. The simple and inexpensive pressure curtain chutes were highly effective in field testing at four underground coal mines. In every instance, the intake pressure went up substantially, and the pressure-raising effect of the chute persisted for a distance of about 4,000 feet (1,220 m). Further field tests and a formal report were planned.[64]

Personal Air Monitor.—In many underground fire situations, such as when miners have not learned of additional fire locations, they do not know when to don self-rescuers to protect themselves from hazardous quantities of toxic gases such as carbon monoxide (CO). Usually miners do not carry the instrumentation necessary to detect toxic, colorless, and odorless CO. For this purpose, a personal-size CO alarm prototype called Pemcoal was developed by the Bureau of Mines. The small Pemcoal unit could be carried on a miner's belt, had a flashlamp visual alarm and a disk sensor that changed color with reaction to CO. Pemcoal was tested to concentrations of 1,000 parts per million of CO, from 5 ° to 40 ° C, in conjunction with several potential mine gas interferents. The unit alarm times were sufficiently fast to warn miners before exposure to hazardous quantities of CO could occur.

Another belt-worn personal air monitor was developed by Neotronics Ltd. of the United Kingdom. The Exotox was an electronic instrument, weighing just over 1.5 pounds (0.68 kg), that was designed to simultaneously detect up to five gases and measure temperature and relative humidity. The unit could measure oxygen and inflammable gas concentrations as well as the toxic gases: CO, hydrogen sulfide, sulfur dioxide, chlorine, and nitrogen dioxide. Depending on which of several models was used, presentation of results ranged from immediate on-unit liquid crystal display to future viewing of the data with a programmed analysis of it on a personal computer after transfer of data stored in the unit's electronic memory. Up to 30 hours of continuous exposure for all measured gases could be recorded and evaluated. Two of the models could be programmed to sound alarms when various instantaneous, threshold limit and short-term exposure limit values were reached.[65]

Respirable Dust Detection.—Electronics again provided the means for several innovative, compact dust monitoring devices. One was the 1.5 pound (0.68 kg) HFM-1 dust meter, made by GSA Gesellschaft of the Federal Republic of Germany. It was designed to instantaneously measure dust levels in the range of 0.1 to 100 milligrams per cubic meter, depending on dust type, and subsequently show the results on its light-emitting diode (LED) display. The HFM-1 made use of sophisticated microprocessors combined with infrared light scattering techniques. The company claimed that use of this device in mine dust surveys could reveal the real sources of dust problems and show how effective current dust control measures were without the use of slower, bulkier traditional equipment such as sample pumps. The unit was convenient and could pinpoint equipment, systems, or operations that were causing the major increases in dust levels. Up to 1,600 dust level measurements could be stored for later recall on the LED display or for direct transfer to a personal computer for further analysis or comparative studies with previous dust surveys.[66]

Bergauforschung GmbH, also from the Federal Republic of Germany, developed a continuous long-term recorder for respirable fine dust and aerosol concentration logging. Measurement was based on the photoelectrical measurement of light scattered by respirable dust-size particles at defined angles and optical wavelengths. Environmental (room) light did not affect readings owing to the instrument's optical and electronic filtering systems. The unit could be integrated into the control system of dust producing processes for direct measurements.[67]

Cleaner Diesel Research.—In the spring, the Department of Energy saw tests by major diesel manufacturers in the United States and Switzerland, which showed that coal-fueled diesel engines produced less than one-half the nitrogen oxides that resulted from conventional diesel engines. The Department committed over $4 million to several companies including Caterpillar, Inc., of Peoria, IL, to develop a coal gas-fired diesel engine. The Department's Energy Technology Center said that an acceptable coal-fueled diesel would likely be ready for use in trucks, trains, and factories by 1993.[68] Caterpillar's version involved the installation inside a locomotive of several gasifier-like vessels which would process about 35 pounds (16 kg) of coal per minute to fuel the gas-fired diesel. After being subjected to high pressures but moderate gasification temperatures in the vessels, the coal would react with steam and air to produce a modified ignition-assisted diesel engine.[69]

Spontaneous Combustion Protection

A range of infrared thermal imagery cameras were adapted by Osprey Electronics Ltd., of Scotland, United Kingdom, to detect heat buildup and spontaneous combustion sources in underground mining operations and coal stockpiles. The cameras were also used to locate electrical and mechanical faults in process plant and other equipment. In the latter regard, the United Kingdom certified camera was intended to augment other machine condition monitoring devices currently in use in mines. The equipment was designed to detect very small temperature differences that show loss of insulation, heat buildup in rotating machinery, and overheating in process modules. It was intended for use in pre-maintenance monitoring checks of machinery in motion to help reveal incipient faults.[70]

Health and Safety Training Via Satellite

MSHA began televised transmission of its safety and health programs through the Agency's Mine Health and Safety Academy in Beckley, WV. This provided mining industry personnel who had satellite reception capabilities access to unscrambled, satellite-delivered, interactive broadcasts of appropriate miner training programs with no user fee or site license fee charges. MSHA believed the

broadcasts were an effective tool for companies and others to use in improving their accident, injury, and illness prevention programs. The interactive features gave viewers an immediate forum for their questions. They could call a displayed toll-free number during each broadcast to ask questions of participants. Those interested needed a satellite dish, receiver, television monitor, and telephone. One of several shows during the year covered employee wellness programs and back injuries and was presented by the West Virginia University School of Medicine, Institute of Occupational Health and Safety. Another was presented by the Bureau of Mines Technology Transfer Program, entitled "Ground Control and Fire Protection for Underground Mining." This program highlighted the latest results of research work performed by Bureau scientists in efforts to improve ground control technology in underground mines and develop more efficient, effective fire protection, suppression, and detection systems for underground use.[71]

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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:									
1984	420	614	1,030	57	10	67	476	624	1,100
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	777	951	1,730	31	6	37	808	957	1,760
Industrial minerals:									
1984[2]	1,060	286	1,340	40	1	41	1,100	287	1,390
1985[3]	1,260	450	1,710	54	2	56	1,320	452	1,770
1986[2]	1,130	380	1,510	34	1	35	1,160	380	1,540
1987[3]	1,430	452	1,880	77	1	78	1,510	453	1,960
1988[2]	1,210	366	1,580	34	(4)	34	1,250	366	1,610
Total metals and industrial minerals:[1]									
1984	1,480	901	2,380	97	11	108	1,570	912	2,490
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

[1]Data may not add to totals shown because of independent rounding.
[2]Crushed and broken and dimension stone data were not available for 1984, 1986, and 1988 because of biennial canvassing.
[3]Includes industrial sand and gravel. Construction sand and gravel data were not available for 1985 and 1987 because of biennial canvassing.
[4]Less than 1/2 unit.

TABLE 2

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

(Thousand short tons)

Commodity	Surface			Underground			All mines[2]		
	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]
METALS									
Bauxite	1,220	W	1,220	—	—	—	1,220	—	1,220
Copper	236,000	336,000	572,000	4,060	W	4,060	240,000	336,000	576,000
Gold:									
Lode	160,000	394,000	553,000	3,560	1,340	4,890	163,000	395,000	558,000
Placer	15,000	17,900	33,000	—	—	—	15,000	18,000	33,000
Iron ore	201,000	130,000	331,000	W	W	W	201,000	130,000	331,000
Lead	W	W	W	7,270	3,400	10,700	7,270	3,400	10,700
Molybdenum	140,000	—	140,000	W	W	W	140,000	W	170,000
Silver	13,900	35,100	49,000	3,950	462	441	17,900	35,500	53,400
Other[3]	10,100	37,500	47,600	12,500	899	13,400	22,600	38,400	61,000
Total metals[2]	777,000	951,000	1,730,000	31,300	6,100	37,400	808,000	957,000	1,760,000

See footnotes at end of table.

TABLE 2—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

(Thousand short tons)

Commodity	Surface			Underground			All mines[2]		
	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]
INDUSTRIAL MINERALS									
Abrasives[4]	124	W	124	W	—	W	124	W	124
Barite	445	—	445	—	—	—	445	—	445
Clays	49,100	42,400	91,800	82	1	83	49,200	42,700	91,900
Diatomite	1,250	2,530	3,770	—	—	—	1,250	2,530	3,770
Feldspar	715	—	715	—	—	—	715	—	715
Gypsum	12,600	W	12,600	3,650	W	3,650	16,200	W	16,200
Mica (scrap)	143	—	143	—	—	—	143	—	143
Perlite	546	96	642	5	—	5	551	96	646
Phosphate rock	187,000	311,000	498,000	W	—	W	187,000	311,000	498,000
Potassium salts	—	—	—	13,500	W	13,500	13,500	W	13,500
Pumice[5]	444	W	444	—	—	—	444	W	444
Salt	2,430	W	2,430	11,400	W	11,400	13,800	W	13,800
Sand and gravel	952,000	—	952,000	—	—	—	952,000	—	952,000
Sodium carbonate (natural)	W	—	W	11,100	—	11,100	11,100	—	11,100
Talc, soapstone, pyrophyllite	1,280	W	1,280	86	W	86	1,360	W	1,360
Vermiculite	1,760	W	1,760	—	—	—	1,760	W	1,760
Other[6]	1,620	9,930	11,600	5,460	180	5,640	7,080	10,100	17,200
Total industrial minerals[2]	1,210,000	366,000	1,580,000	40,100	181	40,300	1,250,000	366,000	1,620,000
Grand total[2]	1,990,000	1,320,000	3,310,000	71,400	6,280	77,700	2,060,000	1,320,000	3,380,000

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Excludes materials from wells, ponds, or pumping operations.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes beryllium, magnesium, mercury, platinum-group metals, tin, titanium (ilmenite), uranium, zinc, and metal items indicated by symbol W.
[4]Includes abrasive stone and millstones.
[5]Excludes volcanic cinder and scoria.
[6]Includes aplite, boron minerals, graphite (natural), iron oxide pigments (crude), kyanite, magnesite, marl (greensand), sodium carbonate (natural), and industrial minerals indicated by symbol W.

TABLE 3

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] (INCLUDING SAND AND GRAVEL) IN THE UNITED STATES IN 1988, BY STATE

(Thousand short tons)

State	Surface			Underground			All mines[2]		
	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]
Alabama	W	1,910	1,910	—	—	—	W	1,910	1,910
Alaska	27,600	14,400	42,000	—	W	W	27,600	14,400	42,000
Arizona	272,000	179,000	451,000	97	61	158	272,000	179,000	452,000
Arkansas	10,500	10,700	21,200	—	—	—	10,500	10,700	21,200
California	173,000	66,200	239,000	170	63	233	173,000	66,200	239,000
Colorado	25,300	6,530	31,800	6,410	417	6,830	31,700	6,940	38,600
Connecticut	8,540	W	8,540	—	—	—	8,540	W	8,540
Delaware	1,930	—	1,930	—	—	—	1,930	—	1,930
Florida	194,000	260,000	454,000	—	—	—	194,000	260,000	454,000
Georgia	22,000	9,800	31,800	W	1	1	22,000	9,800	31,800

See footnotes at end of table.

TABLE 3—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[1] (INCLUDING SAND AND GRAVEL) IN THE UNITED STATES IN 1988, BY STATE

(Thousand short tons)

State	Surface			Underground			All mines[2]		
	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]	Crude ore	Waste	Total[2]
Hawaii	657	—	657	—	—	—	657	—	657
Idaho	16,300	27,100	43,400	658	366	1,020	16,900	27,500	44,400
Illinois	34,900	361	35,300	W	—	W	34,900	361	35,300
Indiana	27,400	992	28,400	W	—	W	27,400	992	28,400
Iowa	13,700	387	14,100	W	—	W	13,700	387	14,100
Kansas	11,500	553	12,000	1,640	—	1,640	13,100	553	13,700
Kentucky	7,400	934	8,330	—	—	—	7,400	934	8,330
Louisiana	16,600	327	17,000	W	—	W	16,600	327	17,000
Maine	10,200	W	10,200	—	—	—	10,200	W	10,200
Maryland	19,700	343	20,000	—	—	—	19,700	343	20,000
Massachusetts	22,300	W	22,300	—	—	—	22,300	W	22,300
Michigan	108,000	57,600	166,000	5,110	W	5,110	114,000	57,600	171,000
Minnesota	186,000	73,700	260,000	—	—	—	186,000	73,700	260,000
Mississippi	14,500	1,040	15,600	—	—	—	14,500	1,040	15,600
Missouri	13,800	1,550	15,300	8,190	3,160	11,400	22,000	4,710	26,700
Montana	45,700	49,700	95,400	3,170	665	3,840	48,900	50,300	99,200
Nebraska	11,500	206	11,700	—	—	—	11,500	206	11,700
Nevada	138,000	277,000	414,000	59	310	369	138,000	277,000	415,000
New Hampshire	9,110	W	9,110	—	—	—	9,110	W	9,110
New Jersey	20,300	W	20,300	—	—	—	20,300	W	20,300
New Mexico	59,800	130,000	190,000	13,700	145	13,800	73,500	130,000	204,000
New York	35,100	529	35,600	3,990	142	4,130	39,100	671	39,700
North Carolina	28,300	44,100	72,400	—	—	—	28,300	44,100	72,400
North Dakota	3,900	W	3,900	—	—	—	3,900	W	3,900
Ohio	51,600	3,240	54,800	W	—	W	51,600	3,240	54,800
Oklahoma	13,500	660	14,200	—	—	—	13,500	660	14,200
Oregon	15,800	326	16,100	—	W	W	15,800	326	16,100
Pennsylvania	21,900	1,250	23,200	—	—	—	21,900	1,250	23,200
Rhode Island	1,900	—	1,900	—	—	—	1,900	—	1,900
South Carolina	16,700	4,190	20,900	—	—	—	16,700	4,190	20,900
South Dakota	10,800	16,800	27,600	W	W	W	10,800	16,800	27,600
Tennessee	10,100	3,870	14,000	W	W	W	10,100	3,870	14,000
Texas	58,200	9,910	68,100	W	—	W	58,200	9,910	68,100
Utah	94,500	49,600	144,000	561	38	599	95,100	49,600	145,000
Vermont	6,350	—	6,350	—	—	—	6,350	—	6,350
Virginia	14,400	1,000	15,500	W	—	W	14,400	1,000	15,500
Washington	32,100	401	32,500	W	W	W	32,100	401	32,500
West Virginia	2,450	229	2,670	—	—	—	2,450	229	2,670
Wisconsin	26,400	—	26,400	—	—	—	26,400	—	26,400
Wyoming	6,610	8,020	14,600	5,200	W	5,200	11,800	8,020	19,800
Undistributed	16,100	2,070	18,200	22,500	912	23,400	38,600	2,990	41,600
Total[2]	1,990,000	1,320,000	3,310,000	71,500	6,280	77,700	2,060,000	1,320,000	3,380,000

W Withheld to avoid disclosing company proprietary data; included with "Undistributed."
[1]Excludes material from wells, ponds, or pumping operations.
[2]Data may not add to totals shown because of independent rounding.

TABLE 4

VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES MINED IN THE UNITED STATES IN 1988

(Value per ton)

Ore	Surface			Underground			All mines[2]		
	Principal Mineral product	By-product	Total	Principal mineral product	By-product	Total	Principal mineral product	By-product	Total
METALS									
Bauxite	$8.67	W	$8.67	—	—	—	$8.67	W	$8.67
Copper	13.99	$0.94	14.93	$14.31	$0.66	$14.98	14.00	$0.93	14.94
Gold:									
Lode	20.51	1.77	22.28	27.91	7.01	34.92	20.76	1.94	22.07
Placer	4.82	.01	4.82	—	—	—	4.82	.01	4.82
Iron ore	7.71	W	7.71	W	W	W	7.71	.03	7.71
Lead	W	W	W	35.63	24.47	60.10	35.63	24.47	60.10
Molybdenum	2.39	—	2.39	W	—	W	2.39	—	2.39
Silver	6.46	6.67	13.13	23.12	15.49	38.61	10.07	8.58	18.65
Average[1]	11.48	.88	12.36	35.47	7.54	43.00	12.66	1.21	13.86
INDUSTRIAL MINERALS									
Abrasives[2]	40.64	W	40.64	W	—	W	40.64	W	40.64
Barite	34.88	—	34.88	—	—	—	34.88	—	34.88
Clays	27.96	.48	28.44	30.75	2.02	32.77	27.96	.48	28.45
Diatomite	187.70	—	187.70	—	—	—	187.70	—	187.70
Feldspar	16.49	22.76	39.25	—	—	—	16.49	22.76	39.25
Gypsum	6.70	—	6.70	5.84	W	5.84	6.50	W	6.50
Mica (scrap)	47.57	—	47.57	—	—	—	47.57	—	47.57
Perlite	17.30	—	17.30	30.57	—	30.57	17.39	—	17.39
Phosphate rock	3.82	—	3.82	W	—	W	3.82	—	3.82
Potassium salts	—	—	—	16.31	—	16.31	16.31	—	16.31
Pumice[3]	10.03	—	10.03	—	—	—	10.03	—	10.03
Salt	20.46	W	20.46	14.60	W	14.60	15.64	W	18.40
Sand and gravel	3.69	—	3.69	—	—	—	3.69	—	3.69
Talc, soapstone, pyrophyllite	1.61	19.05	20.66	W	W	W	1.61	19.05	20.66
Vermiculite	17.42	—	17.42	—	—	—	17.42	—	17.42
Average[1]	5.18	.06	5.24	19.85	.97	20.82	5.56	.08	5.64
Average, metals and industrial minerals[1]	7.38	.35	7.72	27.84	4.33	32.17	8.07	.48	8.56
Average, metals and industrial minerals (excluding sand and gravel)[1]	10.89	.67	11.56	27.75	4.32	32.07	11.97	.91	12.88

W Withheld to avoid disclosing company proprietary data.
[1]Includes unpublished data.
[2]Includes abrasive stone and millstones.
[3]Excludes volcanic cinder and scoria.

TABLE 5

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1988, BY COMMODITY

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Bauxite	100.0	—	100.0	—
Copper	98.3	1.7	99.3	0.7
Gold:				
Lode	97.8	2.2	99.1	.9
Placer	100.0	—	100.0	—
Iron ore	[1]100.0	W	[1]100.0	W
Lead	W	[2]100.0	W	[2]100.0
Molybdenum	[1]100.0	W	[1]100.0	W
Silver	77.9	22.1	91.7	8.3
Average[3]	96.1	3.9	97.9	2.1
INDUSTRIAL MINERALS				
Abrasives[4]	[1]100.0	W	[1]100.0	W
Barite	100.0	—	100.0	—
Clays	99.8	.2	99.9	.1
Diatomite	100.0	—	100.0	—
Feldspar	100.0	—	100.0	—
Gypsum	77.5	22.5	81.8	18.2
Mica (scrap)	100.0	—	100.0	—
Perlite	99.2	.8	99.3	.7
Phosphate rock	[1]100.0	W	[1]100.0	W
Potassium salts	—	100.0	—	100.0
Pumice[5]	100.0	—	100.0	—
Salt	17.5	82.5	17.5	82.5
Sand and gravel	100.0	—	100.0	—
Sodium carbonate (natural)	W	[2]100.0	W	[2]100.0
Talc, soapstone, pyrophyllite	93.7	6.3	93.6	6.4
Vermiculite	100.0	—	100.0	—
Average[3]	97.3	2.7	97.9	2.1
Average, metals and industrial minerals[3]	96.8	3.2	97.9	2.1

W Withheld to avoid disclosing company proprietary data; included with "Surface" or "Underground."
[1]Includes underground; the Bureau of Mines is not at liberty to publish separately.
[2]Includes surface; the Bureau of Mines is not at liberty to publish separately.
[3]Includes unpublished data.
[4]Includes abrasives stone and millstones.
[5]Excludes volcanic cinder and scoria.

TABLE 6

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1988, BY STATE

(Percent)

State	Crude ore		Total material	
	Surface	Underground	Surface	Underground
Alabama	[1]100.0	W	[1]100.0	W
Alaska	100.0	—	W	[2]100.0
Arizona	100.0	—	100.0	—
Arkansas	100.0	—	100.0	—
California	99.9	0.1	99.9	1.1
Colorado	79.8	20.2	82.3	17.7
Connecticut	100.0	—	100.0	—
Delaware	100.0	—	100.0	—
Florida	100.0	—	100.0	—
Georgia	[1]100.0	W	[1]100.0	W
Hawaii	100.0	—	100.0	—
Idaho	96.1	3.9	97.7	2.3
Illinois	[1]100.0	W	[1]100.0	W
Indiana	[1]100.0	W	[1]100.0	W
Iowa	[1]100.0	W	[1]100.0	W
Kansas	87.5	12.5	88.0	12.0
Kentucky	100.0	—	100.0	—
Louisiana	[1]100.0	W	[1]100.0	W
Maine	100.0	—	100.0	—
Maryland	100.0	—	100.0	—
Massachusetts	100.0	—	100.0	—
Michigan	95.5	4.5	[1]100.0	W
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	62.7	37.3	57.4	42.6
Montana	93.5	6.5	96.1	3.9
Nebraska	100.0	—	100.0	—
Nevada	100.0	—	99.9	.1
New Hampshire	100.0	—	[1]100.0	W
New Jersey	100.0	—	[1]100.0	W
New Mexico	81.4	18.6	93.2	6.8
New York	89.8	10.2	89.6	10.4
North Carolina	100.0	—	100.0	—
North Dakota	100.0	—	100.0	—
Ohio	[1]100.0	W	[1]100.0	W
Oklahoma	100.0	—	100.0	—
Oregon	100.0	—	[1]100.0	W
Pennsylvania	100.0	—	100.0	—
Rhode Island	100.0	—	100.0	—
South Carolina	100.0	—	100.0	—
South Dakota	[1]100.0	W	[1]100.0	W
Tennessee	[1]100.0	W	[1]100.0	W
Texas	[1]100.0	W	[1]100.0	W
Utah	99.4	.6	99.6	.4

See footnotes at end of table.

TABLE 6—Continued

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1988, BY STATE

(Percent)

State	Crude ore		Total material	
	Surface	Underground	Surface	Underground
Vermont	[1]100.0	W	[1]100.0	W
Virginia	[1]100.0	W	[1]100.0	W
Washington	98.4	1.6	98.1	1.9
West Virginia	100.0	—	100.0	—
Wisconsin	100.0	—	100.0	—
Wyoming	56.0	44.0	[1]100.0	W
Average[2]	96.8	3.2	97.9	2.1

W Withheld to avoid disclosing company proprietary data; included with "Surface."
[1]Includes underground; the Bureau of Mines is not at liberty to publish separately.
[2]Includes surface; the Bureau of Mines is not at liberty to publish separately.
[3]Includes unpublished data.

TABLE 7

NUMBER OF DOMESTIC AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

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	5	1	—	1	3	—	—
Copper	24	3	2	2	1	5	11
Gold:							
Lode	138	16	5	31	46	38	2
Placer	26	4	5	9	4	4	—
Iron ore	20	—	1	6	2	4	7
Lead	11	1	—	1	6	3	—
Molybdenum	8	—	—	—	1	2	5
Silver	21	6	3	2	5	5	—
Others[2]	34	10	3	4	14	3	—
Total	287	41	19	56	82	64	25
			INDUSTRIAL MINERALS				
Abrasives[3]	15	8	1	6	—	—	—
Barite	14	—	7	5	2	—	—
Clays	984	38	342	450	153	1	—
Diatomite	12	—	1	6	5	—	—
Feldspar	13	—	1	10	2	—	—
Gypsum	63	1	2	17	42	1	—
Mica (scrap)	15	1	8	6	—	—	—
Perlite	9	—	3	4	2	—	—
Phosphate rock	32	—	—	1	9	14	8
Potassium salts	6	—	—	1	—	5	—
Pumice[4]	16	—	7	7	2	—	—
Salt	20	—	2	4	8	6	—

See footnotes at end of table.

TABLE 7—Continued

NUMBER OF DOMESTIC AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

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
Sand and gravel	5,804	88	805	2,720	2,068	122	1
Sodium carbonate (natural)	5	—	—	—	1	4	—
Talc, soapstone, pyrophyllite	28	3	5	15	5	—	—
Vermiculite	5	1	—	2	1	1	—
Other[5]	14	2	4	6	1	1	—
Total	7,055	142	1,188	3,260	2,301	155	9
Grand total	7,342	183	1,207	3,316	2,383	219	34

[1]Excludes wells, ponds, or pumping operations.
[2]Includes beryllium, magnesium, manganese, mercury, molybdenum, platinum-group metals, rare-earth metals, tin, titanium (ilmenite), uranium, and zinc.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.
[5]Includes aplite, boron minerals, fluorspar, greensand (marl), iron oxide pigments, kyanite, magnesite, pyrite, and wollastonite.

TABLE 8

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1988, IN ORDER OF OUTPUT OF CRUDE ORE

Mine	State	Operator	Commodity	Mining method
		METALS		
Morenci	Arizona	Phelps Dodge Corp.	Copper	Open pit.
Bingham Canyon	Utah	Kennecot, Utah Copper Div.	do.	Do.
Smokey Valley	Nevada	Round Mountain Gold Corp.	Lode gold	Do.
Pinto Valley	Arizona	Pinto Valley Copper Corp.	Copper	Do.
Minntac	Minnesota	USX Corp.	Iron ore	Do.
Chino	New Mexico	Phelps Dodge Corp.	Copper	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Hibbing Taconite	Minnesota	Pickands Mather & Co.	Iron ore	Do.
Hoyt Lakes	do.	LTV Steel Co. Inc.	do.	Do.
Empire	Michigan	Empire Iron Mining Co.	do.	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Continental	Montana	Montana Resources Inc.	do.	Do.
Tilden	Michigan	Tilden Mining Co.	Iron ore	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro	Copper	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Do.
National Pellet Project—Itasca	Minnesota	Hanna Mining Co.	Iron ore	Do.
Thunderbird	do.	Oglebay Norton Co.	do.	Do.
Sleeper	Nevada	AMAX Gold Inc.	Lode gold	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Inspiration	do.	Cyprus Miami Mining Co.	do.	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	Lode gold	Do.
Mission	Arizona	ASARCO Incorporated	Copper	Do.
Eisenhower	do.	do.	do.	Do.
Green Cove	Florida	Associated Minerals Corp.	Titanium	Dredging.
Monorca	Minnesota	Inland Steel Mining Co.	Iron ore	Open pit.

See footnotes at end of table.

TABLE 8—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1988, IN ORDER OF OUTPUT OF CRUDE ORE

Mine	State	Operator	Commodity	Mining method
		INDUSTRIAL MINERALS[2]		
Suwanee	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock.	Open pit.
Kingsford	do.	International Minerals & Chemical Corp.	do.	Do.
Ft. Green	do.	Agrico Chemical Co.	do.	Do.
Noralyn	do.	International Minerals & Chemical Corp.	do.	Do.
Haynsworth	do.	American Cyanamid Co.	do.	Do.
Swift Creek	do.	Occidental Chemical Agricultural Products, Inc.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Ft Meade	Florida	Mobil Mining and Minerals Co	do.	Open pit.
Payne Creek	do.	Agrico Chemical Co.	do.	Do.
Hookers	do.	W.R. Grace & Co.	do.	Do.
4 Corners	do.	do.	do.	Do.
Clear Spring	do.	International Minerals & Chemical Corp.	do.	Do.
Sun Valley	California	CalMat Co. of California	Sand and gravel.	Dredging.
Rockland	Florida	U.S. Agri-Chemicals Corp.	Phosphate rock.	Open pit.
International	New Mexico	International Minerals & Chemical Corp.	Potassium salts.	Stopes.
Irwindale	California	United Rock Products Corp.	Sand and gravel.	Dredging.
Perkins	do.	A. Teichert & Son Inc., Teichert Aggregates	do.	Do.
Radum	do.	Koppers Co., Kaiser Sand and Gravel	do.	Do.
Azuza	do.	Owl Rock Products Co.	do.	Do.
Durbin	do.	CalMat Co. of California	do.	Do.
Big Island	Wyoming	Stauffer Chemical Co. of Wyoming	Sodium carbonate	Stopes.
Jordanel	Utah	Torno American Inc.	Sand and gravel.	Dredging.
Irwindale	California	Symons Corp., Livingston Graham Inc.	do.	Do.
Silver City	Florida	Estech General Chemical Corp.	Phosphate rock.	Open pit.
Steilacoom	Washington	Lone Star Northwest	Sand and gravel.	Dredging.

[1]Excludes brines and materials from wells.
[2]Crushed and broken and dimension stone were not available in 1988 because of biennial canvassing.

TABLE 9

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1988, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine	State	Operator	Commodity	Mining method
		METALS		
Tyrone	New Mexico	Phelps Dodge Corp.	Copper	Open pit.
Morenci	Arizona	do.	do.	Do.
Bingham Canyon	Utah	Kennecot, Utah Copper Div.	do.	Do.
Smokey Valley	Nevada	Round Mountain Gold Corp.	Lode gold	Do.
Pinto Valley	Arizona	Pinto Valley Copper Corp.	Copper	Do.
Empire	Michigan	Empire Iron Mining Co.	Iron ore	Do.
Goldstrike	Nevada	Barrick Goldstrike Mines Inc.	Lode gold	Do.
Hoyt Lakes	Minnesota	LTV Steel Co. Inc.	Iron ore	Do.
Hibbing Taconite	do.	Pickands Mather & Co.	do.	Do.
Minntac	do.	USX Corp.	do.	Do.

See footnotes at end of table.

TABLE 9—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[1] MINES IN THE UNITED STATES IN 1988, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine	State	Operator	Commodity	Mining method
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Open pit.
Ray	do.	ASARCO Incorporated	do.	Do.
Inspiration	do.	Cyprus Miami Mining Co.	do.	Do.
Chino	New Mexico	Phelps Dodge Corp.	do.	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Continental	Montana	Montana Resources Inc.	do.	Do.
Sleeper	Nevada	AMAX Gold Inc.	Lode gold	Do.
Jerritt Canyon	do.	Freeport-McMoran Gold Co.	do.	Do.
National Pellet Project—Itasca	Minnesota	Hanna Mining Co.	Iron ore	Do.
Candelaria	Nevada	Nerco Metals Co.	Silver	Do.
Tilden	Michigan	Tilden Mining Co.	Iron ore	Do.
Mercur	Utah	Barrick Mercur Gold Mines Inc.	Lode gold	Do.
Golden Sunlight	Montana	Golden Sunlight Mines Inc.	do.	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	do.	Do.
Mesquite	California	Goldfields Mining Co.	do.	Do.
		INDUSTRIAL MINERALS[2]		
Suwanee	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock.	Do.
Ft. Green	do.	Agrico Chemical Co.	do.	Do.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Kingsford	Florida	International Minerals & Chemical Corp.	do.	Open pit.
Haynsworth	do.	American Cyanamid Co.	do.	Do.
Clear Spring	do.	International Minerals & Chemical Corp.	do.	Do.
Noralyn	do.	do.	do.	Do.
Payne Creek	do.	Agrico Chemical Co.	do.	Do.
Ft Meade	do.	Mobil Mining and Minerals Co	do.	Do.
Hookers	do.	W.R. Grace & Co.	do.	Do.
Swift Creek	do.	Occidental Chemical Agricultural Products, Inc.	do.	Do.
Ft Meade	do.	Gardinier Inc.	do.	Do.
Gay	Idaho	J.R. Simplot Co.	do.	Do.
4 Corners	Florida	W.R. Grace & Co.	do.	Do.
Watson	do.	Estech General Chemical Corp.	do.	Do.
Sun Valley	California	CalMat Co. of California	Sand and gravel.	Dredging.
Henry	Idaho	Monsanto Co.	Phosphate rock.	Open pit.
Silver City	Florida	Estech General Chemical Corp.	do.	Do.
Caribou complex[3]	Idaho	Conda Partnership	do.	Do.
Vernal	Utah	Chevron Resources Co.	do.	Do.
Rockland	Florida	U.S. Agri-Chemicals Corp.	do.	Do.
Hardee	do.	C.F. Mining Corp.	do.	Do.
International	New Mexico	International Minerals & Chemical Corp.	Potassium salts.	Stopes.
Irwindale	California	United Rock Products Corp.	Sand and gravel.	Dredging.
Perkins	do.	A. Teichert & Son Inc., Teichert Aggregates	do.	Do.

[1]Excludes brines and materials from wells.
[2]Crushed and broken and dimension stone were not available in 1988 because of biennial xancassing.
[3]Includes Champ, Mountain Fuel, and Maybie Canyon mines.

TABLE 10

ORE TREATED OR SOLD PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

Commodity		Surface			Underground			Total[2]		
		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	1,220	579	2.1:1	—	—	—	1,220	579	2.1:1
Copper	thousand short tons	234,000	1,360	172.1:1	7,780	46	169.1:1	241,000	1,400	172.1:1
Gold:										
Lode	thousand troy ounces	112,000	5,250	21.3:1	3,790	241	15.7:1	116,000	5,490	21.1:1
Placer	do.	14,000	153	91.5:1	—	—	—	14,000	153	91.5:1
Iron ore	thousand long tons	218,000	55,100	4.0:1	W	W	W	218,000	55,100	4.0:1
Lead	thousand short tons	W	W	W	7,110	341	20.9:1	7,110	341	20.9:1
Molybdenum	thousand pounds	79,600	71,200	1.1:1	W	W	W	79,600	71,200	1.1:1
Silver	thousand troy ounces	13,700	13,600	1.0:1	3,800	15,000	.3:1	17,500	28,500	.6:1
					INDUSTRIAL MINERALS					
Abrasives[3]	thousand short tons	123	123	1.0:1	W	W	W	123	123	1.0:1
Barite	do.	445	445	1.0:1	—	—	—	445	445	1.0:1
Clays	do.	49,100	47,000	1.0:1	82	52	1.6:1	49,200	47,100	1.0:1
Diatomite	do.	766	693	1.1:1	—	—	—	766	693	1.1:1
Feldspar	do.	715	350	2.0:1	—	—	—	715	350	2.0:1
Gypsum	do.	12,600	12,600	1.0:1	3,650	3,010	1.2:1	16,200	15,600	1.0:1
Mica (scrap)	do.	143	143	1.0:1	—	—	—	143	143	1.0:1
Perlite	do.	680	379	1.8:1	5	5	1.0:1	685	384	1.8:1
Phosphate rock	do.	247,000	52,600	4.7:1	W	W	W	247,000	52,600	4.7:1
Potassium salts	do.	—	—	—	13,100	1,270	10.3:1	13,100	1,270	10.3:1
Pumice[4]	do.	412	389	1.1:1	—	—	—	412	389	1.1:1
Salt	do.	2,480	2,300	1.1:1	11,400	19,300	.6:1	13,900	21,600	.6:1
Sand and gravel	do.	952,000	952,000	1.0:1	—	—	—	952,000	952,000	1.0:1
Sodium carbonate (natural)	do.	W	W	W	11,300	6,590	1.7:1	11,300	6,590	1.7:1
Talc, soapstone, pyrophyllite	do.	1,280	121	10.6:1	W	W	W	1,280	121	10.6:1
Vermiculite	do.	1,950	304	6.4:1	—	—	—	1,950	304	6.4:1

W Withheld to avoid disclosing company proprietary data.
[1]Excludes wells, ponds, and pumping operations.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.

TABLE 11

MATERIAL HANDLED PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[1] IN THE UNITED STATES IN 1988, BY COMMODITY

Commodity		Surface			Underground			Total[2]		
		Total material handled[3] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[4]	Total material handled[3] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[4]	Total material handled[3] (thousand short tons)	Marketable product (units)	Ratio of units of material handled to units of marketable product[4]
METALS										
Bauxite	thousand long tons	9,090	579	15.7:1	—	—	—	9,090	579	15.7:1
Copper	thousand short tons	572,000	1,360	422.1:1	4,150	46	89.8:1	577,000	1,400	411.2:1
Gold:										
Lode	thousand troy ounces	553,000	5,250	105.4:1	4,890	241	20.3:1	558,000	5,490	101.7:1
Placer	do.	32,900	153	215.3:1	—	—	—	33,000	153	215.3:1
Iron ore	thousand long tons	331,000	55,100	6.0:1	W	W	W	331,000	55,100	6.0:1
Lead	thousand short tons	W	W	W	10,700	341	31.3:1	10,700	341	31.3:1
Molybdenum	thousand pounds	140,000	71,200	2.0:1	W	W	W	140,000	71,200	2.0:1
Silver	thousand troy ounces	49,000	13,600	3.6:1	4,410	15,000	.3:1	53,400	28,500	1.9:1
INDUSTRIAL MINERALS										
Abrasives[5]	thousand short tons	256	123	2.1:1	W	W	W	256	123	2.1:1
Barite	do.	445	445	1.0:1	—	—	—	445	445	1.0:1
Clays	do.	91,800	47,000	2.0:1	83	52	1.6:1	91,900	47,100	2.0:1
Diatomite	do.	3,770	693	5.4:1	—	—	—	3,770	693	5.4:1
Feldspar	do.	715	350	2.0:1	—	—	—	715	350	2.0:1
Gypsum	do.	16,500	12,600	1.3:1	3,670	3,100	1.2:1	20,200	15,700	1.3:1
Mica (scrap)	do.	143	143	1.0:1	—	—	—	143	143	1.0:1
Perlite	do.	642	379	1.7:1	5	5	1.0:1	646	384	1.7:1
Phosphate rock	do.	498,000	52,600	9.5:1	W	W	W	498,000	52,600	9.5:1
Potassium salts	do.	—	—	—	13,500	1,270	10.6:1	13,500	1,270	10.6:1
Pumice[6]	do.	466	389	1.2:1	—	—	—	466	389	1.2:1
Salt	do.	2,440	2,300	1.1:1	11,500	19,300	.6:1	14,000	21,600	.6:1
Sand and gravel	do.	952,000	952,000	1.0:1	—	—	—	952,000	952,000	1.0:1
Sodium carbonate (natural)	do.	W	W	W	11,200	6,590	1.7:1	11,200	6,590	1.7:1
Talc, soapstone, pyrophyllite	do.	1,300	121	10.7:1	W	W	W	1,300	121	10.7:1
Vermiculite	do.	3,740	304	12.3:1	—	—	—	3,740	304	12.3:1

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

TABLE 12

MINING METHODS USED IN OPEN PIT MINING IN THE UNITED STATES IN 1988, BY COMMODITY

(Percent)

Commodity	Total material handled	
	Preceded by drilling and blasting	Not preceded by drilling and blasting[1]
METALS		
Bauxite	100	—
Beryllium	—	100
Copper	99	1
Gold:		
Lode	98	2
Placer	—	100
Iron ore	96	4
Lead	100	—
Magnesium	100	—
Mercury	—	100
Molybdenum	100	—
Silver	100	—
Tin	—	100
Titanium (ilmenite)	—	100
Zinc	100	—
INDUSTRIAL MINERALS		
Abrasives[2]	71	29
Aplite	100	—
Barite	100	—
Boron	100	—
Clays	—	100
Diatomite	19	81
Feldspar	100	—
Greensand (marl)	—	100
Graphite	100	—
Gypsum	91	9
Iron oxide pigments, crude	100	—
Kyanite	100	—
Magnesite	100	—
Mica (scrap)	29	71
Perlite	26	74
Phosphate rock	3	97
Pumice[3]	21	79
Salt	1	99
Sand and gravel	—	100
Talc, soapstone, pyrophyllite	95	5
Vermiculite	58	42
Average	78	22

[1]Includes drilling or cutting without blasting, dredging, or mechanical excavation and nonfloat washing, and other surface mining methods.
[2]Includes abrasive stone and millstones.
[3]Excludes volcanic cinder and scoria.

TABLE 13[1]

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1988, 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	—	61,800	—	18,100	—	540	80,400	4,410	60	—	W	4,470
Gold:												
Lode	([3])	412,000	719,000	2,610,000	398,000	58,000	4,190,000	101,000	14,600	1,390	W	117,000
Placer	—	W	—	5,100	39,900	10,700	55,700	—	15	15	—	30
Lead	18,600	59,400	W	11,500	35,600	([4])	125,000	74,300	W	([5])	—	74,300
Platinum-group	—	109,000	—	—	—	—	109,000	—	W	—	—	—
Silver	—	41,000	W	3,080	W	1,830	46,000	31,600	6,720	315	—	36,700
Zinc	—	31,400	W	—	—	—	31,400	W	W	—	—	—
Other[6]	—	32,600	235,000	1,390,000	122,000	—	1,780,000	28,500	2,660	—	703,000	734,000
Metals total[2]	18,600	747,000	953,000	4,030,000	595,000	71,000	6,420,000	240,000	24,100	1,720	703,000	969,000
Percent of metals total[7]	0.3	11.6	14.9	62.8	9.3	1.1	100.0	24.7	2.5	0.2	72.6	100.0
INDUSTRIAL MINERALS												
Boron	—	—	—	67,200	—	—	67,200	—	—	—	—	—
Diatomite	—	—	—	3,000	—	—	3,000	—	—	—	—	—
Perlite	—	—	—	1,000	—	—	1,000	—	—	—	—	—
Phosphate rock	—	—	—	3,500	—	—	3,500	—	—	—	—	—
Sulfur (Frasch)	—	—	—	29,100	—	—	29,100	—	—	—	—	—
Other[8]	—	7,940	2,900	174,000	430	7,620	193,000	2,180	176	—	—	2,360
Industrial minerals total[2]	—	7,940	2,900	278,000	430	7,620	297,000	2,180	176	—	—	2,360
Percent of industrial minerals total[7]	—	2.7	1.0	93.6	0.1	2.6	100.0	92.5	7.5	—	—	100.0
Grand total[2]	18,600	755,000	956,000	4,310,000	596,000	78,600	6,720,000	242,000	24,200	2,080	703,000	971,000
Percent of grand total[7]	0.3	11.2	14.2	64.2	8.9	1.2	100.0	24.9	2.5	0.2	72.4	100.0
STATE												
Alaska	—	8,720	22,000	30,600	W	36,600	97,900	W	—	—	—	—
Arizona	—	62,100	3,000	W	W	W	65,100	4,480	5,290	90	W	9,860
California	W	36,600	W	327,000	26,200	3,210	393,000	1,310	4,350	215	1,200	7,070
Colorado	—	217,000	W	37,800	11,900	W	267,000	35,700	3,400	115	—	39,200
Florida	—	—	—	3,500	—	—	3,500	—	—	—	—	—
Idaho	—	W	10,200	124,000	48,000	2,740	184,000	23,600	2,600	—	—	26,200
Missouri	18,600	41,900	—	11,500	35,600	—	108,000	55,600	—	([5])	—	55,600
Montana	—	W	19,000	6,580	142,000	3,080	170,000	10,300	2,110	660	—	13,100
Nevada	([3])	128,000	703,000	2,140,000	170,000	24,600	3,170,000	16,700	1,030	—	—	17,800
New Mexico	—	3,440	W	2,490	W	W	5,920	8,300	W	—	—	8,330
Oregon	—	—	5,200	3,000	2,800	—	11,000	W	—	—	—	—
South Dakota	—	W	W	166,000	2,200	—	168,000	W	W	W	—	—
Tennessee	—	31,400	W	—	—	—	31,400	W	W	—	—	—
Texas	—	—	—	277,000	—	—	277,000	—	—	—	W	—

See footnotes at end of table.

TABLE 13[1]—Continued

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1988, 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]
Utah	—	W	—	45,300	—	—	45,300	W	W	—	—	—
Washington	—	W	W	9,590	—	3,120	12,700	W	—	W	—	—
Wisconsin	—	1,800	—	—	—	—	1,800	—	—	—	—	—
Wyoming	—	50	—	W	—	—	50	—	—	—	W	—
Undistributed[9]	—	224,000	194,000	1,130,000	157,000	5,300	1,710,000	85,800	5,470	998	702,000	794,000
Total all States[2]	18,600	755,000	956,000	4,310,000	596,000	78,600	6,720,000	242,000	24,200	2,080	703,000	971,000
Percent of all States[7]	0.3	11.2	14.2	64.2	8.9	1.2	100.0	24.9	2.5	0.2	72.4	100.0

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]This table is a compiliation of previous Mineral Yearbook tables 13, 14, and 15. Data has been compilied and reorganized.
[2]Data may not add to totals shown because of independent rounding.
[3]"Churn drilling" data included with Other drilling" data to avoid disclosing company proprietary data.
[4]"Lead" data included with Copper" data to avoid disclosing company proprietary data.
[5]"Shaft and winze sinking" data included with "Drifting, cross-cutting, or tunneling" data to avoid disclosing company proprietary data.
[6]Includes beryllium, iron ore, molybdenum, titanium, uranium, and metals items indicated by symbol W.
[7]Based on unrounded footage.
[8]Includes gypsum, lime, potassium salts, sand and gravel, talc and pyrophyllite, and mineral items indicated by symbol W.
[9]Includes Maine, Michigan, Minnesota, New Jersey, New York, and states items indicated by symbol W.

TABLE 14[1]

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT IN THE UNITED STATES IN 1988, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total[2]
METALS					
Copper	45	([3])	—	73,300	73,300
Gold:					
Lode	1,060	55	12	90,200	91,300
Placer	—	W	W	188	188
Iron ore	W	—	—	38,300	38,300
Lead	3,020	W	W	W	3,020
Silver	176	62	1	([3])	239
Uranium	73	6	—	—	78
Other[4]	120	386	5	4,290	4,800
Total[2]	4,500	509	18	206,000	211,000
INDUSTRIAL MINERALS					
Gypsum	W	—	—	3,700	3,700
Other[5]	23	1	—	2,990	3,010
Total[2]	23	1	—	6,690	6,710
Grand total[2]	4,520	509	18	213,000	218,000

See footnotes at end of table.

TABLE 14[1]—Continued

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT IN THE UNITED STATES IN 1988, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total[1]
			STATE		
Alaska	W	—	—	483	483
Arizona	26	13	1	—	41
California	6	17	1	W	24
Colorado	262	18	[3]	80	360
Idaho	151	46	—	44	241
Missouri	2,790	—	W	—	2,790
Montana	105	387	3	950	1,450
North Carolina	—	—	—	50	50
Nevada	261	7	—	75,600	75,900
Utah	W	W	—	11,000	11,000
Washington	W	—	W	20	20
Undistributed[6]	921	21	13	125,000	126,000
Total[2]	4,520	509	18	213,000	218,000

W Withheld to avoid disclosing company proprietary data; included with "Other" or "Undistributed."
[1]This table had been table 16 in previous issues of the Mineral Yearbook.
[2]Data may not add to total shown because of independent rounding.
[3]Less than 1/2 unit.
[4]Includes bauxite, molybdenum, platinum-group metals, zinc, and metal items indicated by symbol W.
[5]Includes abrasives, potassium salts, pumice, salt, talc and pyrophyllite, and mineral items indicated by symbol W.
[6]Includes Arkansas, Kansas, Michigan, Minnesota, New Mexico, New York, Oregon, South Dakota, Tennessee, Texas, Wyoming, and items indicated by symbol W.

TABLE 15[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
			TOTAL, BY USE				
1984	2,758,659	437,217	479,873	3,675,749	302,273	378,836	4,356,858
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	3,137,000	440,000	595,250	4,172,250	320,200	245,000	4,736,702
			BY CLASS AND USE				
			PERMISSIBLE EXPLOSIVES				
1984	[2]37,721	[2]195	[2]345	38,261	[2]902	[3]75	39,238
1985	[2]34,563	[2]117	[2]481	35,161	[2]836	[3]71	36,068
1986	34,971	7	[2]155	35,133	245	[3]61	35,439
1987	33,391	—	248	33,639	214	—	33,853
1988[4]	27,000	—	250	27,250	200	—	27,670

See footnotes at end of table.

TABLE 15[1]—Continued

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
BY CLASS AND USE							
OTHER HIGH EXPLOSIVES							
1984[5]	[2]20,357	[2]7,771	[2]29,658	57,786	[2]23,189	[3]17,271	98,246
1985[5]	[2]21,705	[2]9,466	[2]55,470	86,641	[2]35,460	[3]13,775	135,876
1986	18,004	7,027	[2]63,249	88,280	37,403	[3]6,106	131,789
1987	23,171	9,013	62,250	94,434	43,355	5,458	143,247
1988[4]	20,000	10,000	65,000	95,000	45,000	10,000	150,769
WATER GELS AND SLURRIES							
1984[5]	[2]99,340	[2]78,959	[2]102,849	281,148	[2]42,464	[3]11,146	334,758
1985[5 6]	[2]133,858	[2]66,653	[2]80,283	280,794	[2]27,487	[3]16,245	324,526
1986[6]	180,201	57,153	[2]128,854	366,208	38,582	[3]15,300	420,090
1987[6]	195,737	63,125	160,412	419,274	55,758	6,326	481,358
1988[4 6]	240,000	100,000	220,000	560,000	80,000	20,000	658,273
AMMONIUM NITRATE: FUEL-MIXED AND UNPROCESSED							
1984[7]	[2]2,601,241	[2]350,292	[2]347,021	3,298,554	[2]235,718	[3]350,344	3,884,616
1985[6 7]	r[2]2,051,177	[2]306,174	[2]374,266	2,731,617	[2]183,668	[3]388,599	3,303,884
1986[6]	2,333,161	255,657	[2]392,962	2,981,780	182,421	[3]171,317	3,335,518
1987[6]	2,968,463	268,145	260,001	3,496,609	209,585	133,605	3,839,799
1988[4 6]	2,850,000	330,000	310,000	3,490,000	195,000	215,000	3,899,990

[r]Revised.
[1]This table is a compilation of previous Mineral Yearbook issues tables 17 and 18. In addition a breakout of data for "construction work" and "All other purposes" is included.
[2]Some quantities of this use are included with "All other purposes" to avoid disclosing company proprietary data.
[3]Includes some quantities from "Coal mining," "Metal mining," "Quarrying and nonmetal mining," and "Construction work."
[4]Estimated from correlation patterns between explosives sales and end-use sectors were developed from Bureau of Mines time series data and leading indicators of industrial production and economics as reported by the Department of Energy, Federal Reserve Board, Department of Transportation, and Bureau of the Census.
[5]Some quantities of this use are included with "Ammonium nitrate: fuel-mixed and unprocessed" to avoid disclosing company proprietary data.
[6]Data for 1985–88 are not comparable to data for prior years. Higher strength blasting agents classification was discontinued. Blasting agents formerly in that classification are now included in "Water gels and slurries."
[7]Includes some quantities from "Other high explosives," and "Water gels and slurries."

ABRASIVE MATERIALS

By Gordon T. Austin

Mr. Austin, a physical scientist with over 30 years of 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 includes tripoli, special silica stone, garnet, staurolite, and emery, increased about 21% in 1989. The increase in the value of staurolite and tripoli production was the result of an increase in the quantity of materials produced and an increase in the unit value. Emery decreased due to the significant decline in the volume of the material produced. Special silica stone experienced both a decrease in unit value and quantity produced. Garnet showed a small increase in quantity, but a decrease in unit value.

The silicon carbide industry saw a slight decrease in the quantity produced and a 12% increase in the value of production. The fused aluminum oxide industry showed a 5% decline in the quantity produced, but enjoyed a 15% increase in the value of production. Combined production for both industries decreased 4% in quantity but increased 13% in value compared with those of 1988.

The metallic abrasives industry experienced a decline of 6% in quantity and 5% in value after 4 consecutive years of sales increases in both quantity and value. The industry includes the primary producers of steel, chilled and annealed iron, and cut wire shot and grit, and shot and grit reclaimed by primary producers. Shipments in 1989 were about 9% below the 239,619 metric tons[1] of 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 rebounded from the 48-year low in 1987 with an increase of 185% to 3.9 million carats in 1988.

DOMESTIC DATA COVERAGE

Domestic production data for abrasive materials was from seven separate voluntary Bureau of Mines surveys. Of the 61 operations producing natural

TABLE 1

SALIENT U.S. ABRASIVES STATISTICS

		1985	1986	1987	1988	1989
Natural abrasives production by producers:						
Tripoli (crude)	metric tons	r108,706	106,298	104,259	99,928	105,230
Value	thousands	r$844	$918	$975	$864	$2,537
Special silica stone[1]	metric tons	1,050	973	r1,378	r1,892	898
Value	thousands	$515	$501	r$489	r$566	$147
Garnet[2]	metric tons	33,318	24,298	38,353	42,506	42,605
Value	thousands	$2,973	$2,603	$4,350	$4,707	$4,408
Emery	metric tons	W	2,611	1,764	869	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	434,448	438,043	441,292	555,635	535,213
Value[4]	thousands	$171,974	$173,858	$182,039	$219,322	$227,761
Foreign trade (natural and artificial abrasives):						
Exports (value)[5]	do.	$191,272	$207,624	$238,522	$281,633	$260,363
Reexports (value)[5]	do.	$23,845	r$27,011	$21,192	$19,302	$33,771
Imports for consumption (value)[5]	do.	$382,877	r$406,572	$424,640	$501,707	$420,982

r Revised. 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.

[3] Includes Canadian production of crude silicon carbide and fused aluminum oxide and shipments of metallic abrasives by producers.

[4] Excludes the United States and Canadian production and value of aluminum-zirconium oxide.

[5] Bureau of the Census.

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 $300.9 million, an increase of 16% compared with the 1987 value. The average total value for the last 10 years was $237.9 million per year with the high of $300.9 million in 1988 and the low of $196.8 million in 1982. The last 3 years have each shown a significant increase in total value compared with the essentially level period of 1983–85.

The total value of abrasive materials imported was $420.9 million, a decrease of 16% compared with the 1988 value. The average total value for the past 10 years was $362.2 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 last 6 years.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. The trade deficit averaged $109.2 million per year for the past 10 years and averaged $173.8 million per year for the past 5 years. The deficit increased 23% to a record high of $200.8 million in 1988.

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 Minerals Yearbook chapters, such as pumice.

Production

Processed tripoli, sold or used, decreased 6% in quantity and 5% in the value, but the value per ton increased slightly. The quantity of crude tripoli produced increased after 5 consecutive years of decline. The average production for the past 10 years was 104,786 tons per year with a high of 112,928

TABLE 2

U.S. EXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind		1988		1989	
		Quantity	Value	Quantity	Value
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	carats	72,093	$112,094	73,168	$113,446
Industrial diamond, natural or synthetic, other	do.	1,830	15,063	1,521	13,645
Natural abrasives, crude	kilograms	1,501	4,065	3,339	4,270
Natural abrasives, other	do.	NA	NA	9,027	12,836
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	15,496	25,796	17,207	19,192
Silicon carbide, crude or in grains	do.	4,207	7,763	8,452	9,954
Other refined abrasives	do.	16,781	24,601	5,672	2,788
Grinding and polishing wheels and stones:					
Diamond	number	NA	6,641	761	9,896
Polishing stones, whetstones, oilstones, hones, similar stone	do.	1,312	2,486	3,311	6,235
Wheels and stones, n.e.c.	do.	NA	29,471	777	1,075
Abrasive paper and cloth, coated with natural or artificial abrasive materials	kilograms	6,664	50,276	11,451	60,729
Grit and shot, including wire pellets	do.	11,900	9,736	8,646	6,297
Total		XX	287,992	XX	260,363

NA Not available. XX Not applicable.

Source: Bureau of the Census.

TABLE 3

U.S. REEXPORTS OF ABRASIVE MATERIALS, BY KIND

(Thousands)

Kind		1988		1989	
		Quantity	Value	Quantity	Value
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	carats	2,440	$3,336	5,067	$10,734
Industrial diamond, natural or synthetic, other	do.	1,164	14,279	1,234	19,603
Emery, natural corundum, pumice in blocks	kilograms	80	193	59	111
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	57	90	1,803	1,598
Silicon carbide, crude or in grains	do.	77	82	90	102
Grinding and polishing wheels and stones:					
Diamond	carats	6	118	9	299
Polishing stones, whetstones, oilstones, hones, similar stone	number	12	10	45	150
Wheels and stones, n.e.c.	kilograms	39	653	—	—
Abrasive paper and cloth, coated with natural or artificial abrasive materials	do.	76	541	584	1,174
Total		XX	19,302	XX	33,771

XX Not applicable.

Source: Bureau of the Census.

tons in 1984 and a low of 97,368 tons in 1981. Production in 1989 was 105,230 tons, valued at $2.5 million. The significant increase in the value of crude produced was the result of a change in the reporting methodology.

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

Because tripoli grains lack distinct edges and corners, it has unique abrasive uses. It is the mild abrasive in toothpaste and toothpolishing compounds, industrial soaps, 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 declined for the sixth consecutive year. Over this 6-year period consumption declined about 29%. The average annual consumption of abrasive tripoli for the past 10 years was 31,971 tons, with a high of 37,024 tons in 1984 and a low of 26,192 tons in 1989. The 1989 consumption was the lowest since 1953, when only 22,680 tons were sold or used.

After 5 consecutive years of growth from 1982 to 1987, the amount of tripoli used as a filler declined 4% in 1988 and an additional 8% in 1989. The average consumption of filler-grade tripoli for the past 10 years was 60,741 tons per year, with a high of 71,160 tons in 1987 and a low of 55,180 tons in 1982. 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

TABLE 4

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

(Thousands)

Kind		1988		1989	
		Quantity	Value	Quantity	Value[1]
Silicon carbide, crude	metric tons	93	$47,208	80	$45,439
Aluminum oxide, crude	do.	128	55,197	78	34,529
Other crude artificial abrasives	do.	10	6,452	9	1,339
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	8	12,908	12	18,056
Aluminum oxide	do.	16	18,545	20	28,589
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	5	10,786	4	4,078
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives		(2)	125,873	20	105,414
Hones, whetstones, oilstones, polishing stones	number	1,850	1,554	2,300	1,786
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	NA	61	701	4,597
Solid natural stone wheels	do.	408	469	1,404	2,592
Diamond	do.	516	15,465	508	13,143
Abrasive wheels bonded with resins	do.	5,341	24,677	6,076	25,880
Other		(2)	23,178	(2)	24,919
Grit and shot, including wire pellets	do.	3,537	3,406	4,168	3,428
Diamond, natural and synthetic:					
Diamond dies	number	101	2,542	NA	NA
Crushing bort	carats	515	638	NA	NA
Natural industrial diamond stones	do.	6,326	61,204	6,232	34,610
Miners' diamond[3]	do.	563	2,965	2,558	26,426
Powder and dust, synthetic[4]	do.	50,748	54,901	49,466	36,637
Powder and dust, natural	do.	12,995	10,592	12,087	7,622
Total		XX	501,707	XX	420,982

NA Not available. XX Not applicable.
[1] Customs values.
[2] Quantity not reported.
[3] Includes 10,000 carats of synthetic miners' diamonds in 1988.
[4] Includes 676,413 carats of synthetic diamonds in 1988.

Source: Bureau of the Census.

TABLE 5

PROCESSED TRIPOLI[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[2]

Use		1985	1986	1987	1988	1989
Abrasives	metric tons	36,489	33,188	26,637	26,360	26,192
Value	thousands	$3,670	$3,590	$3,089	$3,151	$3,172
Filler	metric tons	62,414	67,048	71,160	r68,618	63,080
Value	thousands	$6,452	$8,588	$9,855	r$9,876	$9,185
Other	metric tons	—	W	W	W	W
Value	thousands	—	W	W	W	W
Total	metric tons	98,722	100,237	97,796	r94,978	89,272
Total value	thousands	$10,122	$12,178	$12,944	r$13,027	$12,357

r Revised. W Withheld to avoid disclosing company proprietary data.
[1] Includes amorphous silica and Pennsylvania rottenstone.
[2] Partly estimated.

States was $121.11 per ton. The average annual value reported for abrasive tripoli for the past 10 years was $96.95 per ton, with the high value in 1989 of $121.11 and the low in 1980 of $74.00. 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 1980 through 1984.

The average reported value of filler tripoli, sold or used, in the United States was $145.61 per ton. The average annual value for the past 10 years was $112.90 per ton, with a high of $145.61 per ton in 1989 and a low of $74.00 per ton in 1980. 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 in which the products were manufactured, except for the oilstones in New Hampshire. The novaculite for the New Hampshire oilstones was produced in Arkansas. The process for estimating the production of crude material changed in 1981 and again in 1987. Because of the two changes in the way of estimating production, 10-year averages and other production trends would be of no practical use.

The quantity of oilstones, hones, whetstones, files, and grindstones produced was only slightly greater than the 10 year low in 1988 at 377 tons and had essentially the same value at $5.5 million. The average annual production of the products for the past 10 years was 522 tons, with a high of 647 tons in 1982 and a low of 37 tons in 1988. The average value of annual production for the past 8 years was $5.5 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 1989, when the value of production was 54% greater at an average value of $6.3 million a year. During (1985–89), the average annual quantity of production was less than the 10-year average, 473 tons versus 522 tons. During the same period the average annual value of production was 13% 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.

TABLE 6
SPECIAL SILICA STONE FINISHED PRODUCTS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1]

Year	Quantity (metric tons)	Value (thousands)
1985	402	r$5,371
1986r	463	6,520
1987r	598	7,367
1988r	371	5,415
1989	377	5,459

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

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; Washita Stone has a porosity of 16% and resembles unglazed porcelain. The four main types were as follows:

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

Arkansas accounted for 96% of the value and 98% of the total quantity of special silica stone products reported as sold or used by U.S. producers.

Consumption and Uses

The domestic consumption of special silica stone products 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. 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 value 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 1989 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was $14,443 per ton or about $14.44 per kilogram. The average annual value of the same items for the past 8 years was $11,102 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 10 years, the unit value of special silica stone products followed two distinct negative trends plus the significant increase in 1989. The first trend, a gradual decrease, occurred during the period 1980 to 1984. 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

TABLE 7

PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1989

Company and location	Type of operation	Product
Arkansas Abrasives Co.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	
Arkansas Oilstone Co:		
Hot Springs, AR (inactive)	Stone cutting and finishing	Whetstones and oilstones.
Arkansas Whetstone Co., Inc:		
Hot Springs, AR (inactive)	do.	Do.
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.
Hindostan Whetstone Co.:		
Bedford, IN	do.	Cuticle stone.
Do.	Quarry	Crude silica stone.
Hiram A. Smith Whetstone Co., Inc.:		
Hot Springs, Ark	Stone cutting and finishing	Whetstones and oilstones.
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.
Poor Boy Whetstones:		
Hot Springs, AR (inactive)	do.	Do.
Robert Lowery:		
Hot Springs, AR (inactive)	do.	Do.
Taylor Made Crafts, Inc.:		
Lake Hamilton, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	Quarry	Crude novaculite.
Washita Mountain Whetstone Co.:		
Lake Hamilton, AR (inactive)	Stone cutting and finishing	Whetstones and oilstones.

value per ton more than doubled from $6,411 to $13,361. The average annual value per ton for the period 1985 to 1988 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 over 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 the 1988 value, 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 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 almandine and pyrope that breaks under pressure into sharp chisel-edged plates. Industry uses this garnet as an abrasive powder and in the manufacture of coated abrasives. Low-quality industrial garnet found uses primarily as an airblasting or hydroblasting media and as filtration media.

Production

The United States continued to be the largest garnet producer and consumer, accounting for about 45% of the world's production and 40% of the consumption. Four domestic producers operated five plants, three in New York and one each in Idaho and Louisiana.

The quantity and value of crude garnet concentrates produced were 42,605 tons worth $4.4 million, essentially the same as those of 1988. The average annual production for the past 10 years was 31,225 tons, with a high of 42,605 in 1989, and a low of 23,089 in 1981. Over the past 10 years, production increased about 75%, or at an annual compounded rate of about 6% 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

The quantity of garnet sold or used by producers was 41,320 tons, essentially the same as in 1988, but the value decreased about 12% to $9.8 million. The average annual quantity of garnet sold or used for the past 10 years was 29,973 tons, with a record high of 41,896 tons in 1988 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 require 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 U.S. 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 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.

TABLE 8

GARNET SOLD OR USED BY PRODUCERS IN THE UNITED STATES

Year	Quantity (metric tons)	Value (thousands)
1985	27,791	$6,102
1986	28,899	6,748
1987	35,812	7,744
1988	41,896	11,144
1989	41,320	9,768

Prices

The average value per ton of crude garnet concentrates was $103, a 7% decrease compared with the 1988 average. The average value for the past 10 years was $95 per ton, with a high of $113 in 1987 and a low of $78 per ton in 1980. During the past 10 years, the overall trend for the value of crude concentrates was a net increase with decreases in some years. The 1989 value was 132% of the 1980 value.

The average value per ton of garnet sold or used was $236, a decrease of 11% from that of 1988. The average value for the past 10 years was $227 per ton, with a high of $266 in 1988 and a low of $205 per ton in 1980. Excluding the highest and two lowest values, the difference between the highest value and lowest value in the remaining 7 years was only 6.5%. The price trend of garnet sold or used during the past 10 years has been stable with very minor changes, except the 23% increase from 1987 to 1988.

Foreign Trade

Garnet exports, as reported by producers to the Bureau of Mines, were about 9,716 tons, an increase of 22% compared to 1988. Export data on garnet were not available from the Bureau of Census. Producers have reported exports to the Bureau of Mines for the past 3 years; before that, the Bureau estimated garnet exports. Trend analysis beyond the past 3 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 Bureau about 5,000 tons of imported garnet, unchanged from 1988. Import data for garnet also were not available from the Bureau of the Census. Bureau of Mines data, which are available for only 3 years, showed a significant increase in garnet imports each year. The United States was a net exporter of garnet in 1989; exports exceeded imports by 114%.

World Review

The United States was the dominant world producer and consumer of garnet, accounting for approximately 45% of the estimated world output and nearly 40% of estimated world consumption. Target Mines Ltd. 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.

TABLE 9

WORLD GARNET ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(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 capacities of operating plants as well as plants on standby basis.

Outlook

The U.S. production and consumption of industrial garnet over 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 1995. If garnet were not available, other abrasives could be used in its place, but often 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.

Background

Definition, Grades, and Specifications.—Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form, the 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 ($Ca[Mg.Fe]Si_2O_6$). 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 another 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 byproduct from its wollastonite operation. It sold both crude garnet concentrate for additional refining and refined garnet for use as blasting and filtration media. International Garnet Abrasives 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 was 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. The same family has owned Barton Mines 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 locations of the plants are the following: New York and Virginia, two each; Massachusetts, Michigan, Minnesota, Mississippi, Ohio, and Pennsylvania, one 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 over 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 increased.

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 of a kilometer away.

At Emerald Creek and Carpenter Creek, Benewah County, Idaho, stripping 1 to 2 meters of overburden exposes the garnetiferous gravel. Mining is done 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 assured 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.

EMERY

Emery is an impure corundum containing magnesium-aluminum silicates. It is used as an abrasive aggregate for nonskid, wear-resistant floors, pavements, and stair treads, as tumbling or deburring media, and, also, in the manufacture of coated abrasives.

Production

A single firm, Oregon Emery, Albany, OR, produced emery in 1989. Production from the historical producer near Peekskill in Westchester County, NY, stopped in 1988.

Consumption

The Bureau estimated that the United States consumed approximately 12,000 tons of emery in 1989. 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 1989, nor has it exported emery in the past 10 years. During the past 10 years, the U.S. 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. The Bureau estimated Turkey exported approximately 10,500 tons of emery to the United States. Greece, the second largest producer, exports very little emery to the United States because of the high cost of the material.

World Review

Turkey, with production of approximately 21,000 tons, was the world's largest producer of emery. The second largest producer was Greece, with a total production of about 8,500 tons.

STAUROLITE

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

Production

Georgia, North Carolina, and Virginia produced mineral specimen staurolite crystals. The crystals were in the cruciform twinned form commonly called "fairy crosses." E.I. du Pont de Nemours & Co. Inc. produced industrial grade staurolite in Florida. Production industrial staurolite increased 117% in quantity and 41% in value compared with those of 1988.

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

Consumption and Uses

Shipments of staurolite increased 117% in tonnage and 40% in value. 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 price per ton, no international market for staurolite is anticipated 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.

Government Programs

The National Defense Stockpile for industrial diamonds, as of December 31, 1989, had a goal and an inventory of 22 million carats for crushing bort. The goal for industrial stones was 7.7 million carats and the inventory was 7.78 million carats. There were no sales of industrial diamonds from the stockpile during 1989. Currently, there is legislative authority for disposal of 2,355,150 of industrial stones, but there were no disposals 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 world's largest producer of synthetic industrial diamond. This 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. 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. Over the past 10 years, production increased at an average rate of 9% compounded annually.

U.S. secondary production of industrial diamond was from the following five firms: Industrial Diamond Laboratory Inc., Bronx, NY; Industrial Diamond Powders Co., Pittsburgh, PA; International Diamond Services Inc., Houston, TX; Keenkut Inc., Keene, NH; and National Research Co., Fraser, MI. The firms reclaimed a total of about 3.6 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste, a decrease of 50% compared with that of 1988.

Consumption and Uses

The United States continued to be the largest single consumer of industrial diamond. The Bureau of Mines estimate of apparent consumption of industrial diamond was approximately 79 million carats, a decrease of about 8% compared with 1988 consumption. Average annual consumption for the past 10 years was about 59.6 million carats. During this period, two different trends for consumption occurred. The average annual consumption for 1980–1984 was 43.2 million carats, and that for 1985–1989 was 76% greater or 76.1 million carats. The second trend was the result of the strong movement to industrial diamond by U.S. manufacturers. 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 increased demand for most types of industrial diamonds.

Diamond is far harder than any other natural or artificial abrasive material. 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, 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 metals. Beveling automobile glass 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.

The three major types of grinding wheels—resinoid, metal, and vitrified bonds—were made 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. Very thin 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 PCD. Diamond saws, diamond wheels, and diamond abrasive grit and powder still are made almost exclusively from synthetic diamond.

Prices

The 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

TABLE 10

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

(Thousand carats and thousand dollars)

Year	Quantity	Value
1985	46,222	127,191
1986	45,991	110,648
1987	48,877	95,559
1988	71,147	130,300
1989	70,342	105,295

Source: Bureau of the Census.

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 $1.43 a carat. The high value was $2.86 in 1980 and the low was $0.63 in 1989. The average value of natural grit and powder, in current dollars, declined every year since 1980. The 1980 average value was 452% greater than that of 1988.

The average annual value of imported synthetic grit and powder for the past 10 years was $1.41 a carat. The high value was $1.86 a carat in 1981 and the low was $0.74 in 1989. The average value of imported synthetic grit and powder decreased every year since 1981. The 1989 value declined 60% compared with 1981, and the decline from 1988 to 1989 was 31%. During the last 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 1980, the average value of natural grit and powder was 65% greater than the average value for the synthetics. In 1989, the average value for the synthetics was 17% greater than that for natural material. Natural grit and powder declined in value at a much greater rate than did synthetic grit and powder.

The average annual value of imported industrial diamond stones for the past 10 years was $9.92 a carat, with a high value of $13.93 in 1981 and a low of $6.94 in 1989. The trend for the value of industrial stones was mixed for the past 10 years. There was a 23% decrease in the average value. The period started with 2 years of increasing values, followed by 3 years of lower values. Values over the final 5 years were alternating decreases and increases. The 1989 average value was 5% less than the 1988 value, 27% less than the 1981 high, and 23% less than the 1980 value.

Foreign Trade

The United States was the largest exporter of industrial diamond grit and powder in the world. The United States exported and reexported a record 78.2 million carats of natural and synthetic grit and powder. The material was worth a record $119.1 million. Additionally, the U.S. exported and reexported approximately 2.8 million carats of industrial stones, valued at $33.2 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: Japan, 30%; Federal Republic of Germany, 21%; Ireland, 6%; Italy, 7%; Belgium, 7%; and Republic of Korea, 5%. Six countries received about 74% of the total U.S. exports of industrial stones. The countries and the percentage of exports they received were: Ireland, 30%; Belgium, 17%; Federal Republic of Germany, 27%; Japan, 10%; Canada, 4%; and France, 2%.

The average annual exports plus reexports of natural and synthetic grit and powder for the past 10 years was 46.0 million carats, with an average value of $85.9 million. The highest level of exports plus reexports during the past 10 years was 78.2 million carats valued at $119.1 million in 1989. The lowest was 28.5 million carats in 1980 and 1981, and valued at $65.8 million in 1981. The trend of exports plus reexports for the past 10 years was one of continued growth. There was an increase of 178% over the period or an annual average compounded growth rate of just under 12%. The increase from 1988 to 1989 was about 5%, less than one-half of the 10-year average rate.

The average annual exports plus reexports of industrial stones for the past 10 years were 3.0 million carats a year, and the average value was $31.9 million. The high was 3.6 million carats in 1980 and 1986, and the low was 1.9 million carats in 1982. There was no distinct trend for the past 10 years. Exports plus reexports of about 2.8 million carats were 7% less than in 1988, but 22% less than in 1980. The 1989 exports plus reexports were 22% less in quantity than the 10-year high in 1980 and 1986.

The average annual imports of natural diamond grit and powder was 7.3 million carats a 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 1988 and 235% greater than 1980. The trend for the quantity of natural grit and powder imported over 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 79% of U.S. imports of natural grit and powder: Ireland, 49%; the United Kingdom, 13%, U.S.S.R., 11%; and Japan, 6%. The U.S.S.R. was the only producer of natural diamonds in this group.

The average annual imports of synthetic diamond grit and powder were 26.8 million carats a 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 in 1988 and 311% greater than in 1980. The trend of synthetic grit and powder imports over the past 10 years has been 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. Four countries furnished 82% of the synthetic diamond grit and powder imported into the United States in 1989: Ireland, 59%; Japan, 10%; U.S.S.R., 8%; and Romania, 5%.

The 10-year average for imports of industrial diamond stones was 6.9 million carats a 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.

The United States was a net exporter of diamond grit and powder and a net importer of industrial diamond stones. The U.S. was a net exporter of industrial diamond based on the total quantity and total gross value. The excess trade balance in industrial diamonds was about 10.8 million carats and $47.2 million.

World Review

Botswana and the Republic of South Africa were the largest producers of

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL DIAMOND, BY COUNTRY[1]

(Thousand carats and thousand dollars)

Country	Natural industrial diamond stones (including glazers' and engravers' diamond, unset) (7102.21.4000 and .3000)[4 5]				Miners' diamond[2] natural and synthetic[3] (7102.21.1010 and .1020)[6]				Diamond powder and dust, synthetic (7105.10.0020 ; .0030 and .0050)[7]				Diamond powder and dust, natural (7105.1011 and .0015)[4 8]			
	1988		1989		1988		1989		1988		1989		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	45	$597	7	$108	—	—	56	$98	—	—	29	$33	1	$85	—	—
Belgium-Luxembourg	648	5,890	123	1,927	8	$27	35	1,111	174	$764	950	682	462	412	231	$183
Canada	31	90	3	12	8	18	(5)	4	119	75	127	81	256	82	85	33
China	—	—	2	2	—	—	1	8	—	—	634	308	—	—	—	—
Finland	—	—	—	—	—	—	—	—	128	318	—	—	—	—	—	—
France	253	431	3	474	34	71	6	18	—	—	2	4	—	—	—	—
Germany, Federal Republic of	13	151	17	119	64	115	2	2	2,181	975	1,173	581	133	237	260	229
Ghana	240	4,785	246	3,221	2	39	104	918	14	90	1	2	26	109	4	5
Greece	—	—	—	—	—	—	—	—	256	115	164	924	—	—	—	—
Hong Kong	—	—	(9)	215	—	—	10	281	—	—	55	59	—	—	15	23
Ireland	257	966	901	3,219	348	2,259	1,749	5,488	37,642	46,111	29,010	26,273	4,748	5,310	5,965	3,008
Israel	3	232	5	425	—	—	(9)	53	(5)	33	—	—	80	26	—	—
Italy	—	—	4	13	—	—	7	2	679	307	2,116	924	—	—	29	74
Japan	353	1,589	3	201	—	—	19	881	5,583	3,463	5,093	3,107	1,941	1,312	735	219
Mexico	—	—	—	—	2	25	2	14	—	—	—	—	—	—	—	—
Netherlands	99	1,660	6	1,039	1	64	15	1,406	(5)	21	—	—	—	—	5	4
South Africa, Republic of	(5)	1	28	546	1	3	—	—	—	—	—	—	2	1	—	—
Switzerland	8	300	(9)	46	5	7	6	678	862	723	2,015	1,135	735	385	867	715
U.S.S.R.	—	—	20	68	—	—	—	—	430	114	3,794	1,192	3,265	1,294	1,380	496
United Kingdom	1,447	26,829	949	9,648	49	108	322	11,431	629	479	1,349	879	988	930	1,566	1,470
Zaire	2,736	10,249	3,425	8,512	6	22	192	3,331	31	50	(9)	4	216	321	795	1,096
Other	193	7,434	490	4,815	35	207	22	702	2,020	1,263	2,954	449	142	88	149	67
Total[6]	6,326	61,204	6,232	34,610	563	2,965	2,558	26,426	50,748	54,901	49,466	36,637	12,995	10,592	12,086	7,622

[1] Excludes 251,600 carats of crushing bort from Belgium-Luxembourg, Japan, and the United Kingdom in 1988.
[2] Customs value.
[3] Includes and 10,000 carats of synthetic miners' diamonds in 1988.
[4] H.T.S. codes.
[5] Formerly TSUSA No. 520.2900.
[6] Formerly TSUSA Nos. 529.1900 and 520.2340.
[7] Formerly TSUSA Nos. 520.2000; 520.2020; 520.2040; 520.2060 and 520.2100.
[8] Formerly TSUSA No. 520.2800.
[9] Less than 1/2 unit.

Source: Bureau of the Census.

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.[10] The next largest, in order of volume, were Botswana and The Republic of South Africa. Other smaller but significant producers were China, Brazil, Venezuela, Angola, and Ghana.[11] Total world output of natural industrial diamond in 1989 was approximately 51.8 million carats, a slight increase over 1988.

Outlook

Diamond grit and powder should experience substantial increases in domestic demand for every end use over the next 5 years. The increases for synthetic grit and powder are expected to be greater than the increases for natural. The constant-dollar prices of these materials, especially the synthetic diamond products, should continue to decrease or at least remain constant, because planned production increases should make them more cost effective. The greatest increases will occur in the

TABLE 12

WORLD INDUSTRIAL DIAMOND ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Carats)

Country	Rated capacity[1]	
	Natural	Synthetic
North America:		
United States	—	100,000,000
South America:		
Brazil	1,250,000	—
Guyana	10,000	—
Venezuela	600,000	—
Total	1,860,000	—
Africa:		
Angola	200,000	—
Botswana	5,000,000	—
Central African Republic	200,000	—
Ghana	750,000	—
Guinea	25,000	—
Liberia	200,000	—
Namibia	100,000	—
Sierra Leone	100,000	10,000
South Africa, Republic of	8,000,000	20,000,000
Tanzania	100,000	—
Zaire	30,000,000	—
Total	44,675,000	20,010,000
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
Oceania:		
Australia	25,000,000	—
World total	80,370,000	420,010,000

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

contract construction industry, because large quantities of saw-grade diamond will be required for the tools used in 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 U.S. producers. Domestic production of synthetic material is sufficient to supply U.S. diamond grit and powder demand. The United States also 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 industry. 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 over the next 5 years. U.S. consumption should average between 6 and 7 million carats a 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.

Background

Definition, 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 16–20 mesh to 325–400 mesh, and powder as particles smaller than 325 to 400 mesh. These categories are subdivided further into over 100 groups.[12]

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 make synthetic stones of 2 carats or larger. Engineered pieces of this material are marketed rather than 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 American National Standards Institute (ANSI) Specification B74.16-1971,[13] ANSI Specification B74.20-1981,[14] and by a proposed standard developed by the Industrial Diamond Association[15] for subsieve micron sized diamond or cubic boron nitride powders. The terms "sand," "grit," and "powder" also describe decreasing orders of fine diamond.

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

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

The first industrial use of diamond was probably as diamond powder for polishing gem diamonds and other precious stones. The art of diamond cutting and polishing was known in India,

TABLE 13

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

(Thousand carats)

Country	1985			1986			1987			1988[p]				1989[e]			
	Natural																
	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Synthetic[3]	Gem[2]	Industrial	Total	Synthetic[3]
Angola	464	250	714	240	10	[e]250	180	10	[e]190	950	50	[e]1,000	—	950	50	1,000	—
Australia	4,242	2,828	7,070	13,145	16,066	29,211	13,650	16,683	30,333	17,517	17,517	35,034	—	17,540	17,540	35,080	—
Botswana	6,318	6,317	12,635	9,590	3,500	[r]13,090	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	[4]15,252	—
Brazil	233	217	450	310	315	625	320	325	645	353	180	533	—	350	200	550	—
Central African Republic	190	87	277	259	99	358	304	108	412	284	59	343	—	280	60	340	—
China[e]	200	800	1,000	200	800	1,000	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000
Cote d'Ivoire (formerly Ivory Coast)[e 5]	15	5	20	10	4	14	15	6	21	[r]8	[r]3	[r]11	—	11	4	15	—
Czechoslovakia	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	5,000
France	—	—	—	—	—	—	—	—	—	—	—	—	[e]4,000	—	—	—	4,000
Ghana[6]	60	576	636	88	498	[r]586	65	400	465	165	495	[r e 7]660	—	168	452	[7]620	—
Greece	—	—	—	—	—	—	—	—	—	([8])	—	([8])	[e]1,000	—	—	—	1,000
Guinea[6]	123	9	132	190	14	204	163	12	175	136	10	146	—	[4]138	[4]10	[4]148	—
Guyana[e]	4	7	11	3	6	[4]9	[r]2	[r]5	[r]7	1	3	[4]4	—	2	3	5	—
India	14	2	16	13	3	16	13	3	[r]16	12	3	15	—	3	11	14	—
Indonesia[e]	5	22	27	[r]6	22	[r]28	[r]7	[r]22	[r]29	[r]7	[r]22	[r]29	—	7	25	32	—
Ireland	—	—	—	—	—	—	—	—	—	—	—	—	[r]60,000	—	—	—	60,000
Japan	—	—	—	—	—	—	—	—	—	—	—	—	[e]25,000	—	—	—	25,000
Liberia	66	72	138	63	189	252	60	190	[e]250	67	100	167	—	68	102	170	—
Namibia	865	45	910	970	40	1,010	971	50	1,021	901	37	938	—	970	30	1,000	—
Romania	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	4,500
Sierra Leone[5]	243	106	349	215	100	315	150	75	225	100	75	[e]175	—	100	75	175	—
South Africa, Republic of:																	
Finsch Mine	1,770	3,184	4,954	1,821	3,208	5,029	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	[4]4,610	—
Premier Mine	820	1,864	2,684	882	1,977	2,859	772	1,713	2,485	696	1,543	2,239	—	689	1,526	[4]2,215	—
Other De Beers' properties[9]	1,500	569	2,069	1,428	529	1,957	1,427	546	1,973	1,388	531	1,919	—	1,360	520	[4]1,880	—
Other	460	35	495	342	41	383	409	30	439	361	65	[r e]426	—	348	63	411	—
Total	4,550	5,652	10,202	4,473	5,755	10,228	4,063	4,990	9,053	[r]3,817	[r]4,687	[r e]8,504	[r e]55,000	4,010	5,106	9,116	60,000
Swaziland	13	8	21	23	16	39	[r]48	[r]32	[r e]80	44	29	73	—	33	22	[4]55	—
Sweden	—	—	—	—	—	—	—	—	—	—	—	—	[e]25,000	—	—	—	25,000
Tanzania	165	71	236	133	57	190	105	45	[e]150	105	45	[e]150	—	105	45	150	—
U.S.S.R.[e]	4,400	6,400	10,800	4,400	6,400	10,800	4,400	6,400	10,800	4,500	6,500	11,000	41,500	4,500	6,500	11,000	41,500
United States	—	—	—	—	—	—	—	—	—	—	—	—	W	—	—	—	W
Venezuela	35	180	215	45	189	234	35	63	98	55	53	108	—	55	60	115	—
Yugoslavia	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	5,000
Zaire	4,032	16,127	20,159	4,661	18,643	23,304	3,885	15,540	19,425	2,734	15,493	18,227	—	2,850	16,150	19,000	—
Total	[r]26,237	[r]39,781	66,018	[r]39,037	[r]52,726	[r]91,763	38,004	49,599	87,603	42,616	50,730	93,346	[e]241,500	43,016	51,821	94,837	246,000

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

[1] Table includes data available through May 16, 1990. 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 (1985–87), Botswana (1987), Brazil (1987), Central African Republic (1985–88), Guinea (1985–89), and Liberia (1985–86), 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] Includes estimates for artisanal production.

[8] Revised to zero.

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

probably well before 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 The Republic of South Africa in 1867 provided ample supply for the new and growing demand for diamond drill bits.

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

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

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

Currently, about 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.[16]

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[17] 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 uses 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.[18]

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.[19] The treatment used depends primarily on the contaminants present.

Commercial production of synthetic diamond grit is by two basic methods. Currently, the primary method used involves the application of ultrahigh pressure and high temperature to carbon-metal catalyst mixtures by powerful hydraulic presses. This method uses pyrophyllite and other materials for the reaction vessel. Pyrophyllite for this purpose is from the Republic of South Africa, where the local name for it is wonderstone. The major user of the method now uses synthetic reaction-vessel materials, alleviating the dependency on foreign sources for pyrophyllite. The material used for these replacement reaction vessels is proprietary. The other method employs explosive shock to the carbon-metal catalyst mixtures.

Industrial diamond particles of good quality up to 20 mesh and perhaps larger are produced. The shape and other characteristics can be controlled by proper manipulation of the variables, pressure, temperature, time, and catalyst type. Only micrometer-size particles are presently available from the explosive process. Other methods of diamond synthesis exist, but none are in commercial use in the United States. Other countries produce diamond grit; all 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.[20]

The polycrystalline synthetic diamond shape is a dense, nonporous, fully intergrown product that is thermally stable to 1,200° C. The producer 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.[21]

MANUFACTURED ABRASIVES

Manufactured abrasives include silicon carbide, fused aluminum oxide, alumina-zirconia oxide, metallic shot and grit, and cut wire shot and grit. Production data reported for silicon carbide, fused aluminum oxide, and alumina-zirconia oxide were for the United States and Canada. Data for metallic and cut wire shot and grit were for only the United States.

Fused Aluminum Oxide

Government Programs.—The National Defense Stockpile, as of December 31, 1989, contained 226,676 tons of crude fused aluminum oxide and 46,179 tons of abrasive-grain fused aluminum oxide. There is no National Defense Stockpile goal for fused aluminum oxide. The crude and abrasive-grain fused aluminum oxide is held as an offset against a goal of 344,053 tons of abrasive-grain bauxite.

Production.—At yearend, four firms produced fused aluminum oxide at eight plants in the United States and Canada. Production of regular-grade fused aluminum oxide decreased 5% to 164,226 tons. The average annual production for the past 10 years was 138,331 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 1989 production was 14% greater than 1980 production.

Production of high-purity fused aluminum oxide decreased 7% to 30,634 tons. The average annual production for the past 10 years was 25,511 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, 56% between 1980 and 1982. Then production swung between about 14,000 and 28,000 tons until the major increase of 82% in 1988. The 10-year period ended with production essentially unchanged from that of 1980. Total 1989 production of 194,860 tons was 5% less than 1988 production and 63% higher than the low of 119,361 tons in 1982 and 11% higher than the 1980 production of 175,121 tons.

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 $380 a ton. The average annual value for the past 10 years was $358 a ton, with a high of $387 in 1983 and a low of $324 in 1988. In 1989, the average value of high-purity fused aluminum was a 10-year high at $635 a ton. The average annual value of the past 10 years was $538 a ton, with a low of $476 a ton in 1988. The average value of all grades of fused aluminum oxide in 1989 was a 10-year high at $420 a ton. The average annual value for the past 10 years was $382 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 1980 to 1983, then a general downward trend from 1983 to 1988. The 1989 average value increased about 21% compared to that of 1988 and 15% to that of 1980.

Foreign Trade.—The quantity of exports plus reexports of fused aluminum oxide increased 11% to 17,207 tons; the value of exports plus reexports decreased 24% to $19.2 million. The average value of a ton of fused aluminum oxide exported or reexported decreased 33% to $1,115. During the past 10 years, exports plus reexports have averaged 14,710 tons a year with an average annual value of $18.4 million and an

TABLE 14

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

Kind		1985	1986	1987	1988	1989
Silicon carbide[1]	metric tons	102	112	113	118	117
Value	thousands	$42,563	$48,064	$48,790	$50,559	$56,428
Aluminum oxide (abrasive grade)[1]	metric tons	153	137	131	205	195
Value	thousands	$54,061	$50,584	$56,593	$71,325	$81,785
Aluminum-zirconium oxide	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Metallic abrasives[2]	metric tons	179	189	r198	222	224
Value	thousands	$75,349	$75,210	r$62,410	$88,114	$89,546
Total	metric tons	[3]434	[3]438	[3]441	542	536
Total value	thousands	[3 4]$171,974	[3]$173,858	r [3]$167,593	$209,998	$227,761

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.
[4] Data do not add to total shown because of independent rounding.

TABLE 15

CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1989

Company	Location	Product
Washington Mills Electro Minerals (Canada) Corp.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).
Washington Mills (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.	Cap-de-la-Madeleine, Quebec, Canada	Silicon carbide.
Do.	Chippawa, Ontario, Canada	Fused aluminum oxide (regular and high-purity) and aluminum-zirconium oxide.
Do.	Shawinigan, Quebec, Canada	Silicon carbide.
Superior Graphite Co.	Hopkinsville, KY	Do.
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

average value per ton of $1,314. 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. Over 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 1989 with exports about even with those of 1980.

Imports were 98,000 tons, a 10-year low, and the value of imports decreased 15% from $73.7 million in 1988 to $62.8 million in 1989. Average annual imports for the past 10 years were 135,525 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, with 1989 import at 60% of the 1980 level.

Silicon Carbide

Government Programs.—The National Defense Stockpile, as of December 31, 1989, contained 52,990 tons of silicon carbide and the goal was 26,308 tons. During the past year, 12,167 tons of silicon carbide was disposed of from the stockpile; existing legislation authorizes disposal of an additional 26,082 tons in the future.

Production.—Four firms produced silicon carbide at six plants in the United States and Canada in 1989. Production of abrasive-grade material increased about 4% to a 10-year high of 53,454 tons. Average annual production for the past 10 years of abrasive silicon carbide was 45,865 tons, with a low of 36,193 tons in 1983. Production of metallurgical-grade silicon carbide decreased about 4% to 62,189 tons. Average annual production of metallurgical-grade silicon carbide for the past 10 years was 57,828 tons, with a high of 71,010 tons in 1980 and a low of 38,374 tons in 1983. Production of refractory and other grades of silicon carbide decreased 48% to a 10-year low of 980 tons, which was only 8% of 1986 production and only about 0.3% of 1980 production. The average annual production of refractory and other grades of silicon carbide for the past 10 years was 14,601 tons, with a high of 36,445 tons in 1980. Total production of silicon carbide decreased slightly in 1989 to 116,623 tons, compared with a 10-year average annual production of 118,300 tons. The high was 154,241 tons in 1980, 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, 36% in 4 years, and then slow growth and recovery to 76% of the 1980 production level by 1989.

TABLE 16

WORLD FUSED ALUMINUM OXIDE ANNUAL PRODUCTION RATED CAPACITY,[1] DECEMBER 31, 1989

(Metric tons)

Country	Capacity
North America:	
United States and Canada	231,876
South America:	
Brazil	96,162
Europe:	
Austria	58,967
Federal Republic of Germany	86,183
France	45,359
Italy	18,144
Spain	13,880
United Kingdom	63,503
Total	286,035
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	1,094,882

[1] Includes capacities of operating plants as well as plants on standby basis.

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 $509; metallurgical-grade averaged $460; refractory and other grade material averaged $608; and the average value of all grades was $484. The average value per ton of abrasive-grade material for the past 10 years was $497, with a high of $626 in 1982 and a low of $414 in 1980. Metallurgical-grade silicon carbide averaged $420, with a high of $460 in 1989 and a low of $389 in 1980. Refractory grade was $535, with a high of $644 in 1988 and a low of $442 in 1986. For all grades the average was $461, with a high of $535 in 1982 and a low of $417 in 1980 and 1985. The trend for the value of all grades of silicon carbide for the past 10 years was one of sharp increases, 28% in 2 years, followed by a general decrease and then generally stabile with 3 years essentially unchanged at 103% of the 1980 value. Then, in 1989, there was a significant increase of 13% compared to the average value of the past 3 years.

Foreign Trade.—Exports plus reexports of silicon carbide increased 79% to 8,452 tons. The total value of silicon carbide exported plus reexported increased 27% to $10 million, and the value per ton decreased 29% to $1,178. The average annual exports plus reexports for the past 10 years were 6,620 tons, with a high of 12,392 tons in 1980 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 $1,435, with a high of $1,865 in 1986 and a low of $1,068 in 1981. The value of exports plus reexports decreased 25% during the past 10 years.

Imports of silicon carbide in 1989 decreased 4% in quantity to 98,000 tons and increased 7% in total value to $64.6 million. The average value per ton increased 11% to $659. The total value was a 10-year high. The average annual imports for the past 10 years were 76,932 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 $577, with a high of $659 in 1989 and a low of $497 in 1980. 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 and then the decreased in 1989.

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 1988. Export and import data were not available.

Metallic Abrasives

Production.—Eleven firms produced metallic abrasives in 12 plants in the United States. At yearend, a firm purchased a closed plant and announced plans to put the plant into operation in 1989. Quantity, value, and average

TABLE 17

WORLD SILICON CARBIDE ANNUAL PRODUCTION RATED CAPACITY,[1] DECEMBER 31, 1989

(Metric tons)

Country	Capacity
North America:	
Mexico	22,680
United States and Canada	126,552
Total	149,232
South America:	
Brazil	12,701
Europe:	
France	16,329
Federal Republic of Germany	36,287
Italy	36,287
Netherlands	50,001
Norway	73,936
Spain	18,144
Total	226,343
Eastern Europe:	
Czechoslovakia, Poland, U.S.S.R., Yugoslavia	158,757
Asia:	
China	145,150
India	13,608
Japan	86,183
Total	244,940
World total	791,973

[1] Includes capacities of operating plants as well as plants on standby basis.

TABLE 18

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

Use	1988			1989		
	Quantity (metric tons)	Value (thousands)	Yearend stocks (metric tons)	Quantity (metric tons)	Value (thousands)	Yearend stocks (metric tons)
SILICON CARBIDE						
Abrasives	51,202	$23,907	1,879	53,455	$27,196	2,634
Metallurgical	64,999	25,443	1,845	62,920	28,637	3,067
Refractories and other	1,876	1,209	55	980	596	550
Total	118,077	50,559	3,779	117,355	56,430	6,251
ALUMINUM OXIDE						
Regular: Abrasives plus refractories[1]	172,159	55,705	8,651	164,229	62,339	5,976
High purity	32,838	15,620	1,372	30,634	19,446	1,479
Total	204,997	71,325	10,023	194,863	81,785	7,455

[1] Abrasives combined with refractories to avoid disclosing company proprietary data.

value per ton of steel shot and grit production was essentially the same as for 1988 at 206,278 tons, $79 million, and $383 per ton, respectively. The average annual production for the past 10 years was 175,600 tons, with a high of 206,278 tons in 1989 and a low of 135,843 tons in 1982. The average value per ton during the period was $355, 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 1989 production was equal to about 110% of the 1980 production level. Michigan, Ohio, Pennsylvania, Virginia, Maryland, and Indiana, in decreasing order of quantity, supplied the production of steel shot and grit.

Two companies, one each in Indiana and Ohio, produced chilled and annealed iron shot and grit. Additionally, two firms, one in Michigan and one in New York, reported production of cut wire shot. Production and value of chilled and annealed iron and cut wire shot and grit was essentially the same as 1988 at 17,452 tons and $10.6 million. The average value per ton was essentially unchanged at $605. The average annual production of these types of shot and grit for the past 10 years was 18,136 tons, with a high of 27,891 tons in 1980 and a low of 13,352 tons in 1986. The average value per ton for the past 10 years was $440, with a high of $612 in 1988 and a low of $307 in 1980.

Consumption.—The quantity of steel shot and grit sold or used decreased 6% to 202,424 tons, the total value decreased 6% to $81.3 million, and the average value per ton was essentially unchanged at $401. The average annual quantity of steel shot and grit sold or used for the past 10 years was 174,791 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 1989 sold-and-used value was 4% greater than the value in 1980.

The quantity of chilled and annealed iron and cut wire shot and grit sold or used decreased 5% to 16,826 tons. The value was essentially the same as for 1988 at $11.5 million. The average value per ton increased 6% to $681. The average annual quantity of these shot and grit sold or used for the past 10 years was 17,367 tons, with a high of 28,699 tons in 1980 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 a year, with the low in 1985. Since then, continued growth resulted in the 1989 value equaling 120% of the 1980 level.

The estimated apparent consumption of all types of metallic shot and grit decreased 4% in quantity to 214,772 tons, slightly in total value to $89.6 million, and increased 3% in average value per ton to $418. 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 9 years was 186,615 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 $400, with a high of $432 in 1985 and a low of $375 in 1987. The trend of apparent consumption for the past 9 years was one of rapid increases and declines until 1985. This was followed by general growth until consumption in 1988 was 13% greater than that of 1981. Even with the decline, 1989 consumption was 8% greater than 1981.

Foreign Trade.—U.S. exports of metallic shot and grit decreased 27% to 8,646 tons. The total value of exports decreased 35% to $6.3 million, and the average value per ton decreased 11% to $728. The average annual tonnage of metallic shot and grit exports for the past 10 years was 9,363 tons, with a high of 14,146 tons in 1980 and a low of 6,334 tons in 1986. The average value per ton for the past 10 years was $750, with a high of $948 in 1987 and a low of $616 in 1980. The trend for metallic abrasive exports for the past 10 years was one of general decline from 1980 through 1983, followed by fluctuating increases and decreases. The 1989 exports were still 40% below the level of 1980 exports.

U.S. imports of metallic abrasives increased 18% in quantity to 4,168 tons, was essentially the same in total value at $3.4 million, and decreased 15% in value per ton to $822. The average annual imports for the past 9 years were 4,257 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 $607, with a high of $965 in 1988 and a low of $280 in 1984. The trend for the quantity of imports for the past 9 years was one of up-and-down fluctuations resulting in a general decline; 1989 imports were only about 87% of those of 1981.

The United States was a net exporter of metallic abrasives in 1989, a position it has enjoyed by a 2.2-to-1 ratio for the past 10 years.

TABLE 19

PRODUCERS[1] OF METALLIC ABRASIVES IN 1989

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.
Metaltec Steel Abrasives Co.	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets Inc.	Tonawanda, NY	Cut wire.
Steel Abrasives Inc.	Hamilton, OH	Chilled and annealed iron and steel.
U.S. Abrasives Inc.	Tippecanoe, IN	Do.
The Wheelabrator Corp.	Bedford, VA	Steel.

[1] Excludes secondary (salvage) producers.

TABLE 20

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)	
1988:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	204,249	77,344	214,790	85,995	230,247
Other[3]	17,584	10,770	18,051	11,443	XX
Total	221,833	88,114	232,841	97,438	XX
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	202,505	81,263	363,700
Other[3]	17,453	10,566	16,825	11,457	XX
Total	223,730	89,546	219,330	92,720	XX

W Withheld to avoid disclosing company proprietary data; included with "Other." XX Not applicable.
[1] Excludes secondary (recycle) producers.
[2] Total quantity of the various types of metallic abrasives that a plant could have produced during the year, working three 8-hour shifts per day, 7 days per week, allowing for usual interruptions, and assuming adequate fuel, labor, and transportation.
[3] Includes cut wire, aluminum, stainless steel shot, and items indicated by symbol W.

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

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

[3] Height, R. P. Abrasives. Ch. in Industrial Minerals and Rocks (Nonmetallics Other than Fuels). AIME, New York, 5th ed., 1983, pp. 11-32.

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ADVANCED MATERIALS

By Charles A. Sorrell

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Advanced materials are those developed during the past 30 years or so that are being developed at an accelerating rate at present. They all exhibit greater strength, higher strength/density ratios, greater hardness and wear resistance, and one or more superior thermal, electrical, optical, or chemical property when compared with traditional materials. Advanced metals, ceramics, and polymers, including composites, offer the promise of decreased energy consumption, better performance at acceptable cost, and less dependence on imports of strategic and critical materials. New electronic, magnetic, optical, and chemical devices are creating a revolution in communications, data analysis, chemical and structural analysis, medical technology, and industrial processing. These promise dramatic changes in manufacturing and human lifestyle.

The decade of the 1980's saw advanced materials become recognized as critical to future technologies by the industrialized nations, with the United States, Japan, and the European Community (EC) being the major competitors. All three have identified communications technologies (including all aspects of information, computation, and solid-state electronics and optics), biotechnology, and advanced materials as the keys to future industrial leadership. The closing decade of the 20th century is expected to be an era of rapid development and restructuring. Enormous challenges are posed to the position of the United States in the world economy: (1) the progress of EC '92, the effort to develop uniform standards and remove trade barriers in Western Europe; (2) the determination of Japan to commercialize advanced structural ceramics, alloys, composites, and superconductors; (3) the emergence of developing countries as major suppliers of commodity materials and their increasing interest in moving into advanced technologies; (4) and the recognition by other industrialized but smaller nations—such as Australia, Canada, and the Republic of South Africa—of the need to move from the status of commodity mineral and materials suppliers to full participants in advanced industrial technologies.

The decade was one of rapidly increasing internationalization of industry, with greatly accelerating foreign investment in the United States and the recognition that financial, structural, and cultural barriers must be overcome if the Nation is to maintain a competitive position.

New materials developments have occurred throughout human history. Until recently, new materials such as aluminum, copper, plastics, and steel were discovered and applied to existing processes and products, resulting in improvements in performance, durability, reliability, or manufacturing efficiency and cost. It was customary for designers and engineers to select from a limited number of commodity materials, whose properties were well understood and measurable, and to design products and fabrication processes within the property limits of those materials. Modern mass production developed in the 20th century on the basis of the property and processing reliabilities of commodity materials, leading to unprecedented manufacturing efficiencies and standards of living for the industrialized nations. Progress came, however, at the price of increasing energy consumption by the manufacturing sector and the mobile consumer and the increasing environmental effects of that energy use.

During and immediately following World War II, a new perspective began to take shape, prompted by the need for new materials with superior properties for improved performance. Development of electronic and sonic detection devices, improved armor and antiarmor technology, nuclear weapons and fission reactors, and high-performance jet engines required new materials with improved properties specifically tailored to applications. At about the same time, a revolution in computation and analysis began, with the discovery of the field effect transistor in 1947, leading to the first large-scale integrated circuit in 1953. By the late 1960's, electronic computational devices, detection systems, and analytical instrumentation had developed to the point that understanding of the relationships between structures and properties of materials had reached a very high level, and available techniques for synthesis had increased markedly. It became possible to think in terms of making a material with specified properties rather than limiting design, manufacturing, and performance to available commodity materials.

The energy crises of the second half of the 1970's resulted in low economic growth or recession on a global basis and 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 more energy efficiency and reduction of reliance on other nations for raw materials became adequate motivation for development of structural materials with higher strength-to-weight ratios, greater resistance to high temperatures, better corrosion resistance, greater durability, and more reliability. The candidates for new structural materials—metal alloys, engineering polymers, advanced structural ceramics, and composites of these—have become subjects of intense research, development, and commercialization and constitute one of the major areas of international competition.

The intrinsic properties of structural ceramics, including high strengths, hardness, wear resistance, corrosion and oxidation resistance, and stability at very high temperatures, make them prime candidates for a wide variety of applications. They can replace metals and plastics in many existing systems to provide better performance and durability and are enabling

components in new technologies. Their potential, which has been recognized for more than a decade, has been slow to develop, however, because of technical and economic factors. It is fair to say that advanced structural ceramics are yet in their infancy, but certain to become increasingly important as problems are solved and new applications require their superior properties.

Advanced polymer matrix composites (PMC), consisting of a wide variety of commodity or 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, strength-to-weight ratios, corrosion resistance, and potential for reduction of the numbers of parts to be assembled in a given system ensure that applications will increase. 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 because they are generally not cost-competitive with metals. 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 plan for eventual retooling to use new materials.

DOMESTIC DATA COVERAGE

The structure of the ceramics and plastics industries of the United States is diverse in terms of the wide variety of products and the kinds of companies engaged in manufacturing. Unfortunately, no systematic data collection on the structure of the advanced materials industry or production of materials has been done. Between 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 the various value added steps between commodity and product is not covered. The 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 accuracy and completeness of these data, most in highly aggregated form, permit only broad generalizations about the current status of new materials, and virtually no historically valid trends can be discerned.

The publishers of Ceramic Industry magazine, over the past 8 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,[1] 1987,[2] 1988,[3] and 1989.[4] The data for 1989 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.

LEGISLATION AND GOVERNMENT PROGRAMS

Growing awareness of advanced materials as enablers of new technologies was evidenced in 1989 by reorganization of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. The Director of OSTP, who is also the Science Advisor to the President, designated communications technology, biotechnology, and advanced materials as the essential elements of technical and industrial competitiveness. He linked materials to manufacturing by assigning responsibility for materials policy to the Associate Director for Industrial Policy. 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 Science Advisor was also named to the chairmanship of the National Critical Materials Council (NCMC); the other members named were the Director of the Bureau of Mines and an Assistant Secretary of Energy. NCMC has begun working closely with OSTP on policy matters dealing with advanced materials.

The National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189) was signed by the President in November. 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; streamline the processing of agreements. It also assigns a technology transfer mission to the nuclear weapons laboratories. The Secretary of Commerce reported to the President that, by the end of 1988, 111 cooperative research and development agreements (CRADA) had been signed under the provisions of the Federal Technology Transfer Act of 1986, the predecessor to the 1989 act. Many of the CRADA's were for new materials development.

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 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 but had not been enacted by year's end. The American Technology Preeminence Act of 1990 (House Resolution 4329) 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 are to be provided to the Commerce Department Advanced Technology Program, to be administered by NIST.

A bill (S. 1978) introduced in the Senate proposes reorganization of the Department

of Commerce into the Department of Industry and Technology. An Undersecretary for Industry would handle economic development matters, export promotion, and statistical analysis. An Undersecretary for Technology would be in charge of all science and technology offices currently in Commerce along with a new Advanced Civilian Technology Agency that would fund technology development deemed essential to the Nation.

ADVANCED STRUCTURAL CERAMICS

Production and Consumption

Sales of the major categories of ceramics by U.S.-owned companies, derived from the Ceramic Industry surveys for 1986-89,[5] are listed in table 1. Though these data do not include many important ceramic products, including abrasives, pigments, cements, etc., they do provide a perspective from which to view advanced ceramics (which include porcelain insulators, electronic, optical, and magnetic materials). With approximately steady sales over the 4-year period at about $4.3 million, advanced ceramics constituted only 12.6% to 15.2% of the total. Glass, including plate, container, automotive, and specialty glasses, has consistently made up 55% to 60% of the total market, with other segments holding roughly equal shares.

Table 2 shows sales of advanced ceramics in six categories for the years 1986-89. Advanced structural ceramics (listed as engineering ceramics in table 2) made up 23.4%, 22.3%, 18.8%, and 20.9% of the total for the 4 consecutive years. Because low-voltage and high-voltage electrical insulating porcelain are generally not considered advanced materials in the sense that new structural and electronic materials are, table 3 has been prepared to include only two categories, engineering ceramics and combined electronic, optical, and magnetic ceramics. Table 3 shows that total sales of advanced ceramics, as so defined, have remained nearly constant over the past 4 years at about $3 billion and that advanced structural ceramics has remained at about 30% of the total. Their economic importance, moreover, as shown by sales as a percentage of total ceramics sales, has apparently been decreasing.

The data in tables 2 and 3 may be misleading, however, because the surveys do not include significant production of advanced structural ceramics in the United States by foreign-owned companies.

Unfortunately, there are insufficient data to indicate that production. It is likely, however, that total production has actually been increasing in the past several years. There is confidence within the industry that advanced structural ceramics will continue to grow in importance as technical barriers to manufacturing are overcome and economies of scale come into play.

Production data for individual advanced ceramic powders are not available from a single consistent source. This is owing 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 production.

In the case of alumina, there are so many different applications that designating what portion of total production goes into advanced electronic or structural materials is virtually impossible. The Bureau of Mines estimates that about 104,000 metric tons of calcined alumina are produced annually worldwide. Of that, 50% is used for refractories, 20% for abrasives, 15% for white wares and spark plugs, and 5% (5,200 metric tons) for miscellaneous applications. High-purity ceramic alumina powder constitutes part of the 5,200 metric tons, but an accurate estimate is not possible.

TABLE 1

SALES OF MAJOR CATEGORIES OF FINISHED CERAMIC PRODUCTS BY U.S.—OWNED COMPANIES

(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

NA Not available.

Source: Ceramic Industry.

TABLE 2

SALES OF ADVANCED CERAMICS BY U.S.—OWNED COMPANIES

(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

Source: Ceramic Industry.

TABLE 3

SALES OF ENGINEERING CERAMICS AND ELECTRONIC, OPTICAL, AND MAGNETIC CERAMICS BY U.S.—OWNED COMPANIES

Year	Engineering ceramics (million dollars)	E, M, and O[1] ceramics (million dollars)	Total (million dollars)	Engineering ceramics	
				Percentage of total	Percentage of total ceramics
1986	1,010	2,224	3,234	31.2	3.5
1987	976	2,095	3,071	31.8	3.1
1988	851	2,312	3,163	27.8	2.4
1989	896	1,898	2,794	32.0	2.6

[1]E-electronic, M-magnetic, O-optical.

Source: Ceramic Industry.

The West's market for special aluminas is supplied primarily by Aluminum Company of America (Alcoa), Aluminum Company of Canada (Alcan), and LaRoche Chemical Inc., in North America; PUK, Martinswerk (Alusuisse), Alcoa Chemie-Nederland and GmbH, Vereinigte Aluminum-Werke (VAW), and British Aluminum Co. (BACO) in Europe; Alcoa Industrial Chemicals-Asia and Alcoa Industrial Chemicals-Australia, Nippon Lightmetal, Showa Denko, and Sumitomo Chemicals in Asia; and Alcoa-Brazil and Alcan in South America.

The 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 research and development use and is produced in-house for those purposes or is imported from Japan and Western Europe.

Silicon nitride and sialons (silicon aluminum oxynitrides) have no use other than for 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 and that materials availability is not an issue.

Industry Structure

As stated previously, 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, and no systematic information has been gathered, except on a highly aggregated basis. The following is a synthesis of information available for calendar year 1989, derived from the Ceramic Industry survey[6] and compared with data for 1986, 1987, and 1988.[7]

Table 4 shows the size distribution, in terms of sales volumes, for the 80 largest U.S. advanced ceramics companies in the Ceramic Industry survey for 1989.

The largest producers 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 fiber; and Cooper Industries, Houston, TX, which recently acquired the Champion Spark Plug Co. Reported sales for Corning were $869.9 million and for Cooper Industries were $512.9 million. Within the $200 to $500 million range are General Motors Corp., whose AC Spark Plug and GM Hughes Electronics Divs. accounted for $454.5 million in sales of spark plugs and defense electronics; AVX, New York, NY, with $408.0 million in sales of electronic ceramics and a variety of structural ceramics; GTE, Stamford, CT, whose Precision Materials Div. reported sales of $382.2 million in a variety of products associated with lighting; and Allied Signal, Morristown, NJ, whose Autolite Div. posted spark plug sales of $211.7 million.

Among the top 10 advanced ceramics producers with sales of more than $50 million dollars, all but one are primarily manufacturers of spark plugs, optical fiber, electronic components, and porcelain insulators. Only Coors Ceramics Co., Golden, CO, with sales of $108.8 million, is a major producer of structural ceramics, including alumina and partially stabilized zirconia. Even Coors derives a significant portion of its income from electronic substrates and packaging.

The smaller companies with sales of less than $50 million, as tabulated in table 4, are the major producers of advanced structural ceramics. As evident in table 4, many of these are privately held entrepreneurial companies. Ownership of these small companies over the past 4 years has been changing rapidly through mergers and acquisitions, many with and by foreign companies. It should be noted that the Ceramic Industry survey is of U.S.-owned companies and does not include some large foreign companies such as Kyocera America Inc., which employs an estimated 12,000 workers in 9 locations in the United States. The parent company, Kyocera Corp. of Kyoto, Japan, one of the largest Japanese producers of commodity and advanced ceramics, has been expanding rapidly in the United States and Europe. Among significant changes in industry structure during 1989 were several changes in ownership, mainly acquisition by Japanese and European buyers, and some expansion of production capacity.

AVX Corp., New York, NY, with 3,000 employees and sales of $408 million announced a merger with Kyocera Corp. involving an exchange of stock. Later it was announced that AVX would sell all its stock to Kyocera and become a totally owned subsidiary, with no change in AVX management.

Carborundum purchased the Specialty Products Div. of Ceradyne Inc., a maker of high-performance silicon carbide. Carborundum is a U.S. operation of BP Industries of the United Kingdom.

Coors Ceramics Co., announced plans to locate a facility in Oak Ridge, TN, to produce high-precision complex configurations of ceramic materials. Coors also

TABLE 4

SALES BY THE 80 LARGEST U.S. ADVANCED CERAMICS PRODUCERS IN 1989

Range of sales (million dollars)	Number of companies	Number publicly owned	Number privately owned
Greater than 500	2	2	—
200 to 500	4	4	—
100 to 200	2	2	—
50 to 100	2	2	—
40 to 50	6	4	2
30 to 40	12	8	4
10 to 20	14	6	8
5 to 10	24	6	18
4 to 5	9	1	8

Source: Ceramic Industry.

announced that it had acquired a "significant financial interest" in Cercom Inc., Vista, CA, and would relocate some of the activities of Cercom to the Oak Ridge facility. Cercom, with 34 employees, produces silicon nitride, silicon carbide, titanium diboride, boron carbide, and alumina ceramics for the aerospace and defense industries, industrial wear applications, and electronics industry. Advanced Composite Materials Corp. (ACMC), Greer, SC, entered into an agreement with MB Group, P.L.C., United Kingdom, to develop and commercialize its high-performance silicon carbide whisker-reinforced alumina material in a new generation of tooling systems. ACMC is a totally owned subsidiary of Tateho America Inc., a Japanese company.

Sony USA Inc., a subsidiary of Sony Corp. of Japan, reached an acquisition agreement for Materials Research Corp., Orangeburg, NJ, offering a reported $58.5 million for MRC shares. Alcan Aluminum Corp. of Canada, acquired Technical Ceramics Labs Inc. (TCL), Alpharette, GA. TCL has proprietary techniques for injection molding ceramics, including oxides and carbides, as well as composites with ceramic whiskers or fiber preforms. Terms were not disclosed.

Carborundum Co., Niagara Falls, NY, received a subcontract for $5.8 million from Rockwell International to produce the armor protection system for the U.S. Air Force 11 AC-130U gunship aircraft. The system uses Carborundum's sintered silicon carbide affixed to a high-performance fiber board.

In summary, 1989 was an active year in terms of mergers, acquisitions, and cooperative agreements with the most notable trend being toward expansion by some U.S. companies, notably Coors Ceramics Co. and Corning Inc. Acquisition by foreign companies interested in expanding capacity for production of advanced ceramics and developing new markets for these materials continued.

Current Research

The importance of advanced materials to the economic future of the United States has been underlined in a number of assessments and reports over the past 3 years. The Office of Technology Assessment, at the request of the Congress, prepared a report[8] on the importance of advanced ceramics, engineering polymers, and composites and summarized the technical and commercial impediments to successful commercialization of these structural materials. The NCMC of the Executive Office of the President prepared a program plan for advanced materials[9] for submission to the Congress in accordance with the National Critical Materials Act of 1984. Though not a "plan" as such, the report summarized the status of materials development, the barriers to commercialization, and the steps already taken by legislation and Executive order to remove legal barriers and impediments to assist industry.

The National Research Council (NRC) released a major report,[10] 5 years in preparation, that emphasized that there has been inadequate attention paid to synthesis and processing of new materials, and to manufacturing in general, by Federal research establishments, the academic community, and industry. Shortly thereafter, the NIST published a more detailed version of the contribution of Panel 3 of the NRC Committee.[11] The report is a very thorough assessment of the relative positions of the industrialized nations, the national policies, and programs for science and technology in general and materials science and engineering in particular.

The Bureau of Mines, at the beginning of this year, published the widest ranging report on new materials yet available. The two volume report[12] summarizes the status of new materials markets, economic and policy issues, and science and technology, including technical constraints on commercialization of new materials. The Bureau report, unlike others, gives adequate attention to recent and potential developments in metal alloys, with emphasis on improved processing for better physical properties in metal systems. The importance of structural and functional materials to military security was also indicated by the U.S. Department of Defense in a "Critical Technologies Plan."[13] The technologies identified include not only those of strictly military importance but those important to the industrial base in general, upon which the civilian economy also depends.

A good indication of the recognition of advanced materials as essential to future industrial competitiveness is the recent summary[14] of technological challenges and comparative policies relevant to advanced materials in the member nations of the Organization for Economic Operation and Development. Given the emphasis by the Japanese on new materials and the success of Japan in the financial and trade arenas, it is no surprise that other countries, industrialized and developing, are attempting to position themselves to compete. A sizeable portion of research and development (R&D) in advanced structural ceramics is conducted or sponsored by the U.S. Government, as in the following summary. No reliable data are available for estimating research, development, and pilot plant operations in industry. Most estimate that industrial effort is on a par with, or perhaps twice as much as, the Federal effort.

As shown in table 5 (from the Committee on Materials, OSTP), total support for structural ceramics R&D in Fiscal Year 1989 was almost $86 billion, or about 8.5% of the total materials budget. The budget for Fiscal Year 1990 shows a slight decrease in absolute dollars, and the President's request to the Congress for Fiscal Year 1991 shows a considerable cut, about 5% over that of Fiscal Year 1990. It should be pointed out, however, that for the past several years Congress has seen fit to provide add-on funding for materials research and development (R&D) in general and, barring sizable cuts in defense spending, it is likely that the Fiscal Year 1991 budget will be comparable with the previous 2 years.

The U.S. Department of Energy (DOE) funds 51.7% ($44.441/million) of Federal materials R&D, 72% of which is conducted in the DOE National Laboratories, 24% of which is provided in grants to universities, and 4% 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 structures; microstructure, defects, and dislocations; surfaces, interfaces, and grain boundaries; radiation effects; toughening mechanisms; and superplasticity. Of particular note are the efforts of the Office of Transportation Technology to develop applications for advanced ceramics in gas turbines, advanced heat engines, and other ground transportation systems. Total funding over a 5-year period is more than $38 million.

The Department of Defense funds a wide variety of structural ceramics R&D, with the major emphasis on development and rapid application to military systems. Total funding for Fiscal Year 1989 was $21.508 million, 25% 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

TABLE 5

FEDERALLY SUPPORTED RESEARCH AND DEVELOPMENT IN STRUCTURAL CERAMICS

(Million dollars)

Organization	Fiscal year 1989	Fiscal year 1990	President's request fiscal year 1991
NSF	4.400	4.470	4.500
DOC-NIST	3.000	2.720	2.800
DOI-Bureau of Mines	3.100	3.020	3.000
DOE-Basic Energy Sciences			
Materials Science	7.980	7.160	6.500
DOE-Transportation Tech.:			
Ceramic Technology for Advanced Heat Engines	16.600	16.825	15.900
Heavy-Duty Transportation	2.500	2.000	2.000
Advanced Turbine	11.400	12.000	7.400
DOE-ADV Industrial Concepts	2.000	2.250	2.000
DOE-Fossil Energy	1.461	1.418	1.445
DOE-Industrial Technologies	2.500	2.300	1.700
NASA	9.542	10.100	11.100
DARPA	10.000	8.166	8.500
ARO-DURHAM	1.200	8.166	8.500
ARMY-MTL	1.033	1.742	2.400
ONR	2.000	2.000	2.000
AFOSR	3.800	3.700	3.800
Wright Research and Development Command—Materials Lab	2.100	2.000	2.534
Naval Surface Warfare Center	1.250	1.260	1.230
Naval Air Systems Command	.125	.224	.300
Total	85.991	84.155	79.909

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

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. Of interest to Defense are all aspects of structural and electronic materials, including processing and synthesis of ceramics and composites for ultrahigh strength, high-temperature capabilities, and corrosion resistance for use in aircraft and missiles, armored vehicles, naval vessels, gas turbine engines, and weapons systems. R&D for the Strategic Defense Initiative ("Star Wars") is not included in the totals in table 5.

The National Aeronautics and Space Administration spends about $10 million per year, mainly on in-house research on toughened and fiber-reinforced ceramics, coating of fibers and composites, fatigue and fracture studies, structural mechanics, tribology, nondestructive evaluation, and design methodology. Major materials efforts are devoted to the National Aerospace Plane, the space station, and the high-speed civilian transport plane.

The National Science Foundation, which is an independent organization chartered and funded by the Federal Government, funds basic research only by way of grants. These are to universities through the Materials Research Laboratories, the newly established Engineering Research Centers, small research groups, and individual principal investigators. The emphasis is on processing science, mechanical behavior, and characterization.

The Bureau of Mines through the Div. of Minerals and Materials Science, has a research budget of about $24 million. About $15 million is devoted to minerals research—extraction, beneficiation, etc.,—with the remaining $9 million devoted to materials research. Only $3.1 million goes to structural ceramics research at the Tuscaloosa Research Center (TURC), the Albany Research Center (ALRC), and the Idaho National Engineering Laboratory (INEL). The latter is a DOE laboratory where research of interest to the Bureau of Mines is conducted with Bureau funds. At present, TURC research is in processing and structure-property relationships; ALRC research is in vapor phase synthesis of nitrides; and INEL research is devoted to oxynitride compositions and nondestructive evaluation.

NIST spends $3 million in appropriated funds on processing science, mechanical behavior, and characterization of advanced structural ceramics at the Materials Science and Engineering Laboratory. NIST has been quite successful over the years in leveraging research funding by conducting contract research for other Agencies, through a visiting scientist program, and the Research Associates Program. The added funding and support-in-kind from industry effectively doubles the support for many NIST programs.

Outlook

There is no shortage of projections of advanced structural ceramics production; however, estimates for the year 2000 currently published vary by more than an order of magnitude. Given the lack of data gathering capability and the proprietary caution of producers, this is not surprising. The only general statement that can be made is that production and consumption will increase and that, by the year 2000, advanced structural ceramics will be economically significant.

A synthesis of various estimates has been offered by R.N. Katz,[15] who 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 6, do not include present or projected military applications, which could be significant.

Background

Definitions, Grades, and Specifications.—Ceramics are solid inorganic, nonmetallic materials and/or products made from mineral particles by processing in one or another of a variety of ways at high temperatures. Processing may involve melting and rapid cooling, as is the case with glass; partial melting, as with porcelain and porcelain enamel; melting,

TABLE 6

WORLDWIDE MARKET PROJECTIONS FOR HIGH-PERFORMANCE STRUCTURAL CERAMIC PARTS

(Million dollars)

Applications	1985	1995	2005
Heat engine ceramics	30	1,000	4,000
Bearings	—	200	400
Cuttings tools and metalworking	75	150	300
Industrial wear parts	300	450	900
Biomedical and dental, including crown	1,000	2,000	4,000
Total	1,385	3,800	9,600

Source: R. N. Katz.

casting, and recrystallization, as with glass ceramics; or solid-state reaction (sintering), as with alumina (Al_2O_3) or zirconia (ZrO_2). A small quantity of liquid may be formed during solid-state sintering if a component is added as a sintering aid to accelerate reaction and densification. In any case, a ceramic is made by using high temperature to form a solid body by changing the state of aggregation, forming new chemical compounds, or both. Ceramic technology as described previously originated in prehistory and remains today, though with ever improved processing efficiency and property development. The past decade, however, has produced some new methods for ceramic fabrication that promise to improve both processing and properties. These include chemical and physical vapor deposition, plasma spraying to form coatings or fine powders, sol-gel formation, and organic precursors for powder synthesis.

In the broadest sense, ceramics includes all processed inorganic, nonmetallic materials: glass, porcelain and other pottery and dinnerware, porcelain enamels for coating metals or ceramics, whiteware (bathroom and kitchen fixtures), refractories, construction brick, tiles, clay pipe, abrasives, pigments, cements, limes, plasters, and a wide variety of specialty products.

Advanced ceramics are generally classified as having a structural function—i.e., they must retain their physical integrity in harsh environments, at high stresses, at high temperatures, or under chemical attack—or an active function— i.e., their properties are essential to the functioning of an electronic, optical, or magnetic device or system. The two classes are commonly referred to simply as structural or functional ceramics; that convention will be observed here. The following discussion is restricted to structural ceramics, with emphasis on those materials still in the R&D stage or early stage of commercial development.

A summary of important advanced structural ceramics, their uses, fabrication, and important properties is given in table 7.

The number of chemical compositions and processing variables is quite large; however, the potentially important materials for large-scale application are limited. These are alumina (Al_2O_3), 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 aluminas, those with 75% to 100% 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 coefficient of thermal expansion 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 percent by volume of ZrO_2 included in the ceramic body. Cracks that 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 fibers of alumina, targeted for use as reinforcement of 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 components, 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 nearly 100 years as an abrasive and for manufacture 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 these properties and high hardness, it has been under evaluation for use as components in gas turbine engines and heat engines, 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 structural 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

TABLE 7

STRUCTURAL CERAMICS

Materials class	Chemistry and form	Processing methods	Critical properties	Uses or potential uses
Monolithic:				
Oxides	Al_2O_3; partially stabilized ZrO_2 (PSZ); tetragonal zirconia polycrystal (TZP); BeO; cordierite; SiO_2; mullite; Al_2TiO_5; Y_2O_3; ThO_2.	Prepared as submicron powders; formed by pressing; sintered at high temperatures with or without pressure.	Heat resistance; strength; wear resistance; corrosion resistance.	Turbine blades; adiabatic engine components; heat exchangers; cutting tools; bearings; catalyst carriers; mechanical seals; nozzles; RF crucibles; nuclear shielding.
Nonoxides	SiC, Si_3N_4, Sialons, B_4C, AlN, hexagonal BN, cubic BN, TiB_2, ZrB_2, TiN, TiC.	Prepared as submicron powders; formed by cold or hot pressing, with or without sintering aids; sintered at high temperatures, with or without pressure.	Heat resistance; oxidation resistance; strength at high temperatures.	Turbine blades; adiabatic engine components; heat exchangers; cutting tools; bearings; catalyst carriers; mechanical seals; nozzles; RF crucibles; nuclear shielding.
Composites	Matrices of oxides and nonoxides; reinforcements of C, SiC, Si_3N_4, Al_2O_3, aluminosilicate fibers; SiC whiskers; PSZ particulates.	Processing not yet developed; fiber prepregs treated with slurry; chemical vapor deposition.	Heat resistance; improved fracture toughness; "graceful" fracture.	All the applications of monolithic ceramics.
	Carbon matrix-carbon fiber composites.	Continuous fiber prepregs; CVD carbon matrix.	Heat resistance; strength; low density (needs protection from oxidation).	National Aerospace Plane skin; rockets and missiles; space structures.

Source: Bureau of Mines.

growth and total fracture of the ceramic body. This phenomena is called transformation-toughening because the impact resistance is increased many fold. Zirconias containing both cubic and tetragonal zirconia 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 in 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.

***Technology.*—Processing.**—One of the key features of the new materials is that the structures are controlled to obtain optimum properties. In addition to controlling the crystal structures, it is essential that the microstructure, the way in which the crystals are arranged, be controlled. For many materials the level of understanding of the relationships between structures and properties is inadequate, and the relationships between these and processing parameters are only generally understood. Accordingly, a large portion of current research is in this area.

New materials do not lend themselves to assembly line use for several reasons: control of properties during processing is not well understood; the materials cannot be made using existing assembly line equipment; and the low production volumes do not justify large capital expenditures, at least in the early stages of commercialization. Hence, new structural materials will not be widely adopted until fully integrated design and manufacturing processes and a high degree of automation are developed. It will be necessary, moreover, to begin the process even before all the relevant structure-property-processing relationships are fully understood so that the opportunity to learn by error will be available. Improvements in processing and properties of new materials will be, of necessity, an incremental process.

To assemble the components of a piece of complex machinery or device, it is normally necessary to bond dissimilar materials, such as ceramic to metal, different alloys to each other, or polymer to metal. Because of differences in chemistry and coefficients of thermal expansion, this can be a formidable task. If welding, soldering, or brazing media are used, the bond is likely to be the weak point in the structure, nullifying much of the advantage of the new material. If direct bonding between the new materials is possible, the bonding process itself may alter the properties of one or both components. Much research will be needed to overcome these problems. New design concepts will also have to be developed so that mechanical fits can be used to the maximum.

There are technical constraints specific to advanced structural ceramics in addition to the general constraints summarized

previously. The major impediment to successful application of structural ceramics, with their very high strengths, hardness, and corrosion resistance at high temperatures, is their brittleness. Fracture in a ceramic material originates at flaws—voids, scratches, or inclusions—and proceeds to total failure very rapidly. Much research has been done, and considerable progress has been made in controlling flaws. Still, the rejection rate is very high, as much as 80%, and the range of measured strengths in many samples from the same production run is very wide. The dependability and consistency required for mass production has not been attained in most cases.

The problem of critical flaw density cannot be solved by overdesigning, as with metals, because only one critical flaw is necessary for failure; the larger the component is, the more likely it will have a critical flaw. A second major problem with ceramic materials is that the very properties that make them useful, hardness and strength, also make them difficult to fabricate to close dimensional tolerances. Net shape production is difficult because shrinkage during sintering must be uniform and closely controlled. This requires very precise control of processing parameters. They cannot, moreover, be machined to final size and shape by conventional methods. These areas of concern are being actively researched at present, but solutions, which must be found for these materials to be competitive, appear to be several years away.

All three classes of composites—metal matrix, ceramic matrix, and polymer matrix—are handicapped by inadequate understanding of the forces operating between the matrix and the reinforcing materials (fibers, whiskers, or particles). Much research will be required to maximize the effects of reinforcement. Fabrication is complicated by the requirement for uniform, predictable, and controllable distribution of the reinforcing phase and by the labor intensive nature of the layup of materials. Considerable research is needed to make it possible to control and vary curing times so that a range of forming methods can be used for a given material and production rates can be accelerated.

Testing.—Large-volume commodity materials such as sheet steel, copper wire, and so forth, are selected for a particular application on the basis of well-measured and well-understood properties. It is relatively easy to match these materials to specifications because physical property data are readily available. Advanced materials are fundamentally different because they are, in general, engineered for particular designs and applications for which no commodity materials are available. Consequently, physical property data bases, from which a designer or process engineer can select a material with correct specifications, are unavailable. The situation is complicated even more in some cases because two apparently identical materials from different suppliers may not be equally suited for a given manufacturer's needs. Much effort is expended, therefore, in locating a suitable material, and it is necessary for the materials supplier and the manufacturer to work together to develop that material. This situation will be improved only when structure-property-processing relationships are adequately understood. Then many advanced structural materials will be cost-competitive with commodity materials in mass production. Standardization of processing and compilation of property data bases need to be given a very high priority in the R&D arena.

Standardized tests for properties of commodity materials have been devised by the American Society for Testing and Materials and can be used worldwide to provide reliable comparisons of competing materials. Such tests are not yet available for many of the new materials. In fact, the only criterion for acceptance of a new material in many cases is successful performance. It is expensive to proof test each component in simulation tests or actual use, so these materials will not be competitive with commodity materials until standard testing methods are developed. Nondestructive evaluation methods are urgently needed, particularly for materials such as structural ceramics in which critical flaws are difficult to prevent and to detect. It is likely that nondestructive evaluation will be needed for each component made of such materials.

All materials will, in general, suffer from deterioration of critical properties during use. The long-term effects of stress, flexure, exposure to corrosive environments, exposure to radiation, and so forth, cause cumulative damage to materials, causing them ultimately to fail. Methods of assessing cumulative damage and predicting remaining usefulness have not been developed for the new materials. It is essential that methods be devised, perhaps for continual monitoring during use, before manufacturers will have enough confidence in the new materials to adopt them.

POLYMER MATRIX COMPOSITES

Production and Consumption

A polymer composite is a combination of a matrix, formed by polymerization of an organic resin, and a reinforcing material in the form of continuous fibers in a variety of patterns and weaves or short fibers, whiskers, or particles. Generally only polymers reinforced with continuous fibers are considered advanced polymer composites (APC); that convention is followed here. Matrix resins may consist of thermosets such as epoxies, phenolics, polyesters, vinyl esters, or urethanes, or thermoplastics such as polyphenylene sulfide, polysulfones, polyetheretherketone, polyarylenes, or imides. 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. Many of these are widely used as commodity plastics. For these reasons, and to place the production levels and values of APC'S into perspective, an overview of plastics production in the United States precedes that for APC's. The data are provided by Modern Plastics magazine[16] and are compiled from data from the Committee on Resin Statistics of the Society of the Plastics Industry.

Table 8 provides U.S. resin sales, including exports, for 1988 and 1989 by major resin types. Sales for 1989 were less than 0.5% higher than for 1988, compared with gains of 5%, 9%, and 4% for the previous 3 years. The slower growth was attributed to buildup of inventory because of a slower economy in which construction and automotive applications were sluggish.

Eight major market segments, as shown in table 9, accounted for approximately 60% of total sales, with packaging and building applications comprising the major portion and showing slight declines in 1989. These data are for sales of feedstock resins only and do not reflect the total value of products of those industry sectors.

Table 10 provides production data and overall value of advanced polymer composites, compiled by Kline and Co.,

TABLE 8

TOTAL U.S. RESIN SALES

(Thousand metric tons)

Material	1988	1989
ABS	580	564
Acrylic	316	335
Alkyd	145	147
Cellulosics	41	41
Epoxy	212	23
Nylon	260	270
Phenolic	1,385	1,434
Polyacetal	63	64
Polycarbonate	267	282
Polyester, thermoplastic	927	953
Polyester, unsaturated	623	601
Polyethylene, high-density	3,667	3,681
Polyethylene, low-density	4,965	4,824
Polyphenylene-base alloys	78	80
Polypropylene and copolymers	3,215	3,287
Polystyrene	2,280	2,351
Other styrenics	499	531
Polyurethane	1,467	1,472
Polyvinyl chloride and copolymers	3,759	3,768
Other vinyls	431	435
Styrene acrylonitrile	66	62
Thermoplastic elastomers	223	246
Urea and melamine	687	620
Others	131	139
Total	26,287	26,439

Source: Modern Plastics.

TABLE 9

U.S. RESIN SALES TO MAJOR MARKETS

(Metric tons)

	1988	1989
Packaging	6,544	6,392
Building	5,280	5,166
Transportation	965	998
Electrical/electronic	957	999
Housewares	611	618
Appliances	522	543
Furniture	505	540
Toys	343	331
Other	10,560	10,852
Total	26,287	26,439

Source: Modern Plastics.

Fairfield, NJ, for 1988 and projected figures for 1989 and 1998. Though total production by weight of APC's constitutes only 0.03% of the production of commodity resins in the United States, the total product value, averaging $136 per pound, is highly significant. The United States produces about 60% of world supply, and projections are that the percentage will remain nearly constant through 1998. Kline and Co. report that the world market consists of 50% for aerospace applications; 25% for recreational products, 15% for industrial use, mainly for composite tooling; and less than 2% for automotive use. For matrix resins, epoxies account for 95% of total production.

The only available data for reinforcing fiber and prepreg have been compiled by the Suppliers of Advanced Composite Materials Association (SACMA) and are given in table 11. Production by individual countries is not available.

According to Kline and Co.,[17] carbon fibers make up 60%, aramid makes up 25%, and high-strength glass fibers make up about 13% of the total. The remaining 2% consists of developmental fibers such as silicon carbide, ultrahigh molecular weight polyethylene, boron, and quartz.

SACMA has provided production data by volume and dollar value, employment data, and breakdowns by market segment and region (table 12). Though the production levels are comparable with those of Kline and Co., the estimates of dollar value differ by a factor of almost four, and SACMA's projections for world production in the year 2000 (90,000 metric tons) are well ahead of those of Kline and Co. in 1998 (36,300 metric tons).

The structure of the advanced polymer composites industry is indicated by table 12, which lists the member companies of SACMA,[18] who accounted for 95% of world production in 1989. In addition to these major corporations, many small companies have found niche markets as weavers, prepreggers (assemblers of resin impregnated fibers aligned in a unidirectional tape or in a woven preform), or fabricators that provide their services to the major composites producers.

Fibers represent a $500 million world business and resins about a $200 million business. Materials costs, however, make up only about 18% of the cost of a finished part, so the future of the industry will depend not on the cost of high-strength fibers so much as on cost-efficient automated process development.

TABLE 10

PRODUCTION OF ADVANCED POLYMER COMPOSITES AND PROJECTIONS FOR 1998

Year	United States			World		
	Million pounds	Metric tons	Value, billion dollars[1]	Million pounds	Metric tons	Value, billion dollars[1]
1988	16.5	7,500	2.3	28.0	12,700	3.8
1989	[2]18.3	8,300	2.5	[3]30.8	13,970	4.2
1998	[4]47.5	21,500	6.5	[5]80.0	36,300	10.9

[1]Based on average price of $136 per pound 1988 dollars.
[2]Estimated, based on 11% growth.
[3]Estimated, based on 10% growth.
[4]Projected, based on 11% growth per year.
[5]Projected, based on 10% growth per year.

Source: Kline and Co.

Prices

Because advanced polymer composites are not mass produced commodity materials; because there are almost unlimited possibilities for combination of various polymers, blends, and alloys with different fibers; and because APC's are designed and engineered for each individual application, there is no established price structure. The cost of constituent materials—polymer matrix and reinforcing fiber—makes up, on average, only about 18% of the cost of a finished component[19] so the final price is dependent on design, engineering, tooling, and fabrication costs. These costs will remain high until capital

TABLE 11

WORLDWIDE SHIPMENTS OF FIBERS AND PREPREG

(Metric tons)

Year	Fiber	Prepreg
1985	5,279	6,993
1986	5,949	8,219
1987	6,830	8,888
1988	8,117	10,278

Source: Suppliers of Advanced Composite Materials Association.

TABLE 12

ADVANCED COMPOSITES MARKET TRENDS AND FORECASTS

	1986	1988	2000	2015
World growth:				
Production (metric tons)	10,000	13,500	90,000	600,000
Value (millions)	$800	$1,000	$10,000	$30,000
Employment	20,000	25,000	200,000	500,000
By market (percentage):				
Aircraft/aerospace	55	44	50	40
Recreational	28	34	20	10
Industrial/other	17	22	30	50
By region (percentage):				
Asia	19	26	25	28
Europe	23	14	20	22
North America	58	60	55	50

Source: Suppliers of Advanced Composite Materials Association.

investment in automated, flexible manufacturing has been made and increased applications permit economies of scale.

Prices of carbon fibers, made either from pitch or polyacrylonitrile precursor, range from $20 to $60 per pound, though very high-performance fibers may cost as much as $1,000 per pound. Aramid fibers (DuPont Kevlar) are priced at $10 to $20 per pound, and high-strength fiberglass costs less than $5 per pound. Commodity polymers, thermosets, and thermoplastics cost only $1 to $5 per pound, with high-strength, high-temperature engineering polymers ranging to perhaps as much as $100 per pound.

Even the average prices of finished APC components are not agreed upon; Kline and Co.[20] places average prices at $125 to $140 per pound while SACMA[21] estimated the average price at $33.60 per pound in 1988.

Current Research

The level of research effort in polymers, not only for structural applications but also for electronic, optical, magnetic, and medical uses, is very high in the Federal, industrial, and academic sectors. Thousands of technical papers are published each year, and proprietary research is certainly extensive. It is impossible, therefore, to present an adequate summary except in the broadest terms. Much of the effort is driven by the defense and aerospace industries,[22] where about 60% of advanced polymer composites were used in 1989 and likely will be for many years to come. A few major research areas are summarized here.

New Matrix Materials.—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. Epoxies, moreover, 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 also do not have high fracture toughness, i.e., they are brittle and do not resist high impacts. Because epoxies are thermosets, formed by irreversible chemical reactions, they do not soften or melt but decompose, making repair or recycling difficult. Thermoplastics, on the other hand, though not as heat resistant as epoxies, have high fracture toughness and can be melted and reformed. The difficulty with thermoplastics is high viscosity, which cause problems with fiber wetting and infiltration and limits the possible fabrication methods.

Current research to develop new matrix materials is aimed at overcoming these difficulties. A number of blends of epoxies and thermoplastics, with greater fracture toughness than epoxies and lower viscosity than thermoplastics, are being formulated and evaluated. These materials, with potentially better impact resistance, will, nevertheless, be difficult to repair or recycle. A wide variety of commodity polymers, blends, alloys, 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. An enormous effort is being made to improve processing of fibers to improve their strengths by eliminating surface flaws through sol-gel formation, better control of molecular orientation, chemical vapor deposition methods, and surface treatments. A variety of silica, aluminosilicate, boron, silicon nitride, silicon carbide, and organic fibers is also being developed and evaluated as potentially stronger or less costly reinforcements.

Improvement of the bond between fiber and matrix is being sought by development of surface treatments to improve fiber wetting and adherence. Improved bonding may result from development of increased fiber surface area by means of extrusion of fibers with crenulations, i.e., with asterisk-like cross sections.

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.

Nondestructive Evaluation.—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 tomographic microscopy, eddy current measurement, acoustic emission measurement, fluorescence spectroscopy, scanning capacitive and induction probe methods, 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, monatomic oxygen (in space), and ionizing radiation, also 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 during 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.

Processing.—Synthesis and processing have been identified by the NRC[23] as a problem area in commercialization of new materials, resulting from inadequate recognition of the relationships among design, materials properties, and processing. In the case of polymers, this has not been as great a problem as with other materials because the wide variety of materials and processing methods has required attention by polymer engineers and manufacturers from the beginning of the industry.

Outlook

Two of many projections for production of advanced polymer composites are provided in tables 10 and 12. The United States has a dominant position in what is a truly international industry, as indicated by table 13, and is likely to remain in that position. This is because of strong research effort in materials development, processing research, and rapidly developing capabilities in computer-aided design, computer-aided manufacturing, automated flexible manufacturing, and robotics. As in 1989, future growth will be mainly in defense, aerospace, and recreational equipment where the high costs of advanced polymer composites are justified by improved performance and durability. Very large-scale production of composites in automobiles and many other consumer products cannot be realized until the costs of these materials can be justified by their performance characteristics. Automobile makers appear to be convinced, nevertheless, that large-scale substitution of polymer composites for structural metals is inevitable. A consortium was formed by Chrysler Corp., Ford Motors Co., and General Motors Corp. during 1989 to evaluate polymer composites on a precompetitive basis. New fuel efficiency and environmental regulations will likely contribute to acceptance of the higher costs of these materials. After capital investment has been made to convert manufacturing operations to the new materials and processing methods, however, unit costs should decrease dramatically.

Background

Definitions, Grades, and Specifications.—Polymers are composed of thousands to millions of identical units, called monomers, linked together by strong covalent bonds into linear chains, linear chains with branches protruding at intervals, or networks, with cross linking between chains. The process of linking monomers together, called polymerization, can be accomplished by addition, simply by mixing components or with the aid of a catalyst, or by condensation, which results in linkage of monomers with release of a simple molecule such as water.

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. Details of the polymerization process and variations thereof have been described by Catherine Kilgore (Reference 10, pp. 8.1-8.57). Figure 1 illustrates the materials flow from the

TABLE 13

MEMBER COMPANIES[1] OF SUPPLIERS OF ADVANCED COMPOSITE MATERIALS ASSOCIATION

United States	Europe	Japan
3M Co.	Akzo/Enka AG	Asahi-Kasei
Allied Corp.	BASF AG	Mitsubishi Rayon
American Cyanamid Co.	BP/US Polymeric	Toho Rayon
Amoco Corp.	Ciba-Geigy Corp.	Toray Industries
Dow Chemical Co.	Courtaulds PLC	
E.I. du Pont de Nemours & Co.	Hoechst-Celanese	
Ferro Corp.	ICI PLC	
Hercules Inc.	Rhone-Poulenc Inc.	
Hexcel Corp.	RK Carbon Fiber Co.	
M. C. Gill Corp.	Shell Chemical Ltd.	
Owens-Corning Fiberglass		
Phillips 66 Co.		

[1]Represents 95% of world production in 1989.

Source: Suppliers of Advanced Composite Materials Association.

major feedstocks to production of the major classes of polymers. The percentages below each of the feedstocks in figure 1 indicate the relative usages of the feedstock materials. Ethylene, for example, comprises 54.5% by weight of the total feedstocks used for polymer production. Table 14 shows the broad classification of thermoplastic polymers according to use, price, and volume.[24] As indicated, the performances and prices of the materials are directly related. In the case of advanced polymer composites, the materials of interest are the engineering and high-performance thermoplastic polymers and epoxies. The latter presently are used in about 95% of composites while performance polymers are still being evaluated for use as polymer matrices. Table 15 shows comparative thermal stabilities for representative commodity, engineering, and performance polymers.

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.[25] As stated previously, specifications for the composites themselves are not written as with commodity materials; the specifications are written for each individual application.

Products for Trade and Industry.—The number of products utilizing polymer materials, better known in most cases as plastics, is too great to list. They are ubiquitous and are being used in more applications each year. Advanced polymer composites, however, because of cost, have relatively few uses, most notably in defense, aerospace, and sporting goods. In defense and aerospace they are used in helicopter rotors, blades, and tail assemblies and in weapons systems as rocket motor cases on missiles and space vehicles. They are finding increasing use in secondary aircraft structures such as control surfaces (flaps, rudders, and stabilizers) or fairings (streamlining covers for aerodynamics) and more recently as primary structures such as wing, tail, and fuselage sections. Composites use in McDonnell Aircraft's military planes, for example, has increased from about 2% in the F-15 to 27% on the AV-8B *Harrier* currently in production.[26] Boeing Co. is 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.[27]

In sporting goods, the desire for better performance regardless of cost has created a market for fiberglass and carbon reinforced polymers in tennis racquets, 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.**—Current technology in advanced polymer composites processing has been well summarized by the Bureau of Mines (Kilgore, reference 12). Fabrication methodologies, prototyping, testing, and redesign are all important steps in development of processing; the many methods of fabrication need not be repeated here.

Testing.—Performance standards and testing methods are summarized by Kilgore[28] and by Modern Plastics[29] in great detail. The reader may refer to those works for specifics on the many materials, properties, tests, specifications, and performance standards.

Recycling.—During 1989, the issues of waste disposal and recycling received increased attention in response to heightened awareness of environmental problems and the realization that the landfills of the United States are approaching their capacities. Even though plastics constitute only about 6% to 8% by weight of municipal waste,[30] the volume is somewhat more, and the stability of plastics in a landfill environment creates the perception that they are more of a threat than other materials. The

TABLE 14

CLASSIFICATION OF THERMOPLASTIC POLYMERS

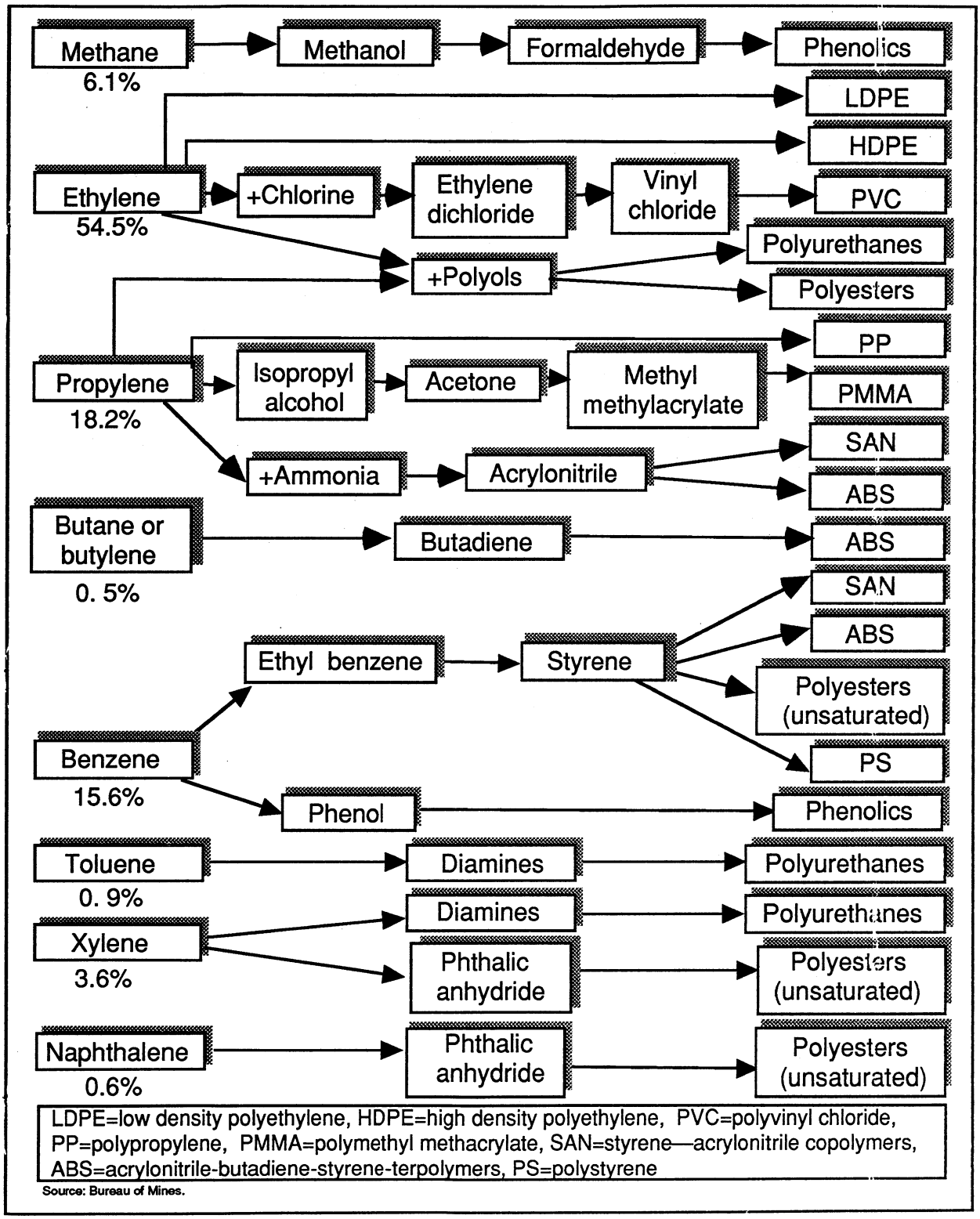
Category	Processibility	Maximum use temperature	Price	Production volume	Examples of polymers
Commodity	Very high temperatures not required, generally forgiving and versatile.	70° C to 110°-120° C	Low	Over 1 million tons per region.	Polyvinyl chloride, low-density polyethylene, high-density polyethylene, polypropylene.
Engineering	High-temperature equipment required, process technology limited.	130°-140° C to 200° C.	Medium	40 to 100 thousand.	Polyamides, polyacetals, modified polyphenylene oxide, polycarbonates, PET, PBT, ABS.[1]
High performance	Very high-temperature equipment, often made of special resistant materials; precise processing techniques required.	Above 200° C	High to very high.	0.1 to thousand tons per region.	Polyphenylene sulfide, polyimide, polysulfone, polyether sulfone, polyetherimide, polyamide-imide, PEEK,[1] liquid crystal polymers.

[1]PET-polyethylene terephthalate, PBT-polybutylene terephthalate, ABS-acrylonitrile-butadiene-styrene terpolymers, PEEK-polyetheretherketone.

Source: Bureau of Mines.

FIGURE 1

MATERIALS FLOW FROM FEEDSTOCK TO RESIN



Source: Bureau of Mines.

TABLE 15

THERMAL STABILITIES OF REPRESENTATIVE POLYMERS

Polymer	Melting temperature, °C	Glass-transition temperature, °C
Polyvinyl chloride (PVC)	—	[1]82
Polystyrene	—	100
Polymethylmethacrylate (PMMA)	—	105
Polyethylene	[2]138	−[2]110
Polypropylene	165	− 10
Polybutylene terephthalate (PBT)	240	17
Polyethylene terephthalate	265	70
Polytetrafluoroethylene (PTFE)	327	−150
Polyarylate	—	190
Polyphenylene sulfide (PPS)	285	185
Polyamide-imide	—	>290
Polyetheretherketone (PEEK)	334	143
Poly (para phenylene benzobisimidazole) (PBI)	Decompose above 400	
Poly (para phenylene benzobisoxazole) (PBO)		
Poly (para phenylene benzoisthiazole) (PBT)		
Polyimide		
Polyphenyl	Decomposes above 530	

[1]Polymers with only a glass-transition are without crystallinity. Below the glass-transition temperature they are stiff; above it they are very viscous fluids.

[2]Semicrystalline polymers have a glass-transition temperature, at which noncrystalline areas develop, and a melting temperature, at which the polymer becomes fluid.

Source: Eric Baer.

major producers of commodity plastics have initiated planning programs for designing products for recycling, opened recycling centers, and intensified research on degradable materials. Increased policy and legislative attention is now being paid to these problems by Federal, State, and local organizations and is likely to intensify.

Unlike metals, discarded plastic items generally lack unit value or recyclability and tend to become environmental problems or hazards. In 1990, the total U.S. resin production will reach about 54 billion pounds, and about 38 billion pounds will be discarded as waste.[31] 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.[32]

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.

Epoxies can 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.

As the volume of polymer composites increases, the greatest growth is likely to be in thermoplastic-fiber materials, as in automotive applications, and then recycling, incineration, and disposal will become part of the overall commodity plastics problem.

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[28]Work cited in footnote 12.

[29]Work cited in footnote 25.

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ANTIMONY

By Thomas O. Llewellyn

Mr. Llewellyn is a physical scientist with the Branch of Nonferrous Metals. He has covered antimony for 3 years. Domestic survey data were prepared by Elsie Isaac, Nonferrous Metals Data Section; and international data were prepared by William L. Zajac, Geographic Data Section.

Production of primary antimony was mostly as a byproduct or coproduct of primary ores of other metals such as lead and silver. Output increased compared with that of 1988, but one antimony refining facility was closed during the year. Antimony oxide exports increased considerably, while total imports of antimony materials decreased sharply from those of 1988. Increased reported industrial consumption was due mainly to the continued strong market for antimony trioxide in flame-retardant applications. The development of high-technology applications for antimony continued in 1989.

LEGISLATION AND GOVERNMENT PROGRAMS

On December 22, 1989, the U.S. Department of State reviewed the list of minerals certified on January 7, 1987, according to section 303(a)(2) of the Comprehensive Anti-Apartheid Act of 1986, as amended. Based on that review, antimony was retained among the revised certified list of strategic minerals now imported from the Republic of South Africa, which are essential for the economy or defense of the United States and are unavailable from other reliable and secure suppliers.

STRATEGIC CONSIDERATIONS

Antimony was included in the National Defense Stockpile (NDS) because of its strategic uses in flame-retardant compounds, camouflage paint, ammunition components, friction bearings, and batteries.

The Government stockpile goal for antimony was set at 32,659 metric tons in April 1980. No inventory acquisitions or sales were made during the year, and, as of December 31, 1989, the stockpile inventory was 32,658 metric tons of antimony metal.

The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on antimony that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

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 July 1989, Amspec Chemical Corp. completed a project to increase its antimony trioxide plant capacity. The company added a new furnace to its plant at Gloucester City, NJ. The new furnace has a production capacity of 10,000 tons per year of antimony oxide compared to about 6,000 tons per year for the old furnace. Amspec did not plan to operate both furnaces simultaneously at full capacity; instead, the old furnace may be used as a backup or to make certain specialty oxides.[1]

The producers of primary antimony metal and oxide products were ASARCO

TABLE 1

SALIENT ANTIMONY STATISTICS

(Metric tons of antimony content unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Primary:					
Mine (recoverable antimony)	W	W	—	W	W
Smelter	14,922	16,309	18,796	r17,616	18,954
Secondary	13,635	14,081	15,833	16,172	18,249
Exports of metal, alloys, waste and scrap	328	540	795	624	293
Exports of antimony oxide	803	526	705	1,227	1,850
Imports for consumption	18,773	23,043	24,248	30,027	25,165
Reported industrial consumption, primary antimony	10,611	9,935	10,374	r12,067	13,424
Stocks: Primary antimony, all classes, Dec. 31	5,479	5,562	6,154	r6,498	6,268
Price: Average, cents per pound[1]	131.1	121.9	110.6	103.9	94.3
World: Mine production	r55,824	r60,015	69,857	p67,992	e68,362

e Estimated. p Preliminary. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] New York dealer price for 99.5% to 99.6% metal, c.i.f. U.S. ports.

TABLE 2

PRIMARY ANTIMONY PRODUCED OR GENERATED IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material produced or generated			Total
	Metal	Oxide	Residues	
1985	855	13,969	98	14,922
1986	343	15,898	68	16,309
1987	W	18,758	38	18,796
1988	W	r17,150	r466	r17,616
1989	W	18,720	234	18,954

r Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

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 3

SECONDARY ANTIMONY PRODUCED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons of antimony content unless otherwise specified)

	1988	1989
KIND OF SCRAP		
New scrap: Lead- and tin-base	1,115	1,265
Old scrap: Lead- and tin-base	15,057	16,984
Total	16,172	18,249
FORM OF RECOVERY		
In antimonial lead	15,634	17,658
In other lead- and tin-base alloys	538	591
Total	16,172	18,249
Value (millions)	r$37	$38

r Revised.

CONSUMPTION AND USES

Increased reported domestic consumption of primary antimony, compared with that of 1988, reflected the continued strong market for fire-resistant textiles and plastics. 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 1989, the Battery Council International reported a 1.5% increase in the total shipments of replacement automotive SLI batteries in the United States compared with those of 1988.

Antimony compounds were used in plastics both as stabilizers and as flame retardants. 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 largest end use for antimony compounds was in flame retardants.

PRICES

The New York dealer metal price, published by Metals Week, started the year ranging from $1.00 to $1.03 per pound, held steady until early March, and decreased to a range of $0.95 to $0.99 per pound by mid-May. In June, during the height of the political crisis in China, the antimony price range firmed back to what it was at the beginning of the year. However, shipments from China were not interrupted, and stocks in warehouses were plentiful. By mid-July, the price range slipped to $0.95 to $1.00 per pound, and at the end of December was $0.81 to $0.84.

Asarco's published price for high-tint antimony trioxide in lots of 40,000 pounds was $1.43 per pound at the beginning of the year, and remained constant for the rest of 1989. Other domestic producers adjusted their prices to about the same level to remain competitive.

European price quotations for antimony ore and concentrates, published by the Metal Bulletin (London), held steady during the first 4 months of the year, and followed a downward trend for the rest of 1989. At yearend, the published price-range quotations were as follows: clean sulfide concentrates, 60% antimony content, $15.50 to $18.50 per metric-ton unit; and lump sulfide ore, 60% antimony content, $16.50 to $19.00 per metric-ton unit.

TABLE 4

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material consumed				Total
	Metal	Oxide	Sulfide	Residues	
1985	1,363	9,120	30	98	10,611
1986	2,211	7,629	27	68	9,935
1987	2,248	8,049	39	38	10,374
1988	2,121	r9,438	42	r466	r12,067
1989	2,523	10,640	27	234	13,424

r Revised.

TABLE 5

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES, BY PRODUCT

(Metric tons of antimony content)

Product	1985	1986	1987	1988	1989
Metal products:					
Ammunition	372	W	W	W	521
Antimonial lead	515	551	1,102	r1,538	1,872
Bearing metal and bearings	161	139	187	178	129
Cable covering	W	62	W	W	W
Castings	10	11	8	13	8
Collapsible tubes and foil	W	W	W	—	—
Sheet and pipe	W	36	76	181	157
Solder	305	252	347	256	245
Type metal	28	8	8	6	4
Other	95	379	584	r609	80
Total[1]	1,486	1,438	2,313	r2,781	3,016
Nonmetal products:					
Ammunition primers	24	21	32	34	20
Ceramics and glass	1,077	932	1,122	1,221	1,050
Fireworks	4	4	3	4	5
Pigments	133	227	279	179	196
Plastics	905	885	750	916	1,141
Rubber products	23	37	W	29	97
Other	128	147	200	147	159
Total[1]	2,294	2,252	2,385	2,530	2,668
Flame-retardant:					
Adhesives	281	154	315	251	219
Paper	101	1	W	W	W
Pigments	7	13	30	104	926
Plastics	5,016	4,517	4,139	5,469	5,842
Rubber	286	398	386	282	174
Textiles	1,140	1,163	800	643	558
Other	—	—	5	7	21
Total	6,831	6,246	5,675	6,756	7,740
Grand total[1]	10,611	9,935	10,374	r12,067	13,424

r Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Data may not add to totals shown because of independent rounding.

TABLE 6

INDUSTRY STOCKS OF PRIMARY ANTIMONY IN THE UNITED STATES, DECEMBER 31

(Metric tons of antimony content)

Stocks	1985	1986	1987	1988r	1989
Metal	732	868	822	2,360	1,873
Ore and concentrate	1,056	934	1,148	W	W
Oxide	3,587	3,646	4,079	3,840	4,077
Residues	90	96	83	274	302
Sulfide	15	17	23	24	16
Total[1]	5,479	5,562	6,154	6,498	6,268

r Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1] Data may not add to totals shown because of independent rounding.

TABLE 7

ANTIMONY PRICE RANGES IN 1989, BY TYPE

Type	Price per pound
Domestic metal[1]	$2.00
Foreign metal[2]	$0.84- 1.03
Antimony trioxide[3]	1.43

[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 were about 51% higher than the previous year. Total imports of antimony materials decreased about 16% from those of 1988. China supplied about 60% of the total imported materials in 1989.

WORLD REVIEW

Capacity

The data in table 12 represent rated annual production capacity for mines and refineries on December 31, 1989. Rated capacity was defined as the maximum quantity that could 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 included both operating plants and plants temporarily closed that, in the judgment of the author, could 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

On January 7, 1989, antimony producers from Bolivia and China signed an agreement with the intent of coordinating their policies on antimony production and trade. The representatives agreed to introduce a joint quarterly producer price for concentrate (60% antimony), which is being published in

TABLE 8

U.S. EXPORTS OF ANTIMONY METAL, ALLOYS, WASTE AND SCRAP, BY COUNTRY

Country	1988		1989	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
Belgium	96	$513	38	$45
Canada	82	206	7	53
Colombia	—	—	33	101
Dominican Republic	45	14	—	—
Germany, Federal Republic of	9	49	1	15
Israel	16	117	—	—
Jamaica	—	—	19	23
Japan	15	17	44	102
Korea, Republic of	34	59	—	—
Mexico	132	248	10	29
Netherlands	56	91	1	5
Taiwan	2	31	—	—
United Kingdom	11	21	56	91
Venezuela	75	274	77	197
Other	49	153	6	32
Total[1]	624	1,793	293	694

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

Source: Bureau of the Census.

the Metal Bulletin of London, United Kingdom.[2]

In November, Empresa Nacional de Fundiciones (ENAF), the state-owned smelting and refining company, resumed production at its Vinto antimony smelter after being closed for more than 5 years. The 4,000-ton-per-year Empresa Metalurgica de Vinto smelter never operated at full capacity since its completion in December 1975. ENAF officials did not provide information on anticipated production output.[3]

Canada

In December 1989, Dominion Explorers Ltd., closed its antimony mine and milling operations at Lake George, New Brunswick. The mine closed once before in 1981 when proven ore reserves were exhausted, but reopened in 1984 when a new zone of antimony-bearing ore was discovered near the existing mine. However, there were not enough proven ore reserves to justify reopening mining operations. The closure was attributed to continuing low metal prices and two consecutive years of revenue losses.[4]

Japan

Antimony trioxide production, mainly from imported materials, was 10,327 tons, a decrease of 3% compared with 1988 production. Antimony metal production also decreased from 185 tons in 1988 to 173 tons in 1989.[5]

CURRENT RESEARCH

Scientists at Boeing High Technology Center, Seattle, WA, achieved a significant advancement in solar cell efficiency using a two-layer cell system. The top layer in the new solar cell was composed of a standard gallium arsenide (GaAs) cell, and gallium antimonide (GaSb) was the material used as the secondary cell. Boeing's solar cell converts more than 31% of available solar energy to electricity. The previously verified record was about 22% set by Variant Associates Inc., using a standard GaAs solar cell.[6]

Following the energy crisis of 1973, Congress passed Public Law 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. This Act supported research and development of electric and hybrid vehicles, required an organizational entity to conduct the management responsibilities, and established the submission of an annual progress report to Congress on the program. In February 1989, the 12th annual report to Congress for fiscal year 1988 was published by the U.S. Department of Energy (DOE). The report contained a description of the program activities during 1988 on battery and propulsion systems developed, a list of company and university participants in electric and hybrid vehicle research and development, and concluded with a list of publications resulting from the DOE program.[7]

OUTLOOK

Mining, beneficiation, and metallurgical procedures for antimony have changed little in the last three decades. No new major technological developments that would affect productivity are foreseen for the near future.

The oversupply of antimony products from China that saturated the market in 1989 could not be absorbed by the lower domestic and rather flat world demand. Therefore, producers were forced to lower prices significantly in order to preserve their share of the world market. The market weakness will probably continue through 1990 and 1991, unless the Chinese policy of offering discounts from the world market price changes.

The prospects for western antimony trioxide producers, for the next 2 years, are not good. China has increased its antimony trioxide output and sales, and supplied 42% of the total U.S. trioxide imports for 1989 compared with 32% the year before.

Industry sources indicate that the projected growth of antimony trioxide demand for the next 2 years will be in the range of 2% to 4% per year. But the demand for antimony metal, during the same period, will continue declining and may do so at a rate of about 2% per year through 1991.

BACKGROUND

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 me-

tallic antimony indicates that about 4000 B.C., the Chaldeans knew the art of reducing the sulfide to metal.

Definition, 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 in 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 oxide, chloride, or other industrial chemical compounds. 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 oxide, 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.

TABLE 9

U.S. EXPORTS OF ANTIMONY OXIDE, BY COUNTRY

Country	1988			1989		
	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)
Australia	19	15	$64	2	2	$8
Belgium	12	10	41	14	12	70
Brazil	—	—	—	9	7	44
Canada	486	406	1,553	505	419	1,564
China	9	7	41	—	—	—
Colombia	—	—	—	41	34	94
Costa Rica	28	24	57	—	—	—
Dominican Republic	—	—	—	111	92	90
France	—	—	—	109	90	161
Germany, Federal Republic of	121	100	422	68	56	276
Hong Kong	59	49	85	3	2	9
India	4	3	16	10	8	23
Ireland	24	20	74	—	—	—
Israel	—	—	—	58	48	154
Italy	148	122	559	294	244	1,042
Japan	51	42	211	51	42	220
Korea, Republic of	91	75	236	11	9	27
Mexico	17	15	58	637	529	1,218
Netherlands	18	15	57	29	24	140
Singapore	22	18	76	28	23	246
Spain	32	26	88	52	43	147
Switzerland	21	17	78	18	15	56
Taiwan	255	211	677	40	33	127
United Kingdom	30	24	126	39	32	150
Venezuela	14	11	52	22	18	51
Other	19	15	92	76	63	185
Total[2]	1,478	1,227	4,663	2,229	1,850	6,106

[1] Estimated by the Bureau of Mines.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

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, has a marketing advantage because its facilities are Government owned. The other major producing countries, Bolivia, Mexico, the Republic of South Africa, the U.S.S.R., plus China, accounted for about 84% of the total world estimated mine production during 1989.

Mine production in the United States during the last decade supplied less than 5% of the yearly domestic demand. The remainder was furnished by imported materials and old scrap. Because of its association with lead, secondary antimony has only met about 50% of the total domestic industrial demand. However, this percentage has decreased in recent years owing to a decreasing average antimony content of the scrap lead source material (automotive batteries).

Antimony metal and oxide producers in the United States are forward integrated companies with a wide scope of activity in the marketing and manufacturing of base metals and chemicals. A few producers and processors of antimony have interests in foreign operations. Essentially all are purchasers of raw materials from mine operations either directly or through dealers.

Geology-Resources

Estimates of the abundance of antimony in the Earth's crust range from 0.2 to 0.5 parts per million. Antimony is chalcophile, occurring with sulfur and the heavy metals, copper, lead, and silver. Over a hundred minerals of antimony are found in nature. However, stibnite (Sb_2S_3) is the predominant ore mineral of antimony.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY, BY CLASS AND COUNTRY

Country	1988			1989		
	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:						
Belgium	93	54	$97	—	—	—
Bolivia	1,161	679	1,158	1,259	737	$1,823
Chile	55	24	29	60	47	102
China	1,260	683	1,471	1,689	1,198	3,022
Guatemala	767	461	255	1,108	665	286
Honduras	—	—	—	6	3	21
Hong Kong	72	45	130	448	290	674
Japan	—	—	—	38	38	67
Mexico	3,797	1,353	1,735	3,734	1,412	1,927
South Africa, Republic of	269	161	231	—	—	—
Thailand	568	268	437	269	161	540
Total[2]	8,044	3,728	5,543	8,613	4,550	8,462
Antimony oxide:						
Belgium	788	655	2,327	779	647	2,367
Bolivia	546	454	1,060	729	605	1,371
Canada	1	1	4	—	—	—
Chile	84	70	173	—	—	—
China	3,697	3,068	7,770	5,091	4,226	9,752
Colombia	—	—	—	20	17	16
Denmark	—	—	—	(3)	(3)	22
France	855	709	2,381	605	502	1,640
Germany, Federal Republic of	170	141	1,238	89	74	855
Honduras	—	—	—	59	49	22
Hong Kong	500	415	1,146	442	367	913
Japan	2	2	26	20	17	76
Mexico	474	394	508	929	771	1,076
Netherlands	35	29	113	33	27	119
South Africa, Republic of	3,931	3,262	2,823	3,107	2,579	1,080
Taiwan	—	—	—	57	47	102
United Kingdom	98	82	437	80	66	358
Yugoslavia	368	306	158	—	—	—
Total[2]	11,549	9,586	20,164	12,041	9,994	19,770
Antimony sulfide:[4]						
Austria	26	17	128	—	—	—
China	104	70	147	—	—	—
Germany, Federal Republic of	20	14	93	—	—	—
United Kingdom	12	8	64	—	—	—
Total	162	109	432	—	—	—

[1] Antimony ore and concentrate content reported by Bureau of the Census. Antimony oxide and antimony sulfide content estimated by the Bureau of Mines.
[2] Data may not add to totals shown because of independent rounding.
[3] Less than 1/2 unit.
[4] Includes needle or liquated.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY METAL, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	15	$19	1	$4
Bolivia	—	—	93	163
Canada	2	131	2	133
Chile	76	151	114	187
China	13,435	29,123	9,742	18,756
Germany, Federal Republic of	1	159	20	208
Hong Kong	1,464	3,230	286	485
Mexico	1,039	842	81	31
Netherlands	200	429	(1)	32
Taiwan	—	—	13	104
Thailand	275	569	219	396
United Kingdom	96	181	—	—
Other	1	3	51	644
Total	16,604	34,837	2 10,621	21,143

[1] Less than 1/2 unit.
[2] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

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 associations 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 the 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.[8]

Principal identified world antimony resources, at about 5 million tons, are in China, Bolivia, the U.S.S.R., the Republic of South Africa, and Mexico. United States resources are mainly in Idaho, Nevada, Alaska, and Montana.

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 these low-grade ores by flotation.

Roasting of the ore to yield a volatile trioxide or the stable nonvolatile tetroxide is the only pyrometallurgical procedure suitable for low-grade ores (5% to 25% antimony content). The sulfur is oxidized and removed from waste gases, and the volatilized antimony oxide is recovered in flues, condensing pipes, a baghouse, precipitators, or a combination of the above. The temperature and quantity of available oxygen determine the kind and quantity of the oxide produced. The oxide produced by this method is generally impure and can be reduced to metal. However, careful control of volatilization conditions will produce a high-grade oxide that can be sold directly to consumers.

Water-jacketed blast furnaces are used in several plants to reduce ores containing 25% to 40% antimony. Oxides, sulfides or mixed ores, residues, mattes, slags, and 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 sepa-

TABLE 12

WORLD ANNUAL ANTIMONY PRODUCTION CAPACITY, DECEMBER 31, 1989

(Metric tons, antimony content)

	Mine	Smelter[1]
North and Central America:		
United States	3,000	28,000
Other	14,000	4,000
Total	17,000	32,000
South America	19,000	11,500
Europe[2]	18,000	28,000
Africa	20,000	6,000
Asia[3]	45,000	35,000
Oceania: Australia	3,000	—
World total	122,000	112,500

[1] Includes antimony oxide plants.
[2] Includes estimates for the U.S.S.R. and other centrally planned economies.
[3] Includes estimates for China.

rated 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.[9]

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 1989, domestic production of antimony was mainly a byproduct of the 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.

TABLE 13

ANTIMONY: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia[2]	1,458	1,131	1,231	[r]1,200	1,200
Austria	477	514	322	228	230
Bolivia	8,925	10,243	10,635	9,943	9,100
Canada[3]	1,075	3,805	3,706	3,171	2,882
China[e]	15,000	15,000	27,000	30,000	30,000
Czechoslovakia[e]	900	[r]1,000	1,000	1,000	1,000
Guatemala	[r]1,239	[r]1,839	1,881	921	1,000
Honduras	87	[r]50	28	19	30
Italy	495	[r]643	—	308	310
Malaysia (Sarawak)	12	—	129	—	—
Mexico[4]	4,266	3,337	2,839	2,185	2,500
Morocco (content of concentrate)	750	617	444	555	500
Namibia (content of sodium antimonate)	—	—	32	98	110
Pakistan	4	—	7	—	—
Peru (recoverable)	594	[e]670	590	420	400
South Africa, Republic of (content of concentrate)	7,390	6,816	6,673	6,264	6,100
Spain	248	45	[e]20	[e]20	[e]20
Thailand	1,240	1,019	409	445	500
Turkey	982	[r]2,752	2,344	1,945	2,000
U.S.S.R.[e]	9,400	9,500	9,600	9,600	9,600
United States[5]	W	W	—	W	W
Yugoslavia	1,088	859	834	725	750
Zimbabwe (content of concentrate)	194	175	153	165	150
Total	[r]55,824	[r]60,015	69,857	67,992	68,362

[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 16, 1990.

[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] Antimony content of ores for export plus antimony content of antimonial lead and other smelter products produced.

[5] Production from antimony mines; excludes amount produced as a byproduct of domestic lead ores.

The antimony deposits of the Republic of South Africa contain gold. High-grade Bolivia antimony ores contain variable and minor values of gold and tungsten and objectionable amounts of lead, copper, and arsenic in some deposits. Chinese ores contain some tungsten.

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, from 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 effluents 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 unit (Btu) per net ton of antimony metal and 186 million Btu per net ton on antimony trioxide.[10]

An estimated 130 persons are employed in the domestic production of antimony ores and in the conversion of antimony ores and raw materials to antimony metal and compounds.

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ARSENIC

By J. Roger Loebenstein

Mr. Loebenstein is a physical scientist with the Branch of Nonferrous Metals. He has covered arsenic for 3 years. Domestic survey data were prepared by Evangeline Hemphill, Nonferrous Metals Data Section. International data were prepared by Virginia Woodson, International Data Section.

Small amounts of arsenic trioxide were shipped in 1989 from remaining stocks at ASARCO Incorporated's closed plant at Tacoma, WA. Shipments of arsenic metal from China were halted at yearend and the price for metallurgical-grade arsenic metal increased from about 60 cents per pound in December to about $4.00 per pound in January 1990.

ISSUES

The former Asarco plant at Tacoma, WA, was a Federal Superfund site designated for environmental cleanup. In addition, soil in residential areas in the town of Ruston, adjacent to the former smelter, was contaminated with arsenic. As a remedy, Asarco proposed cleaning up two playgrounds near its closed plant and creating a trust fund to be administered by the Tacoma-Pierce County Health Department for cleanup work it deemed necessary. Asarco and the Environmental Protection Agency (EPA) continued to negotiate on the extent of Asarco's cleanup efforts.[1]

EPA issued an emergency cleanup order requiring the former and current owners of the Bunker Hill smelter in Kellogg, ID, to clean up hazardous materials at the site. The 350-acre designated Superfund site is contaminated with high levels of arsenic and other heavy metals as well as asbestos and PCB's. The cleanup operation was to be supervised by EPA and carried out by contractors hired by the companies involved.[2]

CONSUMPTION

All arsenic consumed in the United States was derived from imported sources. Apparent demand for arsenic continued to increase in 1989, 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 intermediary used in the production of the wood preservative, chromated copper arsenate (CCA).

The glass industry used arsenic acid as a fining agent. The wood preserving industry supplied some of the arsenic acid used by the glass industry.

In February 1989, Hickson Corp., a subsidiary of Hickson International PLC, United Kingdom, purchased the wood preservative operations of Koppers Co. Inc., Conley, GA. In addition to the Conley, GA, plant, Hickson operated wood preservative plants in 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.

A zinc producer in Illinois used arsenic trioxide as a flotation reagent to separate zinc from copper, cobalt, and nickel. This was the only zinc producer known to use arsenic in its process.

TABLE 1

ARSENIC SUPPLY-DEMAND RELATIONSHIPS

(Metric tons, arsenic content)

	1984	1985	1986	1987	1988	1989
U.S. supply:						
Refinery production	5,200	1,700	—	—	—	—
Imports, metal	300	400	400	600	600	900
Imports, compounds	12,000	13,600	20,200	21,100	21,700	22,800
Industry stocks, Jan. 1	3,100	3,300	900	400	200	100
Total	20,600	19,000	21,500	22,100	22,500	23,800
Distribution of U.S. supply:						
Industry stocks, Dec. 31	3,300	900	400	200	100	100
Apparent demand	17,300	18,100	21,100	21,900	22,400	23,700
Estimated U.S. demand pattern:						
Agricultural chemicals	5,500	4,500	5,300	5,000	5,200	5,200
Glass	1,000	700	800	900	900	900
Industrial chemicals	9,900	12,100	14,100	15,100	15,500	16,600
Nonferrous alloys and electronics	500	400	400	400	400	700
Other	400	400	500	500	400	300
Total	17,300	18,100	21,100	21,900	22,400	23,700

TABLE 2

AVERAGE ARSENIC PRICE QUOTATIONS

(Cents per pound)

	1987	1988	1989
Trioxide, Mexican	36	33	27
Metal, Chinese	95	73	47

Source: Calculated from Bureau of the Census import data.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF ARSENICALS, BY CLASS AND COUNTRY

Class and Country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Arsenic trioxide:						
Belgium	1,643	$1,325	1,563	$1,241	1,425	$881
Bolivia	16	10	—	—	—	—
Canada	2,012	703	2,068	1,589	1,771	799
Chile	4,800	1,935	6,709	2,648	5,057	1,926
China	233	136	18	8	—	—
Finland	—	—	—	—	414	191
France	5,341	3,180	6,909	3,664	7,059	2,977
Germany, Federal Republic of	—	—	16	13	17	28
Hong Kong	36	18	54	42	18	9
Iran	241	87	—	—	—	—
Japan	48	33	1	3	—	—
Korea, Republic of	102	70	—	—	—	—
Mexico	4,457	3,550	4,187	3,064	4,008	2,361
Namibia	93	60	—	—	—	—
Philippines	1,280	436	1,850	792	2,727	979
South Africa, Republic of	1,380	848	1,017	559	94	53
Sweden	4,824	4,140	3,664	2,836	5,676	3,262
Switzerland	307	248	—	—	77	50
United Kingdom	30	22	(1)	2	5	10
Total[2]	26,843	16,800	28,056	16,461	28,348	13,526
Arsenic acid:						
Australia	16	28	—	—	—	—
British Virgin Islands	—	—	7	9	—	—
Canada	—	—	—	—	15	17
Netherlands	—	—	(1)	1	—	—
United Kingdom	1,038	824	181	161	33	50
Total	1,054	852	188	171	48	67
Arsenic sulfide:						
Canada	—	—	12	2	—	—
Germany, Federal Republic of	15	10	15	29	—	—
Taiwan	—	—	—	—	2	19
Total	15	10	27	31	2	19
Arsenic metal:						
Belgium	2	18	—	—	—	—
Canada	16	1,054	19	899	85	658
China	463	972	421	675	627	649
Dominica Republic	(1)	1	—	—	—	—
France	—	—	—	—	1	1
Germany, Federal Republic of	2	174	1	162	3	136
Hong Kong	139	291	75	139	124	129
Japan	9	951	5	613	74	508
Mexico	—	—	78	137	—	—
Sweden	(1)	1	—	—	—	—
United Kingdom	(1)	8	(1)	17	14	69
Total[2]	631	3,471	600	2,642	928	2,150

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

The major agricultural chemical use for arsenic was as arsenical herbicides, monosodium methanearsenate (MSMA) and disodium methanearsenate (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 the major producer of arsenic acid for use by cotton growers and wood preservative companies.

Commercial grade arsenic metal, 99% pure, was used in lead- and copper-based alloys as a minor additive (about 0.01% to 0.5%) to increase strength in the posts and grids of lead-acid storage batteries and to improve the corrosion resistance and tensile strength in copper alloys.

Relatively small quantities of high-purity arsenic metal, 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-based xerography. Gallium arsenide crystals are grown in a highly controlled process that eventually results in gallium arsenide cylinders, generally from 2 to 4 inches in diameter. The cylinders are doped, sawed into wafers, and polished to create semiconductor devices, used in optoelectronic devices.[3]

PRICES

The average price for arsenic trioxide, imported from Mexico, declined slightly in 1989. The average price of arsenic metal, imported from China, declined sharply in 1989 to 47 cents per pound. However, in December 1989, Chinese producers stopped delivering arsenic metal to lead alloyers, causing the intermerchant price of arsenic metal to rise from 60 cents per pound to $1.50 per pound in 1 week.[4] By January 1990, the price of arsenic metal had soared to $4.00 per pound because of the halt in shipments. China is the only country in the world that produces arsenic metal for use in nonferrous alloys.

WORLD REVIEW

Arsenic was recovered as arsenic trioxide in about 20 countries from the smelting or roasting of nonferrous metal ores or concentrates. 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.

CURRENT RESEARCH

Hazen Research Corp., Golden, CO, completed pilot plant testing of the Cashman Process to convert arsenic contained in flue dusts to an insoluble form. The Cashman Process was developed by Artech Recovery Systems Inc., Redmond, WA. The Hazen testing program demonstrated that the process could be operated successfully on a continuous basis. Artech hoped that ARCO Coal Co., owner of the flue dusts, would select its technology to construct a commercial plant at Anaconda, MT, the site of a former Anaconda Co. copper smelter. In the Cashman Process, arsenic is converted into an insoluble residue that meets EPA's standards for safe disposal.[5]

OUTLOOK

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. Over the next 5 years, the growth of wood preservatives is expected

TABLE 4

ARSENIC TRIOXIDE:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Metric tons)

Country[3]	1985	1986	1987	1988[p]	1989[e]
Belgium[e]	3,000	3,000	3,500	3,500	3,500
Bolivia	361	241	132	191	350
Canada[e]	3,000	3,000	2,000	2,000	2,000
Chile	[e]4,000	[e]4,000	3,616	3,207	3,400
France[e]	8,000	10,000	10,000	10,000	10,000
Germany, Federal Republic of[e]	360	360	360	360	360
Japan[e]	500	500	500	500	500
Mexico	4,782	5,315	5,304	5,164	5,100
Namibia[4]	2,471	2,208	1,864	2,983	2,900
Peru[5]	1,257	1,273	1,757	828	1,000
Philippines[e]	5,000	5,000	5,000	5,000	5,000
Portugal	204	176	218	214	180
Sweden[e 6]	10,000	10,000	10,000	10,000	10,000
U.S.S.R.[e]	8,100	8,100	8,100	8,100	8,100
United States	2,200	—	—	—	(7)
Total	[r]53,235	[r]53,173	52,351	52,047	52,390

[e]Estimated. [p]Preliminary. [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 25, 1990.

[3]Austria, China, Czechoslovakia, the German Democratic Republic, 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]Based on arsenic trioxide exported plus the arsenic trioxide equivalent of the output of metallic arsenic exported.

[7]Reported figure.

to average 3% to 5% per year, much less than previous years. 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 leach from treated wood.

The use of arsenic in agricultural chemicals has been under close scrutiny by the Environmental Protection Agency (EPA) for many years. Many pesticide uses for arsenical chemicals have been banned by EPA. The use of arsenicals, DSMA, MSMA, arsenic acid, and cacodylic acid, on cotton is expected to remain stable or decline over the next 5 years.

Gallium arsenide components have long competed 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.[6]

[1]EPA Worker: Cleanup Plan In Bad Faith. Spokane Spokesman-Review. Aug. 25, 1989.

[2]Cleanup of Bunker Hill Imminent. Spokane Spokesman-Review. Nov. 7, 1989.

[3]Henderson, B. W. Harris Unit Develops Advanced GaAs Facility to Supply MMIC's to Military. Aviation Week & Space Tech. April 24, 1989, pp. 101-103.

[4]Metals Week. V. 60, No. 52, Dec. 25, 1989, p. 3.

[5]Skillings Mining Review. Artech's Process Technology for Treatment of Flue Dust. V. 78, No. 48, Dec. 2, 1989, p. 3.

[6]Jackson, P. Metal Bulletin Monthly. Metals Undermined But Far From Obsolete. Feb. 1989, pp. 26-35.

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Gallium in 1989. Mineral Industry Surveys, Annual Review.

ASBESTOS

By Robert L. Virta

Mr. Virta, a physical scientist with 14 years Bureau of Mines experience, has been the commodity specialist for asbestos since 1986. Domestic survey data were prepared by Michael McTootle, mineral data assistant; and international data tables were prepared by Harold Willis, international data coordinator.

The most noteworthy event within the industry was the enactment of a regulation by the Environmental Protection Agency (EPA), after 3 years of review, that phases out the use of asbestos in most products by 1997. Health and liability issues also continued to adversely affect the industry. The number of firms that produce asbestos-containing products declined dramatically in the past few years in response to these issues. Domestic asbestos consumption decreased 22% from that of 1988, continuing a 16-year decline from 800,962 tons in 1973 to 55,306 tons in 1989. Only two companies in California and Vermont mined asbestos in the United States. Approximately 97% of the asbestos consumed in the United States was imported from Canada. Domestically, asbestos was consumed in roofing products, 34%; friction products, 23%; asbestos-cement pipe, 15%; packing and gaskets, 8%; and other, 20%.

DOMESTIC DATA COVERAGE

Domestic production data for asbestos are developed by the 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.

LEGISLATION AND GOVERNMENT PROGRAMS

EPA issued a final rule banning the manufacture, importation, processing, and distribution of most asbestos-containing products on July 12, 1989. The ban will be implemented in three stages. The first stage, effective August 27, 1990, bans asbestos-containing flooring and roofing felt, pipeline wrap, asbestos-cement corrugated and flat sheet, vinyl asbestos floor tile, and asbestos clothing. The second stage, effective August 25, 1993, bans asbestos-containing gaskets, transmission components, and original equipment drum and disk brake components. The third stage, effective August 26, 1996, bans asbestos-cement pipe, commercial and corrugated asbestos paper, roll board and mill board, asbestos-cement shingle, asbestos-containing roof and non-roof coatings, brake blocks, and after-market drum and disk brake components. The sale and distribution of asbestos-containing products, product labeling, exemptions from the ban, and record keeping are covered by provisions in the regulation.[1] The Asbestos Information Association of North America, Asbestos-Cement Pipe Producers Association, the Asbestos Institute, and several other organizations have petitioned the courts to review the EPA ban.

TABLE 1

SALIENT ASBESTOS STATISTICS

		1985	1986	1987	1988	1989
United States:						
Production (sales):						
Quantity	metric tons	57,457	51,437	50,600	18,233	17,427
Value[1]	thousands	$20,485	$17,367	$17,198	W	W
Exports and reexports (unmanufactured):						
Quantity	metric tons	45,656	47,281	60,084	31,544	27,004
Value	thousands	$16,489	$14,520	$16,149	$8,468	$7,690
Exports and reexports of asbestos products:						
Value	do.	$193,765	$163,896	$180,602	$194,858	$153,081
Imports for consumption (unmanufactured):						
Quantity	metric tons	142,431	108,352	93,763	85,326	55,306
Value	thousands	$44,093	$26,537	$22,022	$21,528	$14,031
Consumption, apparent[2]	metric tons	162,000	119,627	84,279	71,354	e55,306
World: Production	do.	r4,248,988	r4,032,213	4,227,662	p4,322,805	e4,325,487

e Estimated. p Preliminary. 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.

The Mine Safety and Health Administration issued proposed revisions to its existing standards for air quality and chemical substances, including the lowering of permissible exposure levels to asbestos from 2.0 fibers per cubic centimeter (f/cc) to 0.2 f/cc.[2] The Occupational Safety and Health Administration extended an administrative stay through November 30, 1990, on the regulation governing exposure to the nonasbestiform varieties of actinolite, anthophyllite, and tremolite and continued to study the economic impact of the regulation on the mining and construction industries.[3]

EPA proposed changes in the national emission standard for hazardous air pollutants. The proposed revisions require daily monitoring of visible emissions for milling, manufacturing, and fabricating operations, weekly inspection of air-cleaning devices, and record keeping. Notification requirements for demolitions and renovations are revised and record keeping is required for asbestos waste disposal.[4]

EPA 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.[5]

STRATEGIC CONSIDERATIONS

A wide variety of asbestos-containing civilian products also have military applications. Examples include friction materials (brakes and clutches), electrical and thermal insulations, packings and gaskets, asbestos-reinforced plastics, etc. for use on military vehicles, ships, rockets, missiles, and in military construction. During World War II and the Korean war, strict controls were placed on the export of asbestos because the United States was dependent on foreign sources for about 90% of its requirements of all grades of asbestos. The United States was totally dependent on foreign sources for low-iron, spinning-grade chrysotile. Since that time, equipment components have been redesigned, new products have been introduced, and substitutes for asbestos are being used more frequently.

TABLE 2

STOCKPILE GOALS AND GOVERNMENT INVENTORIES FOR ASBESTOS, DECEMBER 31

(Metric tons)

	Stockpile goals	Total inventories		
		1987	1988	1989
Amosite	15,422	30,849	30,849	30,849
Chrysotile	2,722	9,709	9,710	9,710
Crocidolite	—	33	33	33
Total	18,144	40,591	40,592	40,592

Source: Department of Defense.

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, 15,427 tons of amosite, and 33 tons of crocidolite and is currently considering the removal of these materials from the stockpile of strategic and critical minerals.

ISSUES

Environmental and liability issues continue to affect the asbestos industry. EPA enacted a regulation that phases out the use of asbestos in most products by 1997 because of concerns over the risks of low-level exposures. The regulation is controversial because it assumes that there is no threshold level of exposure to asbestos beyond which there is no risk. Industry representatives maintain that there are insufficient data available to support this assumption, that environmental risks posed by asbestos are far less than many of those encountered in everyday living, and that stricter control of asbestos can reduce the risks even further.

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 decreased slightly in 1989. The two domestic producers were able to maintain production levels despite the EPA ban and phaseout because export markets remained strong.

CONSUMPTION AND USES

Asbestos was used in a wide variety of products because of its high tensile strength, chemical and thermal stability, high flexibility, low electrical conductivity, and large surface area. Products made from asbestos were more heat resistant (and often incombustible), more resistant to chemical attack (particularly for alkalis), stronger (asbestos acted as a physical reinforcer), less conductive (asbestos had a low dielectric constant), more viscose (asbestos stiffened compounds and coatings), faster setting (asbestos hastened water drainage in asbestos-cement pipe production), and more cost efficient than many nonasbestos products.

U.S. consumption of asbestos decreased 22% in 1989. Approximately 93% of the asbestos consumed domes-

TABLE 3

U.S. ASBESTOS CONSUMPTION, BY END USE, GRADE, AND TYPE

(Thousand metric tons)

End use	Chrysotile[1]							Amosite	Crocidolite	Other[3]	Total asbestos[4]
	Grade 1 and 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Total[2]				
1988	—	0.4	7.6	5.1	5.4	46.4	65.0	—	1.3	5.1	66.2
1989:											
Asbestos-cement pipe	—	(5)	5.1	1.2	1.0	—	7.3	—	.6	—	7.9
Asbestos-cement sheet	—	—	—	—	1.6	1.4	3.0	—	—	—	3.0
Coatings and compounds	—	—	(5)	—	—	4.3	4.3	—	—	—	4.3
Flooring products	—	—	—	—	—	—	—	—	—	—	—
Friction products	—	—	—	1.6	.6	9.9	12.1	—	—	—	12.1
Insulation:											
Electrical	—	—	—	—	—	—	—	—	—	—	—
Thermal	—	—	—	—	—	—	—	—	—	—	—
Packing and gaskets	—	—	.1	.9	.2	3.1	4.3	—	—	—	4.3
Paper	—	—	—	—	—	1.0	1.0	—	—	—	1.0
Plastics	—	—	—	—	—	.5	.5	—	—	—	.5
Roofing products	—	—	—	—	—	17.5	17.5	—	—	—	17.5
Textiles	0.1	—	—	—	—	—	.1	—	—	—	.1
Other	—	.1	.5	(5)	—	.7	1.3	—	—	—	1.3
Total[2]	.1	.1	5.7	3.8	3.4	38.3	51.5	(5)	.6	3.2	52.1

[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.

tically was chrysotile, 1% was crocidolite, less than 1% was amosite, and 6% was an unspecified fiber type. Approximately 74% of the chrysotile consumed in the United States was grade 7, followed by grades 4, 5, 6, 3, 2, and 1.

The construction industry is the major consumer of asbestos fiber in the form of asbestos cement pipe, asbestos cement sheet, coatings, compounds, packings, and roofing products. These end uses accounted for 71% of the asbestos consumed in the United States.

Consumption has declined dramatically from 800,962 tons in 1973 to 55,306 tons in 1989 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 which 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 fibers, ceramic fiber, clay, fibrous glass, fumed silica powder, graphite flake and fiber, limestone, mica, polyacrylonitrile fiber, polybenzimidazole fiber, polyethylene fiber, polypropylene fiber, polytetrafluoroethylene fiber, steel fibers, talc, and wollastonite. Examples of alternative products include aluminum, vinyl, and wood siding; aluminum pipe and sheet; asphalt coatings; ductile iron pipe; fiberglass sheet; polyvinylchloride pipe; prestressed concrete and reinforced concrete pipe; semimetallic brakes; urethane coatings; and vinyl composition floors.

PRICES

The average unit value of domestically produced asbestos increased slightly in 1989. Unit values for imported asbestos ranged from $141 per ton to $3,728 per ton and averaged $234 per ton. Unit values for exported asbestos ranged from $128 per ton to $2,158 per ton and averaged $285 per ton. Customs unit values of imported crude chrysotile decreased 74% because high valued crude chrysotile from Zimbabwe was not imported under this import category in 1989. The unit value of imported spinning chrysotile decreased 49% because the change to the Harmonized System for import reporting resulted in the inclusion of lower valued chrysotile fiber in the "chrysotile, spinning" category.

FOREIGN TRADE

Beginning in 1989, the Bureau of the Census adopted the Harmonized System for reporting commodity imports and exports. Asbestos import categories under the Harmonized System were unchanged from those of previous years.

TABLE 4

CUSTOMS UNIT VALUES OF IMPORTED ASBESTOS

(Dollars per metric ton)

	1985	1986	1987	1988	1989
Canada:					
Chrysotile:					
Crude	576	547	610	635	167
Spinning	731	507	598	756	387
Other	283	229	218	227	227
South Africa, Republic of:					
Amosite	830	—	—	—	3,728
Crocidolite	569	582	572	609	631

Source: Bureau of the Census.

Asbestos export categories under the Harmonized System were considerably different from those of previous years. Export categories that were used prior to 1989 overlap under the Harmonized System and many of the Harmonized System categories were not exclusive for asbestos (i.e., included cellulose pipe and sheet and nonasbestos friction materials).

The total value of asbestos fibers and asbestos products exported and reexported from the United States was $160,771,000. This is a 21% decrease from 1988 and reflects a lower volume of asbestos and asbestos products being exported in 1989. Exports and reexports of brake linings and disk pads accounted for 83% of the value of all manufactured asbestos products. Canada remained the largest importer of unmanufactured fibers and manufactured products, followed by Japan, Mexico, Brazil, and the United Kingdom.

Canada provided 97% of the asbestos imported into the United States, and the Republic of South Africa provided 2%. Several other countries provided minor amounts. Approximately 93% of the asbestos fiber imports were chrysotile.

WORLD REVIEW

Canada continued to be the largest market-economy producer of asbestos, followed by Brazil, the Republic of South Africa, and Italy. 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.

Capacity

The data in table 8 are rated annual capacity for mines and refineries 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

TABLE 5

COUNTRIES IMPORTING U.S. ASBESTOS FIBERS AND PRODUCTS

(Thousand dollars)

Country	1988			1989		
	Unmanufactured fiber	Manufactured products	Total[1]	Unmanufactured fiber	Manufactured products	Total[1]
Australia	9	2,285	2,294	18	1,734	1,752
Brazil	656	4,662	5,317	785	4,203	4,988
Canada	694	144,305	144,999	884	98,974	99,859
Germany, Federal Republic of	228	2,316	2,544	93	3,801	3,894
Japan	3,312	8,538	11,850	3,314	7,211	10,526
Korea, Republic of	182	1,266	1,448	145	953	1,097
Kuwait	—	456	456	—	574	574
Mexico	1,636	7,677	9,313	370	5,797	6,166
Saudi Arabia	—	1,814	1,814	105	1,394	1,499
Thailand	150	757	908	10	167	177
Turkey	—	706	706	—	304	304
United Kingdom	97	2,127	2,224	75	4,841	4,916
Venezuela	106	1,805	1,912	50	709	759
Other	1,399	16,143	17,542	1,841	22,417	24,259
Total[1]	8,468	194,858	203,326	7,690	153,081	160,771

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

Source: Bureau of the Census.

TABLE 6

U.S. EXPORTS AND REEXPORTS OF ASBESTOS AND ASBESTOS PRODUCTS

Products		Quantity	Value (thousands)
1988:			
Unmanufactured:			
Crudes, fibers, stucco	metric tons	26,356	$6,785
Sand and refuse	do.	5,188	1,683
Total	do.	31,544	8,468
Manufactured:			
Asbestos fibers	do.	1,394	5,431
Brake linings	do.	NA	140,186
Clutch facings and linings	number	NA	27,094
Gaskets	metric tons	536	2,244
Insulation	do.	NA	4,558
Packing and seals	do.	641	5,793
Shingles and clapboard	do.	1,095	662
Other articles of asbestos	do.	1,609	2,133
Other articles, n.s.p.f	do.	NA	6,757
Total		XX	194,858
1989:			
Unmanufactured:			
Asbestos[1]	do.	27,004	7,690
Manufactured:			
Asbestos fibers	do.	103,526	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

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.

temporarily closed that in the judgment of the author can be brought into production within a short period of time with minimum capital expenditure.

Canada

Developmental work continued on the underground portion of Cassiar Mining Co.'s McDame asbestos mine in British Columbia. The mine is expected to become operational in March 1990. Reserves in the open pit are sufficient to continue operation through late 1990.[6]

South America

Swiss Eternit Group (SEG) planned to divest itself of asbestos cement operations in Brazil, Colombia, and Bolivia and its holdings in SA Mineracao de Amianto (SAMA), a chrysotile operation in Brazil. SEG will begin to focus on the use of asbestos substitutes.[7]

CURRENT RESEARCH

Fifteen fiber-cement products that are used commercially in place of asbestos-cement products were tested for accelerated absorption, aging, color stability, combustion, density, flexural strength, humidity, impact resistance, porosity, thermal conductivity, warping, and the degree to which a product was waterproof. The fiber-cement products tested performed exceedingly well in the impact resistance test and poorly in the combustibility tests. Mixed results were obtained for the other tests. The study concluded that the overall performance of asbestos-cement products exceeded that of the fiber-cement products.[8]

The Asbestos Information Association (AIA) compiled the results of its third survey of worker exposure to asbestos. Surveys were sent to 32 countries and 26 responded. The survey covered 45,696 workers in mining (30%), asbestos-cement production (39%), friction materials production (22%), textile production (5%), and other asbestos industries (4%). Less than 2% of the workers covered in the survey were exposed to concentrations of more than 2 f/cc. Over 90% were exposed to concentrations of less than 1 f/cc. The bulk of the exposures over 2 f/cc were in the textile industries.[9]

OUTLOOK

Domestic markets will continue to decline because of the EPA ban and phaseout of asbestos and consumer demand for asbestos substitutes. Asbestos mining was not banned under the new EPA regulation so domestic producers will be able to continue to export asbestos fiber. Foreign markets for asbestos fiber should remain strong for several years because of the high demand in Southeast Asian and 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 most uses of asbestos within 7 years. Asbestos consumption probably would continue to decline even if the EPA ban and phaseout of asbestos were rescinded in favor of stricter regulations because of the continuing concern over environmental, health, and liability issues.

[1] Federal Register. Environmental Protection Agency. Asbestos: Manufacture, Importation, Processing, and Distribution in Commerce Prohibitions; Final Rule. V. 54, No. 132, July 12, 1989, pp. 29460-29513.

[2] Federal Register. Mine Safety and Health Administration. Air Quality, Chemical Substances, and Respiratory Protection Standards. V. 54, No. 166, Aug. 29, 1989, pp. 35760–35852; V. 54, No. 201, Oct. 19, 1989, p. 43026.

[3] ———. Occupational Safety and Health Administration. Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite. V. 54, No. 139, July 21, 1989, pp. 30704–30705.

[4] ———. Environmental Protection Agency. Asbestos NESHAP Revision, Including Disposal of Asbestos Containing Materials Removed from Schools. V. 54, No. 6, Jan. 10, 1989, pp. 912–937.

[5] Federal Register. Environmental Protection Agency. National Primary and Secondary Drinking Water Regulations. V. 54, No. 97, May 22, 1989, pp. 22062–22160.

[6] Mining Journal. McDame Schedule for Cassiar. V. 312, No. 8004, Jan. 27, 1989, p. 61.

[7] Industrial Minerals. Swiss Eternit Plans Asbestos Exit. No. 258, Mar. 1989, pp. 12–13.

[8] Asbestos. Comparative Study of Fiber-Cement Products. V. 4, No. 1, June 1989, p. 6.

[9] Asbestos. An International Dust Exposure Survey. V. 3, No. 4, Mar. 1989, pp. 2–3.

OTHER SOURCES OF INFORMATION

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Mining Journal (London).

TABLE 7

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)
1987	90,224	$20,096	3,246	$1,788	293	$137	93,763	$22,022
1988:								
Chrysotile:								
Crude	20	2	—	—	17	21	37	23
Spinning fibers	526	358	—	—	75	97	601	455
All other	77,779	17,421	488	273	61	73	78,328	17,767
Crocidolite (blue)	—	—	1,252	763	—	—	1,252	763
Other (unspecified asbestos type)	1,365	555	2,548	1,480	1,195	484	5,108	2,520
Total[1]	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

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

Source: Bureau of the Census.

TABLE 8

WORLD ASBESTOS ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

	Rated capacity[1] (thousand metric tons)
Chrysotile:	
North America:	
Canada	780
United States	30
Total	810
South America:	
Brazil	250
Colombia	20
Other	1
Total	271
Europe:	
Greece	100
Italy	150
U.S.S.R.	2,800
Yugoslavia	20
Total	3,070
Africa:	
South Africa, Republic of	150
Swaziland	30
Zimbabwe	250
Total	430
Asia:	
China	170
Cyprus	35
India	30
Japan	4
Korea, Republic of	5
Turkey	6
Other	(2)
Total	250
World chrysotile total	4,831
Crocidolite:	
South Africa, Republic of	210
Amosite:	
South Africa, Republic of	110

[1] Includes capacity at operating plants as well as at plants on standby basis.
[2] Less than 1/2 unit.

TABLE 9

ASBESTOS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	1,244	1,697	332	2,328	2,100
Brazil[3]	165,446	204,460	212,807	227,653	230,000
Bulgaria	400	300	400	[e]400	400
Canada (shipments)	750,190	662,381	664,546	704,989	709,800
China	150,000	150,712	144,673	157,478	160,000
Colombia	12,435	12,916	13,272	[r e]10,500	10,500
Cyprus	16,360	13,011	18,070	14,585	—
Egypt	229	476	209	166	160
Greece	46,811	51,355	63,000	[e]80,000	80,000
India	30,183	25,236	29,110	31,303	32,000
Indonesia	([4])	([4])	([4])	([4])	—
Iran (concentrate)[e]	2,500	3,000	3,300	3,000	3,000
Italy	136,006	115,208	100,834	94,549	94,500
Japan	2,971	3,593	3,143	[r e]3,000	3,000
Korea, Republic of	4,703	2,983	2,518	2,428	2,500
Mozambique	55	—	—	—	—
South Africa, Republic of	164,247	138,862	135,074	145,678	150,000
Swaziland	25,130	20,908	25,925	22,804	23,000
Taiwan	625	—	—	—	—
Turkey	[e]1,500	1,098	360	[e]100	100
U.S.S.R.[e]	2,500,000	2,400,000	[5]2,554,600	2,600,000	2,600,000
United States (sold or used by producers)	57,457	51,437	50,600	18,233	[5]17,427
Yugoslavia	6,916	8,596	10,964	17,030	17,000
Zimbabwe	173,580	163,984	193,925	186,581	190,000
Total	[r]4,248,988	[r]4,032,213	4,227,662	4,322,805	4,325,487

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 13, 1990.

[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, in metric tons, as follows: 1985—887; 1986—2,060; 1987—2,000 (estimated); 1988—2,000 (estimated); and 1989—2,000 (estimated).

[4] Revised to zero.

[5] Reported figure.

BARITE

By Sarkis G. Ampian

Mr. Ampian, a physical scientist with more than 36 years experience, has been the commodity specialist for barite since 1981. Domestic survey data were prepared by Bruce Baltas, mineral data assistant, and international tables were prepared by Virginia A. Woodson, international data coordinator.

Domestic production of barite decreased more than 28% to 290,000 metric tons (data in metric units, unless noted), while the value decreased nearly 20% to $13 million. This decline continues the downtrend in barite production, except for 1987, which has persisted since 1981 when the record high of 2.5 million tons was produced. Production from Nevada, the leading producing State, decreased about 18%. Imports for consumption of crude barite decreased nearly 13%, while ground barite imports more than trebled. Imports of barite exceeded domestic production for the eighth consecutive year, but the import figure of 990,000 tons for 1989 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 about 90% of U.S. consumption. Chemical, glass, and filler and/or extender uses accounted for the remaining 10%.

Weak demand for barite by the oil- and gas-well-drilling industry carried over from the third quarter of 1988 and persisted for the entire year owing to volatile oil prices and softening of the overall economy. The downturn in demand has been largely due to the decrease in the number of offshore and onshore drilling rigs, thereby lowering the demand for barite-bearing muds. Overproduction by major oil-producing countries during the last quarter caused crude oil prices to decline, which in turn depressed the demand for barite drilling muds. U.S. mine production of barite continued, although still depressed. Producers were encouraged by declining rail rates, which increased the competitiveness of domestic ores in the gulf coast and midcontinent areas. Barite grinding capacity, despite numerous closures, mergers, and acquisitions, remained sufficient to meet present and future requirements.

TABLE 1

SALIENT BARITE AND BARIUM CHEMICAL STATISTICS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Barite, primary:					
Sold or used by producers	670	269	406	404	290
Value	$21,501	$12,326	$15,810	$15,512	$12,625
Exports	6	7	9	(1)	10
Value	$692	$1,021	$716	$353	$1,622
Imports for consumption (crude)	1,865	676	748	1,132	987
Consumption (apparent)[2]	2,530	939	1,147	1,536	1,271
Crushed and ground (sold or used by processors)[3]	1,981	1,103	1,301	1,612	1,277
Value	$154,463	$75,965	$108,759	$127,373	$103,759
Barium chemicals (sold or used by processors)	24	25	28	27	e30
Value	$16,036	$16,871	$16,466	$15,284	e$17,000
World: Production	r6,067	r4,708	4,704	p5,481	5,712

eEstimated. pPreliminary. rRevised.

[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 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.

PRODUCTION

The term "primary barite" denotes the first marketable product and includes crude run-of-mine barite, flotation concentrates, and material concentrated by other beneficiation processes such as washing, jigging, or magnetic separation. Run-of-mine barite, the lowest cost primary barite sold or used by producers, representing 43% of total production, was unchanged from 1988; the remaining 57% 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 declined nearly 28% from 404,000 in 1988 to 290,000 tons. Nevada and Georgia remained the two leading barite-producing States. Other producing States, in descending order, were Missouri, Tennessee, Montana, and Illinois. Illinois produces barite 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., a Dresser-Halliburton Co.; Milpark Drilling Fluids, a Baker Hughes Inc. company with mines

in Nevada; and Baroid Drilling Fluids Inc., a division of NL Petroleum Services Inc., with mines in Missouri and Nevada.

In domestic barite news, New Riverside Ochre Co. (NRO), of Cartersville, GA, purchased Baroid Corp.'s, formerly NL Baroid, Sweetwater properties in Tennessee. The properties, amounting to about 1,100 and 1,200 acres, respectively, of fee simple and mineral rights lands. Baroid last worked the barite deposits for both the drilling and nondrilling markets. A. J. Smith Co. Inc. built a washer-jigging plant on the property to feed NRO's complex in Cartersville, GA. NRO is the mining arm of Chemical Products Co. (CPC), Cartersville, GA, and produces barium chemicals from the local barite residuum. Both NRO and CPC are wholly owned subsidiaries of Dellinger Management Co., also of Cartersville. In another action, NRO completed the installation of the Kingston washer plant at midyear, purchased from DeSoto Mining Co. Inc., Richlands, MO, at its nearby Emerson, GA, location to treat local and Sweetwater barite. In drilling mud news, American Barite Corp. completed a barite grinding facility at Morgan City, LA, and Milpark Drilling Fluids Inc. added two additional jigs to its existing Argenta, NV, jigging plant. In corporate news, the shareholders of NL Industries Inc. voted on December 22 to spinoff NL Baroid into a separate entity, Baroid Corp.

The recovery of the domestic barite industry that begin in midyear 1987 and continued into the last quarter of 1988 failed to reappear during all of 1989, when overproduction by oil-producing countries caused crude oil prices to decline. During this downturn, volatile but lowering oil prices decreased drilling activity. The slowdown of the growing overall economy did little to spur recovery. The yearend oil glut depressed barite demand by the exploration and development segments of the industry. The decline in production rates in 1989 reversed the near level output in 1971-88 by returning to the trend of declining barite output that had begun after 1981, the high production year (2.8 million tons). Production data indicate that competitive rail rates to the gulf coast and midcontinent areas, based on unit trains and guaranteed-tonnage contracts, combined with a tight barite supply early in the year and attendant price increases, permitted modest domestic mining campaigns.

Nevertheless, the persistent oil glut, exacerbated primarily by overproduction, caused price volatility, lowered energy rates, and continued to temper or limit any major upturn in drilling activity. Another factor depressing the domestic marketplace was the overcapacity of the drilling-fluids producers. The slowly recovering domestic barite industry, the world's largest, continued to be threatened by imports of crude and ground barite. Rising ocean freight rates, in part due to higher bunker fuel costs and limited availability of bottoms, helped reduce competition by foreign ores early in the year.

Most mining and grinding operations continued to be either suspended or operated on minimal production schedules to address the industry's excess capacity. Many of the additions to mining, milling, and grinding capacity were largely to reduce operating costs to remain competitive in a firming but volatile market situation. Many ongoing and planned projects, including exploration programs, were indefinitely deferred.

The International Trade Commission/Import Administration, U.S. Department of Commerce, terminated an antidumping administrative review of barium chloride from China.[1] Earlier in the year, the Department published preliminary results of its administrative review of the antidumping duty order on barium chloride from China.[2] The review covered one manufacturer and/or exporter of this chemical to the United States from the periods April 6, 1984, through September 30, 1984, and October 1, 1985, through September 30, 1986. The margins for the first period were stipulated at 27.70% and 60.84% for the second. A cash deposit estimated antidumping duty of 60.84% was required for all shipments from this one source. These cash deposit requirements were effective for all shipments for Chinese barium chloride entered or withdrawn from warehouse for consumption on or after the date of publication of the notice and remained in force by the Customs Service until the termination decree.

The Environmental Protection Agency proposed to grant the petitions to exempt barium sulfate from the reporting requirements under the category "barium compounds" on the list of toxic chemicals under Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 in recognition that barium sulfate is an insoluble and inert dust.[3] The Department of Labor, Mine Safety and Health Administration, proposed to revise its existing standards for barite air quality and chemical substances at coal and metal-nonmetal mines to a threshold limit value (TLV) of 10 milligrams milligrams per cubic meter (mg/m^3).[4] The preproposal draft specified a limit for barite, a barium sulfate compound, of 0.5 mg/m^3. The same limit was placed on other soluble and reactive barium compounds by the American Conference of Governmental Industrial Hygienists (ACGIH).

CONSUMPTION AND USES

Consumption of crushed and ground barite decreased nearly 17%, from 1.6 million tons in 1988 to 1.3 million tons in 1989. This decrease resumes the decline in total barite consumption, except for the past 2 consecutive years of 1987 and 1988, prevalent since 1981 when the record high of 4.7 million tons of crushed and ground barite was set. The decrease reflects a downturn not only in barite requirements for oil well drilling, which still accounts for about 90% of total sales, but also in the overall economy. The oil-and gas-well-drilling industry completed nearly 21,000 wells and drilled about 102 million feet of hole;[5] these figures were 16% and 18% lower, respectively, than in 1988.

Total drilling footage exceeded 6 million feet in four States: Texas, 37.7 million feet; Oklahoma, 11.6 million; Louisiana, 9.7 million; and Kansas, 6.5 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, over 7,900 feet, and Kansas the shallowest, about 3,400 feet. Wyoming, absent from the top States this year in well footage drilled and the perennial leader in the highest average well depth, recorded only 7,300 feet. The U.S. average decreased to nearly 4,900 feet, a 4% reduction. Barite consumption decreased accordingly with the 15% reduction in the number of wells drilled despite the upturn in operating offshore rigs in the Gulf of Mexico and California at the expense of shallower drilling onshore varieties elsewhere. Most of the onshore wells were in the Overthrust Belt in Wyoming and Anadarko Basin in Oklahoma, both deep-drilling areas. There was nearly a 43% decrease in the amount of barite used per foot of drilling, from 63.02 pounds in 1988 to 36.08 pounds in 1989.

Another barometer of drilling activity, the Baker Hughes rig count, showed the

TABLE 2

U.S. PRIMARY BARITE SOLD OR USED BY PRODUCERS, BY STATE

State	Number of operations	Run of mine		Flotation concentrates		Beneficiated material		Total	
		Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)
1988:									
California	2	W	W	—	—	—	—	W	W
Georgia	2	—	—	W	W	W	W	W	W
Missouri	3	W	W	—	—	W	W	W	W
Nevada	5	142	$2,163	W	W	149	$2,782	290	$5,053
Tennessee	1	W	W	—	—	—	—	W	W
Total[1]	13	174	3,621	15	$1,908	216	9,983	404	15,512
1989:									
Georgia	2	—	—	W	W	W	W	W	W
Illinois	1	—	—	W	W	—	—	W	W
Missouri	3	W	W	—	—	—	—	W	W
Montana	1	W	W	—	—	—	—	W	W
Nevada	5	122	1,869	—	—	87	1,603	209	3,473
Tennessee	1	W	W	—	—	—	—	W	W
Total	13	125	2,046	W	W	[2]165	[2]9,186	290	12,625

W Withheld to avoid disclosing company proprietary data.
[1]Data may not add to totals shown because of independent rounding.
[2]Includes flotation concentrates.

average number of operating domestic rigs in 1989 decreased 7% to 869.[6] This decline in rigs reestablishes the downward trend that, except for 1984 and 1988, has seen the number of rigs fall from the 1981 record high of 3,974. The 1989 average rig count of 869 is the fourth time since 1971 (976 rigs) that the count was below 1,000. The estimated rig count during the year ranged from 737 to 1,079. The low count of 737, recorded the week of May 21, was the second lowest since World War II. The high, 1,079 rigs, was registered the week of December 24.

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 or direct-ship, beneficiated, and floated material, increased 12%, f.o.b. plant, from $38.40 per ton in 1988 to $43.53. This increase in value for domestic concentrate is attributed to a smaller percentage of lower valued drilling-mud-grade material in the total. The average reported value per ton of ground drilling-mud-grade barite from Louisiana and Texas was $76.77; the average value of that from California, Nevada, and Utah was $64.81. The value of the Louisiana and Texas ground material, in direct response to steadily rising costs of imported crude, rose about 15%. Material from the other major grinding States, supplied largely by domestic mines, rose slightly. The average customs value of barite exported to Canada and Mexico ranged between $200 and $400 per ton; the customs value of material exported to Latin America was under $200 per ton.

FOREIGN TRADE

Exports of natural barium sulfate or barite increased markedly from about 200 tons to more than 9,700 tons. This increases the modest rebound in barite exports for the previous 3 of 4 years, 5,800 to 9,700 tons, and ends the downward pattern that saw exports plummet from 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 more than $50 to $5,000 per ton, drilling-, pharmaceutical-, chemical-, filler-, and glass-grade were all exported. Drilling-mud-grade barite appeared to make up about 75% of the export percentage. Historically, barite exports were predominantly ground drilling-mud-grade material with less than 5% of the tonnage specialty ground barites. Minor amounts of witherite (natural barium carbonate), precipitated barium carbonate, barium sulfate (blanc fixe), and barium chlorides, anhydrous and hydrous oxides, and nitrates also were exported. Crude barite was not exported. Canada and Mexico traditionally either first or second among export recipients of U.S. ground barite, were replaced by Venezuela and Colombia, in decreasing order. These two countries were the leading buyers of U.S. ground barite and accounted for about 55% of the total exports. Exports to Canada and Mexico, major oil-producing countries, declined to less than 2,000 tons from a high of 18,000 tons in 1983. Both Canada and

TABLE 3

PRODUCERS OF BARIUM MATERIALS IN 1989

Company	Plant location	Material
American Minerals Inc.	Camden, NJ	Well drilling and filler.
Do.	El Paso, TX	Do.
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.
Clark Minerals Inc.	South Plainfield, NJ	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.	Adams, 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.
Milpark Drilling Fluids	Argenta, NV	Primary and ground.
Do.	Clinton, OK	Well drilling.
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.
Pfizer 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.
A.J. Smith Co. Inc.	Sweetwater, TN	Primary and ground.
Standard Industrial Minerals	Laws, CA	Filler.
Standard Magnesia Co.	Churchill, NV	Primary.
Standard Slag Inc.	Nye, NV	Do.
BARIUM COMPOUNDS		
J.T. Baker Chemical Co.	Phillipsburg, NJ	Chemicals.
Chemical Products Corp.	Cartersville, GA	Do.

Mexico continued to rely more on domestic production. During the year, the strengthening U.S. dollar had little effect on this trade because of continuing Canadian and Mexican fiscal problems.

Imports for consumption of crude barite decreased about 13%, from 1.132 million tons in 1988 to nearly 990,000 tons. The 1989 barite import figure was nearly 50% below the record high of 2.32 million tons set in 1982. The c.i.f.[7] value of this material resumed its downward trend by declining about 10% to $40.27 per ton. Except for 1988, the value of imported material has declined for 9 of the previous 10 years. The 1989 decrease indicates that prices of foreign ores lowered in response to oversupply and lower ocean shipping rates. Earlier cutbacks in foreign production in 1988, notably in China and India, because of an absence of forward commitments, saw a firming of both crude barite prices and shipping rates, which carried only into the first quarter of 1989. The 25% increase in imports of Indian ores in 1989 was caused primarily by slippages in delivery schedules that carried over into the first part of the year. Softening worldwide crude oil prices and its resultant lowering of oil- and gas-exploration drilling activity combined to lessen domestic demand for most of the year. Domestic producers and consumers in the gulf coast area, still faced with relatively high rail rates from domestic drilling-quality barite mines in Nevada, continued to take advantage of the lower priced foreign ores to meet their demands. Based on average value per ton of material shipped, the principal source countries, in descending order, were China, $40.85; India, $40.27; Mexico, $38.84; Peru, $36.37; and Chile, $33.25. The high-priced Mexican material was chiefly crude filler and extender-quality barite. The high-quality barite, generally material with a specific gravity greater than 4.2, is usually blended during grinding with lower grade ore, foreign or domestic, to meet American Petroleum Institute specifications for 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, 65% (74%); Houston, TX, 31% (23%); and Laredo, TX (Port of Brownsville, TX), 31% (13%). Small amounts were also received, in decreasing order, in Great Falls, MT; Pembina, ND; and Cleveland, OH.

Imports of ground barite more than tripled to nearly 47,000 tons from about 14,000 tons in 1988; of this, Canada (17%) and Mexico (80%) supplied about 97%. Before 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

TABLE 4

CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY STATE

State	1988			1989		
	Number of plants	Quantity (thousand metric tons)	Value (thousands)	Number of plants	Quantity (thousand metric tons)	Value (thousands)
Louisiana	8	849	$58,916	7	700	$50,533
Missouri	1	W	W	1	W	W
Nevada	4	220	12,666	3	97	6,208
Oklahoma	2	W	W	2	W	W
Texas	8	387	32,259	4	313	27,288
Other[2]	12	155	23,532	14	167	19,730
Total	35	1,612	127,373	31	1,277	103,759

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes imports.
[2]Includes Arkansas, California, Georgia, Illinois, New Jersey, and Utah.

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	1988		1989	
	Quantity	Value	Quantity	Value
Barium chemicals, filler and/or extender, glass	211	24,346	140	19,470
Well drilling	1,401	103,027	1,137	84,289
Total	1,612	127,373	1,277	103,759

[1]Includes imports.

compounds have been largely replaced with computer-assisted tomography (CAT) scanners or imaging techniques. Sources of medical-grade barite were Belgium-Luxembourg, Canada, France, the Federal Republic of Germany, and the Netherlands. The average c.i.f. value of imports from Canada, Czechoslovakia, and Mexico ranged from $51 to $314 per ton, suggesting that 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. The value of imports from other countries, $400 per ton, indicates that these ground materials are either an ultrahigh-purity filler or a competitively priced pharmaceutical-grade material.

Imports for consumption of barium chemicals and unwrought and/or waste and scrap barium metal are no longer reported by the Bureau of the Census.

WORLD REVIEW

Capacity

The data in table 13 are rated capacity for mines as of December 31, 1989. 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.

Brazil

A São Paulo-based company, Mineracão Matheus Leme Ltda. (MML), was evaluating a barite deposit in the State of Goiás for the Uruguayan paint market.[8] MML, a diversified industrial mineral filler, was contemplating the engine gasket markets for its anhydrous mineral filler line.

Burma

The Government expects barite production to increase from the present total of about 20,000 tons per year to more than 40,000 tons per year because of new oil explorations.[9] Barite production is near Maymyo, Kyaukse, and Taunggyi in Central Burma.

China

A directive issued by The Ministry of Geology and Mineral Industry called for greater efforts to locate exportable economic mineral reserves in the coastal regions.[10] Industrial minerals specifically targeted include barite. Apparently, 100 small- and medium-sized mines under consideration, largely in rural areas, were currently being evaluated.

France

The Bureau de Recherches et de Participations Minières reported a new sulfate deposit in the Lyon District with the capability of yielding byproduct barite.[11] Preliminary tests were directed toward a 330,000-ton-per-year treatment rate with an unannounced recovery of both sulfides and barite. A joint-venture scheme for financing was reportedly under consideration. Capitalization was in the order of 300 million francs.

Nigeria

Milpark Drilling Fluids Inc. started construction of a new barite grinding facility at Port Harcourt. The facility was scheduled to be on-stream by midyear.

TABLE 6

U.S. BARIUM CHEMICALS[1] PRODUCED AND SOLD OR USED BY PROCESSORS

Barium chemical	1988				1989			
	Plants[2]	Production (metric tons)	Sold or used by processors		Plants[2]	Production (metric tons)	Sold or used by processors	
			Quantity (metric tons)	Value (thousands)			Quantity (metric tons)	Value (thousands)
Barium acetate	1	W	W	W	1	W	W	W
Barium carbonate	2	W	W	W	2	W	W	W
Barium chloride	2	W	W	W	2	W	W	W
Barium nitrate	—	—	—	—	1	W	W	W
Barium sulfide, gray	1	W	W	W	1	W	W	W
Black ash	1	W	W	W	1	W	W	W
Blanc fixe	1	W	W	W	1	W	W	W
Total	3	27,421	27,279	$15,284	2	e30,000	e25,000	e$17,000

eEstimated. W Withheld to avoid disclosing company proprietary data.
[1]Data reported by plants that consume either barite or precursors are included.
[2]A plant producing more than one product is counted only once.

TABLE 7

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			
1969	1,120	14.37	4.08	13.74	32.19	57.3	4,881	38.37
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

[1]Includes exploratory and development wells; excludes service wells, stratigraphic tests, and core tests.

Source: American Petroleum Institute.

TABLE 8

U.S. BARITE MATERIALS IMPORT RATES OF DUTY

Tariff item	January 1, 1990			LDDC[2]	Non-MFN[3] January 1, 1990
	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 - United States-Canadaian Free Trade Agreement.
E - Caribbean Basin Economic Recovery Act.
IL - United States Israel Free Trade Area.

TABLE 9

BARITE PRICE QUOTATIONS

Item	Price per short ton[1]	
	1988	1989
Barite:[2 3]		
Chemical, filler, glass grades, f.o.b. shipping point, carlots:		
Handpicked, 95% $BaSO_4$, not over 1% Fe	$90.00	—
Magnetic or flotation, 96% to 98% $BaSO_4$, not over 0.5% Fe	116.00	—
Waterground, 95% $BaSO_4$, 325 mesh, 50-pound bags	$70.00 - 165.00	—
Dry-ground:		
Southern, off-color, coarse, bags, carload, f.o.b. mines (per pound)	.11	$0.09
Water grade, white, bags, carload, f.o.b. works (per pound)	.13	.13
Unbleached, extra-fine, pigment grade, carload, f.o.b. works	160.00	160.00
Drilling-mud-grade:		
Dry-ground, 83% to 93% $BaSO_4$, 3% to 12% Fe, specific gravity 4.20 to 4.30, f.o.b. shipping point, carlots	60.00 - 90.00	—
Crude, imported, specific gravity 4.20 to 4.30, f.o.b. shipping point	40.00 - 55.00	—
Barium chemicals:[3]		
Barium carbonate:		
Precipitated, bulk, carlots, freight equalized (per pound)	.25	.27
Electronics-grade, bags	510.00	590.00
Barium chloride:		
Technical crystals, bags, carlots, works	470.00	530.00
Anhydrous, bags, carlots, same basis	590.00	657.00
Barium hydrate: Mono, 55-pound bags, carlots, delivered (100 pounds)	46.00	46.00
Barium sulfate:		
Blanc fixe, technical-grade, bags, carlots	400.00	—
U.S.P., X-ray diagnosis-grade, powder, 25-kilogram bags, 10,000-kilogram lots (per pound)	.59	.59
Barium sulfide (black ash), drums, carlots, works	460.00	460.00

[1]Unless otherwise specified.
[2]Engineering and Mining Journal. V. 189, No. 4 , Apr. 1989, p. 21.
[3]Chemical Marketing Reporter. V. 235 No. 1, Dec. 30, 1989, pp. 26-27.

TABLE 10

U.S. EXPORTS OF NATURAL BARIUM SULFATE (BARITE), BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	(1)	$44	23	$11
Barbados	—	—	708	63
Canada	32	61	1,735	347
Chile	—	—	57	120
Colombia	26	132	1,868	248
Guinea-Bissau	—	—	945	109
Italy	—	—	31	202
Japan	70	311	97	25
Mexico	102	47	258	100
Netherlands	—	—	20	55
Senegal	—	—	400	50
United Kingdom	—	—	18	28
Venezuela	16	12	3,490	184
Other[2]	—	—	59	78
Total	246	607	9,709	[3]1,622

[1]Less than 1/2 unit.
[2]Includes the Dominican Republic, the Federal Republic of Germany, India, and the Republic of South Africa.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF BARITE, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Crude barite:				
Canada	41	$8	11,281	$337
Chile	25,398	837	28,110	935
China	755,039	28,274	622,232	25,417
India	215,913	8,438	270,838	10,907
Japan	—	—	30	6
Mexico	32,021	1,238	11,331	440
Morocco	103,491	4,643	1,228	172
Peru	—	—	42,380	1,541
Thailand	—	—	—	
Other	—	—	23	13
Total	1,131,903	43,438	987,452	39,768
Ground barite:				
Belgium-Luxembourg	64	28	38	22
Canada	8,863	2,240	7,802	2,455
China	35	6	—	
Czechoslovakia	—	—	20	3
France	646	219	575	172
Germany, Federal Republic of	256	119	277	138
Japan	36	81	7	5
Mexico	3,388	515	37,509	1,931
Morocco	—	—	—	
Netherlands	483	196	394	185
Other	—	—	—	
Total	[2]13,772	3,403	46,622	4,911

[1]C.i.f. value.
[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

Pakistan

The Government has allocated two large grants to Saindek Integrated Mineral Development Project, in Chaghai District, Baluchistan, and the other to the Geological Survey.[12] Future growths in production were noted for many industrial minerals, including barite.

United Kingdom

A new barite deposit at Cluniemore, approximately 8 kilometers north of the Foss Barite Mine, was announced by Magcobar Minerals-Eimco, a subsidiary of Dresser Industries Inc. The new deposit has estimated reserves of more than 15 million tons of barite. The Foss Mine and the new deposit are strategically important to the North Sea offshore drilling efforts that consume 200,000 tons of barite per year. Chinese and Moroccan barites are the main competitors for this market.

CURRENT RESEARCH

An indepth review was published on the industrial minerals of Brazil, which includes detailed sections on barite, local geology, reserves, mineralogy, mining and milling flowsheets, indigenous mining methods, and markets.[13] The report also highlighted the Brazilian mining laws and barite production statistics by region and State. A noteworthy feature on the individual barite mining companies and their long-term goals was of particular interest. A technical article on drilling for oil and gas in the U.S. Gulf of Mexico was published.[14] This publication stressed the importance of the Gulf of Mexico to the U.S. oil and gas production, the geology of deepwater versus shallow water exploration, and the structure of the drilling fluids industry not only in the gulf but also nationally. A highlight of the work was the tables listing the minerals used in drilling fluids, their average consumption rates, technical rationale for use, and the general classification methods for water-, salt-, and oil-base systems employed in drilling.

A review of Canadian barite beneficiation schemes was outlined.[15] A map pinpointing Canada's barite mines and tables summarizing beneficiation techniques, principal flotation parameters, collector concentration data for rougher flotation, reagent facts, and analyses of heads and concentrates were features of the publication. Brief sections on mineralogy,

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF BARIUM CHEMCIALS

Year	Lithopone		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)	Quantity (metric tons)	Value[1] (thousands)
1985	NA	NA	8,138	$6,295	2,575	$1,125	5,178	$3,959
1986	NA	NA	9,479	8,530	1,741	733	4,468	3,960
1987	NA	NA	10,405	8,586	1,795	775	4,760	4,147
1988	NA	NA	23,326	8,754	4,188	834	8,558	4,109
1989	NA	NA	10,638	8,945	1,477	702	4,644	5,335

	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)
1985	1,215	$643	11,301	$5,400	1,445	$2,556
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	—	—

NA Not available.
[1]C.i.f. value.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF WITHERITE[1]

Year	Quantity (metric tons)	Value[2] thousands)
1985	129	$74
1986	133	78
1987	396	144
1988	1,213	253
1989	76	30

[1]Barium carbonate.
[2]C.i.f value.

Source: Bureau of the Census no longer reports crude and ground witherite separately.

gravity concentration, flotation, physicochemical considerations for collectors, absorption, and depressant mechanisms were noteworthy additions to the barite mineral dressing literature.

The chemical properties and origin of high-temperature oxide superconductors, generally $Ba_2YCu_3O_7$, yttrium barium copper oxide and its analogs, were reviewed.[16] This theoretical study reveals the dependence of copper-bearing or cuprate superconductors on the barium ions not only for charge considerations but also for the superconducting mechanism to function.

OUTLOOK

Domestic demand for barite is expected to recover slowly at an annual rate of between 1% and 2% through 1995. Primary barite production should approach 500,000 tons per year by 1995 and the apparent consumption of barite in this period should be in the vicinity of 2.0 million tons.

The atmosphere for the past 10 years has seen volatile crude oil prices depress oil- and gas-exploration drilling activity. Little gas and oil reserves have been added to the national inventory. Principal drilling areas continue to be offshore rigs in the Gulf of Mexico and California. Most of the onshore wells are in the Overthrust Belt in Wyoming and the Anadarko Basin in Oklahoma. Drilling activities in these areas, however, appear to have focused in the past few years on the search for gas reserves at the expense of oil because of its economic uncertainties. Recent statistics[17] show in the past 3 years, 1987-89, gas-well-drilling footage has increased from about 50% to 80%. The domestic oil- and gas-exploration industry has not enjoyed the steady economic growth the Nation has enjoyed for the past 8 years. In addition, the uncertainty of alternate fuels as a political solution to national air pollution standards has clouded the future of the oil industry. It is anticipated that inroads of alternate fuels, such as alcohol and electric-power systems, will be challenged by the 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 of petroleum products.

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.

TABLE 14

WORLD BARITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand metric tons)

Country	Rated capacity[1]
Afghanistan	3
Algeria	109
Argentina	64
Australia	23
Austria	1
Belgium	41
Bolivia	2
Brazil	154
Burma	9
Canada	73
Chile	109
China	1,633
Colombia	5
Czechoslovakia	64
Egypt	5
Finland	11
France	154
German Democratic Republic	36
Germany, Federal Republic of	204
Greece	9
Guatemala	4
India	590
Iran	181
Ireland	181
Italy	136
Japan	64
Kenya	5
Korea, North	91
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 standby basis.

TABLE 15

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Afghanistan[e 3]	2,000	2,000	2,000	2,000	2,000
Algeria	60,000	60,000	[e]60,000	[e]60,000	60,000
Argentina	[r]55,753	58,617	33,462	48,872	40,000
Australia	22,423	5,818	10,363	10,970	10,000
Belgium[e]	40,000	40,000	40,000	35,000	40,000
Bolivia	1,282	129	1,337	—	6,000
Brazil	142,575	103,072	102,345	85,287	95,000
Burma[4]	8,100	8,149	17,273	13,000	20,000
Canada	71,000	40,000	42,000	51,000	[5]42,000
Chile	54,494	53,121	52,109	43,135	40,000
China[e]	1,000,000	1,000,000	1,250,000	1,500,000	1,750,000
Colombia	5,050	4,198	4,189	[e]4,000	4,000
Czechoslovakia[e]	60,000	60,000	60,000	60,000	60,000
Egypt	4,426	[e]4,500	4,116	5,651	5,000
Finland	8,690	6,969	11,000	[e]11,000	10,000
France	120,800	116,400	104,050	[e]100,000	100,000
German Democratic Republic[e]	34,000	34,000	32,000	32,000	30,000
Germany, Federal Republic of	171,269	201,565	173,356	[e]167,000	160,000
Greece[6]	3,283	2,305	2,227	2,300	2,300
Guatemala	3,703	750	—	2,415	2,000
India	579,742	344,000	247,000	393,000	395,000
Iran[e]	90,000	90,000	90,000	90,000	90,000
Ireland	213,800	127,500	70,000	83,000	85,000
Italy	128,356	[r]114,132	81,643	85,650	85,500
Japan	76,665	52,848	31,625	—	([5])
Kenya	255	420	50	48	50
Korea, Republic of	2,785	3,778	2,942	2,573	2,800
Malaysia	23,394	17,677	38,935	38,766	36,500
Mexico	467,693	321,186	401,336	534,954	[5]566,000
Morocco	500,000	189,881	143,503	321,562	320,000
Pakistan	29,932	39,047	10,031	22,198	20,000
Peru	21,661	9,945	8,354	8,500	8,400
Philippines	—	—	—	349	500
Poland	91,000	77,100	73,100	[e]75,000	75,000
Portugal	1,094	120	660	1,720	1,200
Romania[e]	75,000	75,000	72,000	72,000	70,000
South Africa, Republic of	4,387	8,653	8,617	8,735	8,800
Spain	67,512	49,100	33,761	[e]20,000	20,000
Thailand	230,970	142,232	33,370	40,587	40,000
Tunisia[e]	20,000	20,000	[5]14,412	14,000	14,000
Turkey	220,497	309,568	294,481	387,733	460,000
U.S.S.R.[e]	540,000	540,000	540,000	540,000	540,000
United Kingdom	107,344	86,754	81,360	76,028	80,000
United States[7]	670,000	269,000	406,000	404,000	[5]290,000
Yugoslavia	35,488	18,250	19,270	23,350	22,000
Zimbabwe	400	298	191	3,400	3,000
Total	[r]6,066,823	[r]4,708,082	4,704,468	5,480,783	5,712,050

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through May 23, 1990.

[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]Data are for fiscal year beginning Apr. 1 of that stated.

[5]Reported figure.

[6]Barite concentrates.

[7]Sold or used by producers.

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 its different uses. Material for weighting muds must be finely ground, heavy, and chemically inert; consequently, barite for this purpose must have a specific gravity of 4.2 or higher, it must be free of soluble salts, and 90% to 95% of the material must pass through a 325-mesh screen. A small percentage of iron oxide is not objectionable. In chemical manufacturing, purity is the principal concern, and a maximum of 1% each of ferric oxide (Fe_2O_3) and strontium sulfate ($SrSO_4$) and a trace of fluorine usually are specified, with a minimum of 94% barium sulfate ($BaSO_4$). If the mineral is to be used in the production of lithopone, the $SrSO_4$ content may be somewhat higher. Mesh size is important to chemical manufacturers; if the material is too fine, dust is lost, and if it is too coarse, mixing with carbonaceous material is poor. Most chemical manufacturers specify a size range of 4 to 20 mesh; some purchase lump barite and grind it to their own needs.

Glass manufacturers usually require a minimum of 95% $BaSO_4$ with a maximum of 2.5% silicon dioxide (SiO_2) and 0.15% Fe_2O_3. The particle size range generally preferred is −30 to +140 mesh. 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 90% of total U.S. consumption in 1989. Drilling muds have five main functions: (1) Transport drill cuttings to the surface, (2) control formation pressures, (3) maintain borehole stability, (4) protect producing zones, and (5) cool and lubricate the bit and drill string. 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 less than 10% of total U.S. consumption in 1989. 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 material where a degree of purity higher than natural barite is required. Lithopone, 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. It is used as a "getter" to remove traces of gas from vacuum tubes. It also is used 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 peroxide is manufactured from barium oxide.

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 was begun in Missouri. In 1880, Tennessee became the third barite-producing State, and 1901 and 1903 saw Georgia and Kentucky, respectively, become producers. California came into production in 1914, Nevada in 1916, and Arkansas in 1941.

Barite's first use was as a filler in white paints; however, in 1842, with the advent of the domestic lithopone (a white pigment composed of a mixture of barium sulfate, zinc sulfide, and zinc oxide) industry, a second important market was 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 ($BaCO_3$) was formerly produced from the Settlingstones Mine in England. 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 in the Western States are postulated to be of epithermal origin. The Eastern and Midwestern vein deposits are thought to be of hydrothermal or telethermal origin.

In central Missouri, barite occurs in circular deposits in karst or collapse and sink structures. These ores are rich, but the deposits are generally small in overall extent. These deposits are also important as the source of the residual ore upon weathering.

Residual barite deposits are formed by weathering of preexisting deposits. The principal residual deposits are found in southeastern Missouri; the Appalachian region; Sweetwater, TN; Cartersville, GA; and in the Rio Grande area of Texas. A concentration of at least 100 to 300 pounds of barite per cubic yard is required in a commercial deposit. In Washington County, MO, the residuum is 10- to 15-feet thick, while in Cartersville, GA, the ore is 150-feet thick in some spots. This form of deposit has been of considerable economic significance.

The most important commercial deposits are of bedded barite. These are principally in Arkansas, California, and Nevada.[18] 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 as yet 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.

Barite grinding is usually accomplished by heated airswept Raymond mills; 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. Also, barite to be bleached for filler use is ground wet; 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.[19] 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.

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BAUXITE, ALUMINA, AND ALUMINUM

By Errol D. Sehnke and Patricia A. Plunkert

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BAUXITE AND ALUMINA

World production of bauxite and alumina rose during 1989 to record high levels in response to a strong but moderating demand for primary aluminum metal. Mine production of bauxite was reported from 26 countries. Domestic consumption of bauxite increased significantly, with the majority of the increase driven by metal market requirements for primary aluminum. Within the specialty materials area, consumption of abrasive grade bauxite was comparable with 1988 usage, but bauxite consumption by the chemical and refractory industries declined in 1989. Demand for alumina was strong but weakened at the end of the year, easing the tight supply situation that had developed in the past several years. U.S. production and shipments of cell-grade alumina increased, while specialty alumina production and shipments declined sharply during the year. Alumina was produced in 25 countries.

Legislation and Government Programs

On September 1, 1989, the Environmental Protection Agency (EPA) presented its final rule on the list of specific solid wastes from ore and mineral processing that would remain within the Bevill exclusion amendment to the Resource Conservation and Recovery Act (RCRA) as special wastes. Red and brown muds generated in the bauxite refining process were among five processing waste streams that were found to satisfy all of the special waste criteria for exclusion from regulation as hazardous wastes under subtitle C of RCRA.[1]

The EPA proposed to delete nonfiberous aluminum oxide from the list of toxic chemicals contained in the Superfund Amendments and Reauthorization Act passed by Congress in October 1986; final removal of the toxic chemical designation was expected to occur in early 1990.

The National Defense Stockpile (NDS) goals for bauxite remained unchanged at 21.3 million metric tons of Jamaica-type and 6.2 million tons of Suriname-type metallurgical grade bauxite. Goals for calcined refractory grade and abrasive grade bauxite were 1.4 million and 1 million tons, respectively. The Defense Logistics Agency, 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. The NDS contained 279,000 tons of calcined refractory grade bauxite and no stocks of abrasive grade bauxite at the close of 1989.

Production

Bauxite was produced from surface mining operations in Alabama, Arkansas, and Georgia. At Bauxite, AR, the Aluminum Co. of America (Alcoa) mined bauxite for use in the manufacture of proppants for the petroleum industry and processed crude ore at the company's local alumina plant to produce specialty aluminum oxides and hydroxides. Alcoa announced that its mining and refining operations in Arkansas were scheduled for permanent closure in 1990, but that the alumina chemical products production would continue at this location using alumina feedstocks from other company facilities. 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 in Eufaula, AL. Mullite Co. of America (Mulcoa) mined bauxite in Alabama and Georgia, which was shipped to Mulcoa's processing plant in Andersonville, GA, for the production of refractory materials.

Martin Marietta Corp.'s 635,000-ton-per-year alumina plant on the Is-

TABLE 1

SALIENT BAUXITE STATISTICS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Production: Crude ore (dry equivalent)	674	510	576	588	W
Value[e]	12,855	10,361	10,916	10,566	W
Exports (as shipped)	56	69	201	63	44
Imports for consumption[1]	7,158	6,456	9,156	9,944	10,666
Consumption (dry equivalent)	8,206	6,901	9,548	10,074	11,805
World: Production	84,189	[r]87,751	91,724	[p]97,946	[e]105,029

[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.

land of St. Croix in the U.S. Virgin Islands was purchased in April by Clarendon Ltd., an aluminum trading group based in Switzerland. Damage caused by Hurricane Hugo hampered efforts to restart the facility, which had been idle since 1985. The new owners announced that the refinery, renamed Virgin Islands Alumina Inc. (Vialco), should be operational in the first quarter of 1990.

Reynolds Metals Co. announced plans to spend approximately $50 million over the next 2 years to increase the efficiency of its 1.7-million-ton-per-year alumina plant near Corpus Christi, TX.

Consumption and Uses

A continued strong demand for cell-grade alumina propelled consumption of crude and dried metallurgical grade bauxite to a level well above that of 1988. Most of this increase was supplied from imports. Consumption of bauxite by the abrasive industries was essentially unchanged during 1989, while consumption by the chemical and refractory industries decreased for the year. About 90% of the bauxite consumed in the United States was refined to alumina, and an estimated average of 2.31 tons of dried bauxite was required to produce 1 ton of calcined alumina. Twenty-two primary aluminum smelters reported consumption of 8 million tons of calcined alumina in 1989. An estimated 97% 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 other industries accounted for the balance of the alumina usage.

Prices

Contract terms for the purchase of metallurgical grade bauxite and cell-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 1989, the 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 $132 per ton. Base

TABLE 2

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]
1987	689	576	10,916	756	680	22,173
1988	714	588	10,566	770	688	24,703
1989	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 Bureau of Mines.

TABLE 3

PERCENT OF DOMESTIC BAUXITE SHIPMENTS, BY SILICA CONTENT

SiO_2 (percent)	1985	1986	1987	1988	1989
Less than 8	74	77	70	71	88
From 8 to 15	14	—	7	5	7
More than 15	12	23	23	24	5

TABLE 4

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]				
1985	2,860	860	3,725	3,465
1986	2,570	750	3,320	3,105
1987	3,555	830	4,385	4,150
1988	3,885	1,110	4,995	4,575
1989	4,580	285	4,860	4,670
Shipments:[e]				
1985	2,890	760	3,650	3,425
1986	2,590	740	3,330	3,120
1987	3,530	845	4,375	4,135
1988	4,645	1,115	5,760	5,340
1989	4,665	605	5,270	4,815

[e] Estimated.
[1] Data may not add to totals shown because of independent rounding.
[2] Trihydrate, activated, tabular, and other aluminas. Excludes calcium and sodium aluminates.
[3] Includes only the end product if one type of alumina was produced and used to make another type of alumina.

TABLE 5

CAPACITIES OF DOMESTIC ALUMINA PLANTS,[1] DECEMBER 31

(Thousand metric tons)

Company and plant	1987	1988	1989
Aluminum Co. of America:			
Bauxite, AR	340	340	340
Point Comfort, TX	1,735	1,735	1,735
Total	2,075	2,075	2,075
Kaiser Aluminum & Chemical Corp.: Gramercy, LA	795	795	795
Ormet Corp.: Burnside, LA	—	545	545
Reynolds Metals Co.: Corpus Christi, TX	1,700	1,700	1,700
Grand total	4,570	5,115	5,115

[1] Capacity may vary depending on the bauxite used.

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, $90 to $130 per ton; and Guyanese, f.o.b. rail car, Baltimore, MD, or f.o.b. barge, Gulf Coast, $164.28 per ton. Abrasive grade bauxite, minimum 86% Al_2O_3, c.i.f. main European port, was priced at $95 to $108 per ton. Base prices were subject to adjustment for various grain-size specifications, size of order, and fuel cost factors.

The average value of domestic calcined alumina shipments was estimated to be $310 per ton. Trade data released by the Bureau of the Census indicated the average value of imported calcined alumina was $280 per ton, f.a.s. port of shipment, and $295 per ton, c.i.f. U.S. ports.

Foreign Trade

Dried bauxite exports totaled 18,900 tons in 1989, a continuation of the sharp downward trend recorded in 1988. Canada received 15,700 tons; Mexico, 1,300 tons; and Algeria, 1,000 tons. U.S. exports of calcined refractory grade bauxite totaled 12,000 tons for 1989. Mexico received 8,900 tons

TABLE 6

U.S. CONSUMPTION OF BAUXITE, BY INDUSTRY

(Thousand metric tons, dry equivalent)

Industry	Domestic	Foreign	Total
1988:			
Alumina	[1] 506	[1] 8,738	8,970
Abrasive[2]	W	W	274
Chemical	W	W	236
Refractory	[3] 140	[3] 690	524
Other	W	W	70
Total	646	9,428	10,074
1989:			
Alumina	W	[1] 10,538	10,782
Abrasive[2]	W	W	275
Chemical	W	W	223
Refractory	W	[3] 727	402
Other	W	W	123
Total	540	11,265	11,805

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."

TABLE 7

U.S. CONSUMPTION OF CRUDE AND PROCESSED BAUXITE

(Thousand metric tons, dry equivalent)

Type	Domestic origin	Foreign origin	Total
1988:			
Crude and dried	W	W	9,259
Calcined and activated	W	W	815
Total	646	9,428	10,074
1989:			
Crude and dried	W	W	11,104
Calcined and activated	W	W	701
Total	540	11,265	11,805

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

TABLE 8

PRODUCTION AND SHIPMENTS OF SELECTED ALUMINUM SALTS IN THE UNITED STATES IN 1988

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)	79	1,118	1,057	$123,007
Iron-free (17% Al_2O_3)	24	125	123	15,547
Aluminum chloride:				
Liquid and crystal	3	W	W	W
Anhydrous (100% $AlCl_3$)	4	W	W	W
Aluminum fluoride, technical	3	W	W	W
Aluminum hydroxide, trihydrate (100% $Al_2O_3 \cdot 3H_2O$)	7	587	662	159,953
Aluminates	15	61	64	27,603
Other aluminum compounds[1]	NA	NA	NA	90,337

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 1988 Current Industrial Reports, Series MA-28A, "Inorganic Chemicals."

TABLE 9

STOCKS OF BAUXITE IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, dry equivalent)

Sector	1988[r]	1989
Producers, processors, and consumers	3,021	2,891
Government	18,474	18,474
Total	21,495	21,365

[r]Revised.
[1] Domestic and foreign bauxite; crude, dried, calcined, activated; all grades.

TABLE 10

STOCKS OF ALUMINA IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, calcined equivalent)

Sector	1988[r]	1989
Producers	[e]710	[e]601
Primary aluminum plants	1,252	1,346
Total	[e]1,962	[e]1,947

[e] Estimated. [r] Revised.
[1] Excludes consumers' stocks other than those at primary aluminum plants.

and Canada 1,900 tons. Exports of all other grades of calcined bauxite (chiefly abrasive grade) amounted to 12,900 tons for the year. Canada received 8,600 tons and Venezuela 4,200 tons. Specialty aluminum compounds exported included 940 tons of aluminum sulfate, 17,200 tons of aluminum oxide abrasives, and 34,300 tons of various fluoride-based compounds of aluminum, including synthetic cryolite and aluminum fluoride.

Imports for consumption of crude and dried bauxite increased from 1988 receipts, and the three traditional primary suppliers, Guinea, Jamaica, and Australia, in order of shipments, provided most of the total. Brazil's shipments to the United States increased sharply, and it greatly strengthened its fourth place ranking.

World Review

World production of bauxite and alumina continued the upward trends that began in the mid-1980's. Twenty-six countries mined bauxite in 1989, and the total world production of bauxite reached a record 105 million tons, an increase of 7% over 1988 produc-

TABLE 11

AVERAGE VALUE OF U.S. IMPORTS OF CRUDE AND DRIED BAUXITE[1]

(Per metric ton)

Country	1988		1989	
	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. mainland:				
Australia	$14.75	$22.42	$15.94	$25.37
Brazil	25.55	33.72	31.22	40.59
Guinea	22.89	29.63	30.85	38.62
Guyana	30.53	42.84	30.15	42.06
Jamaica	29.25	33.70	26.23	30.82
Suriname	34.15	48.04	—	—
Weighted average	23.90	30.34	26.89	34.44

[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 12

MARKET QUOTATIONS ON ALUMINA AND ALUMINUM COMPOUNDS

(Per metric ton, in bags, carlots, freight equalized)

Compound	Dec. 30, 1988	Dec. 29, 1989
Alumina, calcined	$418.88	$418.88
Alumina, hydrated, bulk	209.44	278.88
Alumina, activated, granular, works	905.00	905.00
Aluminum sulfate, commercial, ground,(17% Al_2O_3)	239.20	253.53
Aluminum sulfate, iron-free, dry (17% Al_2O_3)	369.27	358.25

Source: Chemical Marketing Reporter.

TABLE 13

U.S. EXPORTS OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	1	629	1	740	1	849
Belgium-Luxembourg[2]	2	2,543	3	2,955	5	5,292
Brazil	75	10,789	115	19,780	20	6,966
Canada	575	89,890	509	91,337	942	257,466
France	1	2,005	1	1,422	3	2,225
Germany, Federal Republic of	1	2,989	2	3,372	2	7,216
Ghana	270	38,942	183	27,854	125	22,579
Japan	24	8,162	20	7,491	23	19,842
Mexico	150	32,431	175	35,341	150	56,280
Netherlands	2	2,274	3	3,520	8	9,709
Sweden	(3)	106	(3)	323	27	5,634
United Kingdom	2	2,134	6	3,448	2	4,471
Venezuela	2	1,512	4	3,028	3	2,008
Other	22	[r]13,618	[r]15	[r]15,495	17	19,388
Total[4]	1,127	[r]208,026	1,036	216,107	1,328	419,924

[r] Revised.
[1] Includes exports of aluminum hydroxide (calcined equivalent) as follows: 1987—18,727 tons; 1988—15,656 tons; and 1989—33,316 tons.
[2] For 1987, Belgium and Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.
[3] Less than 1/2 unit.
[4] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

tion. Australia, Guinea, Jamaica, and Brazil, in order of volume, accounted for 70% of the total bauxite mined during the year. The corresponding world output of alumina rose to nearly 39 million tons, also a new production record, and was 6% greater than the 1988 production level. Three countries, Australia, the U.S.S.R., and the United States, contributed nearly 50% of the total world production.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF BAUXITE, CRUDE AND DRIED,[1] BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989
Australia	1,167	1,612	1,535
Brazil	451	792	1,373
China	5	20	69
Dominican Republic[2]	70	33	—
Ghana	36	—	—
Guinea	4,256	4,526	3,390
Guyana	244	225	379
Indonesia	—	39	306
Jamaica[2]	2,799	2,654	3,330
Malaysia	23	12	59
Sierra Leone	—	29	167
Suriname	104	3	—
Other	—	—	58
Total[3]	9,156	9,944	10,666

[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: 1987—9,827,818 tons; 1988—10,498,913 tons; and 1989—11,346,182 tons.

Source: Bureau of the Census and The Jamaican Bauxite Institute.

Capacity.—A slight increase in the annual rated capacity of plants producing alumina helped to alleviate the shortages of cell-grade alumina required for the production of primary aluminum that had developed in recent years.

Australia.—In 1989, the world's largest bauxite and alumina producing country achieved new production records for the seventh consecutive year.

The Comalco Ltd. mining operations at Weipa, Queensland, operated at full annual rated capacity during the year and produced about 9.7 million tons of bauxite. Comalco announced that, in addition to the main production based on standard metallurgical grade bauxite and about 250,000 tons a year of abrasive grade product, trial shipments of cement grade, chemical grade, and trihydrate bauxite were made to markets in the United States and Europe. The Queensland Alumina Ltd. alumina plant at Gladstone reported that it was expanding its capac-

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF CALCINED BAUXITE, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1988				1989			
	Refractory grade		Other grade		Refractory grade		Other grade	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	—	—	20	1,788	—	—	8	570
China	103	6,696	152	8,765	176	10,044	147	8,218
Guinea	—	—	—	—	—	—	114	3,036
Guyana	98	12,948	15	836	74	10,871	96	3,449
Malaysia	—	—	—	—	—	—	113	1,073
Suriname	5	175	—	—	—	—	—	—
Other	(2)	15	(2)	7	5	292	26	1,233
Total[3]	206	19,834	188	11,396	254	21,207	505	17,579

[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.

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1987		1988		1989	
	Quantity	Value[2]	Quantity	Value[2]	Quantity	Value[2]
Australia	3,361	431,041	3,532	562,479	3,603	915,113
Brazil	25	4,977	65	15,574	44	21,465
Canada	59	25,078	91	39,241	154	69,711
France	7	13,825	6	14,740	5	13,369
Germany, Federal Republic of	14	20,922	20	27,328	20	30,576
Guinea	13	2,484	—	—	—	—
India	—	—	79	1,761	36	8,916
Israel	25	3,612	—	—	—	—
Italy	20	3,037	(3)	783	(3)	386
Jamaica	90	13,107	201	47,890	217	92,144
Japan	6	6,688	7	8,503	8	13,109
Suriname	324	40,568	417	77,124	209	52,124
Venezuela	111	13,936	207	34,286	1	136
Other	13	2,586	8	22,142	15	11,075
Total[4]	4,068	581,864	4,634	851,851	4,311	1,228,123

[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.

ity from 3 million to 3.3 million tons per year of alumina by "sweetening" the refining process with trihydrate bauxite from Comalco's Weipa operations, the sole source of the refinery's bauxite feed.

The Gove bauxite-alumina project in the Northern Territories, managed by Nabalco Pty. Ltd., produced 6 million tons of bauxite and 1.45 million tons of alumina in 1989. Participants in this project released plans to increase the alumina plant capacity at Gove by 150,000 tons per year.

Alcoa of Australia Ltd. announced that it planned to proceed with the second stage of its Wagerup alumina plant expansion in Western Australia. The 630,000-ton expansion would double the capacity at the refinery and was part of a two-stage program to increase the total alumina output at Alcoa's three Australian refineries (Wagerup, Kwinana, and Pinjarra) from 5.5 million to 6.1 million tons per year.

The U.S. International Trade Commission determined on March 21, 1989, under Section 735(b) of the Tariff Act of 1930, that U.S. industry was not materially injured or threatened with material injury by imports of calcined proppants from Australia that were found to have been sold in the United States at less than fair market value.[2]

Brazil.—Mineração Rio do Norte S.A. (MRN), the world's third-largest bauxite producer and exporter, reported it had begun an expansion program at its Trombetas mining operation in Pará State that would increase mine capacity from 6.5 million to 8.5 million tons per year. MRN indicated that the main focus of this program was the transfer of its existing ore-crushing and -washing facilities to sites within the proximity of active mine workings, plus the construction of a new system for tailings thickening and disposal.

The state-owned mining company Cia. Vale do Rio Doce announced preparation of a feasibility study for a new bauxite mining operation at Jabuti in the Paragominas region of Pará State.

Mineração Santa Lucrecia S.A. (MSL) indicated that the new refractory bauxite beneficiation plant it was installing at its Caracuru mine in the Almeirim district of Pará State would have a capacity of 200,000 tons per year of green bauxite product. MSL stated that construction had also commenced on a 60,000-ton-per-year production capacity rotary calciner near the Jari River port of Munguba, and the plant was expected to be operational in early 1990.

Companhia Brasileira de Alumínio (CBA) announced that the new alumina and aluminum plants it was installing near its existing complex at Sorocaba, in São Paulo State, would utilize bauxite supplied by the company's 850,000-ton-per-year Poços de Caldas mines in Minas Gerais. CBA indicated that it planned to rely on the newly discovered bauxite reserves near Cataguazes in Rio de Janeiro State to supply the Sorocaba operations following the depletion of the ore reserves at Poços de Caldas.

Canada.—Alcan Aluminium Ltd. announced that a solar drying method of red-mud disposal was introduced at its Vaudreuil alumina plant in Quebec to provide a more environmentally compatible method for handling these mineral processing wastes.

Germany, Federal Republic of.—In mid-1989, Vereinigte Aluminium-Werke AG (VAW) announced its withdrawal from tabular alumina production in the Federal Republic of Germany.

Guinea.—Compagnie des Bauxites de Guinée (CBG) produced about 11.2 million tons of the total bauxite mined. CBG reportedly achieved this production despite infrastructure problems due to working beyond normal rated capacity.

Hydro Aluminium A/S of Norway announced that it bought a 20% share in Frialco, the 51% owner of the bauxite and alumina company, Frigua. The new shareholder structure for Frialco was reported as follows: Pechiney 30%, Noranda 30%, Alcan 20%, and Hydro 20%.

A modernization project, financed by the European Community, was reportedly started by Frigua at its Kimbo bauxite-alumina complex.

Guyana.—The decline in bauxite production recorded for 1989 was partially due to a 7-week strike by bauxite workers at the state-owned Guyana Mining Enterprise Ltd. (Guymine).

The Government of Guyana and Reynolds International Inc., a wholly owned subsidiary of Reynolds Metals, reported the signing of an agreement to mine and market bauxite from deposits at Aroaima in the Berbice region of Guyana.

Norway's Hydro Aluminium and Kaiser Aluminum & Chemical Corp. of the United States reportedly participated in a feasibility study conducted for the state-owned Bauxite Industry Development Corp. to determine what would be required to reopen the Linden alumina plant that had been closed since 1982. It was reported that an estimated $106 million would be required to restart the idled refinery.

The U.S. firm Green Mining Inc. announced that it began work under an 18-month contract with the Government to remove 1.3 million cubic meters of overburden and mine approximately 800,000 tons of metallurgical grade bauxite at Linden. Green Mining reported that it had delivered its first shipment of bauxite to Guymine in mid-September.

At yearend, Alcan Aluminium announced the signing of an agreement to study the feasibility of renovating Guyana's bauxite production and marketing operations at Linden.

India.—Bharat Aluminium Company announced the closure of its bauxite mining project in the Gandhamardhan Hills, Orissa State, because of strong environmental opposition by the local population. Heightened environmental awareness prompted the Indian State-owned National Aluminium Co. to publicize the environmental preservation and restoration programs developed for their bauxite mining areas.

Italy.—Clarendon Ltd. reportedly bought an 18% interest in Eurallumina SpA the owner-operator of the 720,000-ton-per-year alumina plant at Porto Veseme, Sardinia. This reduced the share of ownership held by the State-owned Allumina SpA from 62.5% to 52.1% and that of the Australian-owned Comalco from 37.5% to 29.9%.

Jamaica.—The Alumina Partners of Jamaica (Alpart) alumina plant at Nain, owned by Kaiser Aluminum (65%) and Hydro Aluminium (35%), restarted operations in April after being closed since 1985.

Plans to increase the capacity of the

Jamalco alumina plant in central Jamaica, jointly owned by the Government and Alcoa, were reportedly delayed by technical problems following a strike and 2-week shutdown in July and August.

Suriname.—The Suriname Aluminum Co. mining operations at Moengo reportedly experienced a brief shutdown in October due to civil strife and ethnic violence associated with the continuing political conflict and insurgent rebel action that had troubled the country in recent years.

Sweden.—On March 27, 1989, the U.S. International Trade Commission determined there was no reasonable indication that U.S. industry was materially injured or threatened by imports of dry aluminum sulfate from Sweden that had been allegedly sold within the United States at less than fair value.[3]

Venezuela.—The U.S. Department of Commerce reported on October 18, 1989, that aluminum sulfate imports from Venezuela had been subsidized and sold in the United States at less than fair market value.[4] In December, the U.S. International Trade Administration determined that U.S. industry was materially injured by the imports of aluminum sulfate from Venezuela and these imports were liable for assessment of antidumping and countervailing duties.[5]

TABLE 17

BAUXITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia	31,839	32,384	34,102	36,192	[2]38,583
Brazil	5,846	6,544	6,567	7,728	8,500
China[e]	1,650	1,650	2,400	3,500	4,000
Dominican Republic[3]	—	—	211	106	[2]164
France	1,530	1,379	1,271	878	800
Germany, Federal Republic of	([4])	([4])	—	—	—
Ghana	170	226	230	300	[2]375
Greece	2,453	2,230	2,472	[e]2,400	2,400
Guinea[e 5]	11,790	13,300	13,500	15,600	[2]16,523
Guyana[3]	[e]1,675	2,074	2,785	1,774	[2]1,281
Hungary	2,815	3,022	3,101	2,593	2,700
India	2,281	2,322	2,736	3,961	[2]4,768
Indonesia	830	650	635	513	[2]862
Italy	—	—	17	17	17
Jamaica[3 6]	6,239	6,944	7,660	7,408	[2]9,395
Malaysia	492	566	482	361	350
Mozambique	5	4	5	7	[2]6
Pakistan	2	3	3	2	[2]2
Romania[e]	600	600	600	600	[2]313
Sierra Leone	1,185	1,246	1,390	1,379	[2]1,500
Spain	2	3	1	2	3
Suriname	3,738	3,731	2,522	3,434	[2]3,530
Turkey	214	280	247	269	345
U.S.S.R.[e 7]	4,600	4,600	4,600	4,600	4,600
United States[3]	674	510	576	588	W
Venezuela	—	—	217	700	[2]760
Yugoslavia	3,538	3,459	3,394	3,034	[2]3,252
Zimbabwe	21	24	—	—	—
Total	84,189	[r]87,751	91,724	97,946	105,029

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1] Table includes data available through June 13, 1990.

[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: 1985—1,615; 1986—1,638; 1987—1,660; 1988—1,640; and 1989—1,600 (estimated). Estimated alunite ore production was as follows, in thousand metric tons: 1985—615; 1986—620; 1987—625; 1988—625; and 1989—600. 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.

Current Research

Exploratory research by the Bureau of Mines on high-temperature structural materials for new and emerging technologies demonstrated that hard, dense composite materials can be produced from metallic nitrides such as titanium or zirconium when combined with alumina (Al_2O_3) and aluminum nitride (AlN). Of these nitrides, titanium nitride (TiN) has shown the best results for meeting the high-performance demands placed upon this new class of advanced materials, and investigations have been conducted to characterize the physical properties of various combinations of ceramic particulate composites made from the system TiN-Al_2O_3-AlN.[6]

The Ames Research Center of the National Aeronautics and Space Administration reported the development of a rigid, fiberous refractory composite material called "alumina-enhanced thermal barrier" (AETB) that extends the high-temperature capability of insulating materials.[7] This improved fiberous ceramic tile material had a composition of 14% aluminoborosilicate fibers, 66% silica fibers, and 20% alumina fibers. Although it was intended primarily for use in the heat shield of the Space Shuttle orbiter, the new material had obvious potential for industrial usage in kilns, furnaces, heat engines, and other applications for which lightweight and high operating temperature are major requisites.

An improved method for the removal of iron from Bayer process solutions was developed for mixed gibbistic-boehmitic or boehmitic bauxites.[8] The removal of the iron oxide was achieved by passing the pregnant alumina plant liquors through a bed of activated sand

(washed and heated coarse red mud) that had a high iron oxide content, which promoted precipitation of iron from the solution.

Outlook

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, the added possibility of using lower grade bauxite deposits and other alternative sources of alumina, world resources of aluminum are adequate to meet demand for the foreseeable future.

As the costs of imported bauxite and alumina increase, alternate domestic sources of alumina may appear to become economically more attractive. On the other hand, high fuel prices tend to make nonbauxitic materials less competitive because the processes for treating alternate materials require considerably more energy than Bayer-processed bauxite. It therefore appears 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.

In the future, the structure of the aluminum industry was expected to see a continued 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. Imports of primary aluminum metal from countries with low electrical energy costs and secondary production from recycled aluminum was likely to be used in ever-increasing proportions to meet the domestic demand for aluminum.

TABLE 18

WORLD ANNUAL ALUMINA CAPACITY, BY COUNTRY

(Thousand metric tons)

Country	1987	1988	1989
Australia	9,750	10,000	10,850
Brazil	1,150	1,150	1,555
Canada	1,225	1,225	1,140
China	850	1,300	1,500
Czechoslovakia	100	100	100
France	1,040	1,040	700
German Democratic Republic	65	60	60
Germany, Federal Republic of	1,745	1,745	1,380
Greece	500	500	600
Guinea	700	700	700
Guyana	355	355	300
Hungary	920	920	920
India	675	1,000	1,580
Ireland	800	800	900
Italy	920	720	720
Jamaica	2,825	3,100	2,950
Japan	975	550	500
Romania	540	540	540
Spain	800	800	1,000
Suriname	1,350	1,350	1,400
Turkey	200	200	200
U.S.S.R.	4,600	4,600	4,600
United Kingdom	120	120	120
United States	4,570	5,115	5,115
Venezuela	1,000	1,300	1,300
Yugoslavia	1,635	1,635	1,570
Total	39,410	40,925	42,300

TABLE 19

ALUMINA: WORLD PRODUCTION,[1] BY COUNTRY[2]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia	8,792	9,423	10,109	10,518	[3]10,800
Brazil	1,096	1,258	1,326	[e]1,300	1,600
Canada	1,019	1,015	953	993	1,400
China[e]	825	825	1,200	[r]1,500	1,440
Czechoslovakia[e]	[r]75	[r]70	[r]75	[r]75	75
France	736	740	711	563	560
German Democratic Republic	47	46	51	64	60
Germany, Federal Republic of	1,657	1,560	1,313	1,145	1,200
Greece	380	470	518	514	521
Guinea	572	556	543	590	617
Hungary	798	856	858	873	870
India	587	586	650	1,188	[3]1,419
Ireland	555	686	784	843	865
Italy	555	618	700	708	700
Jamaica	1,622	1,586	1,572	1,522	[3]2,221
Japan	978	607	358	415	[3]466
Romania	548	555	584	[e]550	550
Spain[4]	725	748	801	[e]800	880
Suriname[4]	1,242	1,471	1,363	1,632	[3]1,567
Turkey	113	144	95	182	200
U.S.S.R.[e]	3,500	3,500	3,500	3,500	3,500
United Kingdom	110	[r]110	110	[e]110	110
United States[e]	3,465	3,105	4,150	[3]4,575	4,670
Venezuela	[e]1,085	1,269	1,381	[e]1,350	1,241
Yugoslavia	1,138	1,117	1,113	1,051	1,168
Total	[r]32,220	[r]32,921	34,818	36,561	38,700

[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 13, 1990.
[3]Reported figure.
[4]Hydrate.

ALUMINUM

Most primary aluminum smelters operated close to and, in some cases, above rated capacities during the year. Exports of aluminum in 1989 increased significantly for the second successive

year to a level that was more than twice that of 1986. A record 49.4 billion used beverage cans (UBC) were recycled in 1989, equivalent to more than 60% of the aluminum can shipments for the year. Prices decreased during the year as world supply and demand came into a more balanced position. World production of primary aluminum approached a record 18 million tons for the year.

Legislation and Government Programs

The U.S. Department of Transportation issued a notice of proposed rulemaking to regulate materials that are transported at elevated temperatures. The proposed changes to the Hazardous Materials Regulations (49 CFR 171-179) would communicate the hazards of these elevated temperature materials by means of marking, shipping papers, and placarding, and would prescribe package requirements. Molten aluminum was one of the materials that would be covered by these proposed changes.[9]

The Office of the U.S. Trade Representative published lists of materials that were under consideration for negotiations with the Canadian Government for accelerated tariff elimination under the United States-Canada Free-Trade Agreement Implementation Act of 1988. These lists included some articles of aluminum for which acceleration of tariff elimination had been requested in petitions submitted either to the Government of the United States or to the Government of Canada.[10]

Production

Primary.—Domestic primary aluminum production was the highest annual production level since 1984. Most smelters operated at or above their rated capacity levels during the year.

In September, a power outage, caused by Hurricane Hugo, damaged the Alumax Inc. 181,000-ton-per-year primary aluminum smelter in Mount Holly, SC. The outage froze metal in the smelter potlines, but company officials reported that structural damage to the plant was not extensive. The company estimated that it would be 20 weeks before full production could be resumed at the plant. However, by the end of the year, a full 10 weeks ahead of schedule, the company announced that repairs had been completed and the plant was back in full production.

Ravenswood Aluminum Corp. announced plans to restart a fourth potline at its smelter in West Virginia, raising the rated capacity of the plant to 166,000 tons per year. This potline had been shut down since April 1981.

Alumax and the United Steelworkers of America (USWA) completed early contract negotiations covering workers at the Frederick, MD, and Ferndale, WA, smelters. In March, a new contract, scheduled to expire on October 1, 1992, was signed by workers at the Frederick, MD, smelter, replacing the previous contract, which was set to expire on October 24, 1990. In November, workers at the Ferndale, WA, plant ratified a new 3-year contract that was scheduled to expire on September 30, 1993. The new Ferndale smelter contract replaced the previous contract that was scheduled to expire at the end of September 1990.

In April, Alcan Aluminum Corp. and the Aluminum, Brick, and Glass Workers International Union (ABGWIU) announced the ratification and signing of a new labor contract covering workers at the Sebree, KY, smelter. This contract took effect immediately and replaced the previous contract that was not scheduled to expire until October 28. The new contract reportedly included an initial pay increase of 4.25%, plus increases of 3.5% in 1990, and 3% in 1991. Additional cash bonuses were also reported to be included in this new contract that was scheduled to expire on October 28, 1992.

Workers at Noranda Aluminum Inc.'s New Madrid, MO, smelter walked off their jobs on September 1, after the previous labor contract expired. The company reported that production levels at the plant would be maintained by salaried personnel. While negotiations continued between the USWA and management, workers returned to their jobs in December without ratifying a new contract.

Alcan Aluminum announced the purchase of Jarl Extrusions Inc., a maker of custom aluminum extrusions. Jarl reportedly operated five presses and a remelt, billet casting center at Elizabethton, TN, and two presses at its facility in Franklin, NH.

Alcan Rolled Products Co., a division of Alcan Aluminum, announced plans to upgrade its sheet rolling facility at Oswego, NY. The $175-million program was reported to include a modernization of the hot rolling mill, a

TABLE 20

SALIENT ALUMINUM STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Primary production	3,500	3,037	3,343	3,944	4,030
Value	6,249,614	5,422,993	5,328,300	9,572,066	7,801,086
Price: Average cents per pound					
U.S. producer list	81.0	[1]81.0	NA	NA	NA
U.S. market (spot)	48.8	55.9	72.3	110.1	87.8
Secondary recovery	1,762	1,773	1,986	2,122	2,054
Exports (crude and semicrude)	908	753	917	1,247	1,613
Imports for consumption (crude and semicrude)	1,420	1,967	1,850	1,620	1,470
Aluminum industry shipments[2]	6,382	6,545	6,813	r6,851	6,857
Consumption, apparent	5,174	5,143	5,469	r5,373	4,959
World: Production	15,398	r15,413	16,385	p17,608	e17,980

e Estimated. p Preliminary. r Revised. NA Not available.
[1] Based on 7 months in 1986.
[2] Shipped to domestic industry.

new melting and casting center, a pusher furnace-preheat facility, a high-speed precision slitting line, and a new roll grinder.

Alcan Aluminum also announced plans to construct an aluminum cable plant in Roseburg, OR. The plant reportedly would be completed by 1991 and would produce transmission and distribution conductor cable as well as aluminum building wire.

Kaiser Aluminum announced plans to build an aluminum forgings plant in Greenwood, SC. The company reported that it would enlarge an existing building on the site and would produce aluminum forgings primarily for the automotive market. Kaiser Aluminum expected production to begin by the end of the year.

Reynolds Metals reported the purchase of Conductor Products Inc., a cable plant in Marshall, TX. The plant manufactured overhead cable and insulated underground cable products.

Reynolds Metals also announced plans for a $30 million expansion and modernization of aluminum plate capacity at its McCook, IL, rolling mill. The company anticipated that the 2-year program, which targeted larger shares of the aircraft and aerospace markets, would increase aluminum plate capacity by 16% to 80 million pounds per year and increase machining capacity for wing skins by 50%.

Logan Aluminum Inc. announced a major two-stage expansion program for its aluminum can stock mill in Logan, KY, that would double the plant's capacity. The first phase of the program included a 90-inch high-speed cold mill, a coating line, a slitting line, two ingot preheat furnaces, and an ingot scalper. The second phase reportedly included another cold mill plus a fourth stand added to the hot mill. Logan Aluminum was jointly owned by Atlantic Richfield Co. (Arco) and Alcan Aluminum.

Columbia Aluminum Corp., which owns a primary aluminum smelter in Goldendale, WA, announced several acquisitions of fabrication facilities. Columbia Aluminum reported the purchase of an extrusion plant in Rockwall, TX, from Alumax; extrusion facilities in City of Industry, CA, and City of Commerce, CA, from Indal Ltd.; and an extrusion plant in Modesto, CA, from Pacific Aluminum Corp.

TABLE 21

PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons)		1989 Ownership (percent)
	1988	1989	
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	
National-Southwire Aluminum Co.:			
Hawesville, KY	172	172	National Steel Corp., 50%; Southwire Co., 50%.
Noranda Aluminum Inc.:			
New Madrid, MO	204	204	Noranda Mines Ltd., 100%.
Northwest Aluminum Corp.:[1]			
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.:[2]			
Ravenswood, WV	110	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	3,960	4,016	

[1] Northwest Aluminum Corp. signed a lease-purchase agreement for The Dalles smelter with Martin Marietta Corp. in 1986.
[2] Purchased from MAXXAM Inc. in Dec. 1988.

VAW of America Inc. reported the purchase of Easco Corp.'s aluminum extrusion plant in Phoenix, AZ. The plant produced extrusions and pipes for the construction, building products, and consumer goods markets.

National Intergroup Inc. (NII), the parent company of National Aluminum Corp., announced the sale of its aluminum rolling and extrusions divisions. NII reported that Noranda had purchased a foil rolling mill in Newport, AR; a light-gauge foil mill in Salisbury, NC; and some laminating facilities in Ohio and Massachusetts. R. D. Werner announced the purchase of NII's custom extrusion plant in Anniston, AL.

Secondary.—According to a survey conducted by the Aluminum Association, the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, a record 49.4 billion aluminum UBC's were recycled in 1989, surpassing by almost 7 billion the number of UBC's recovered in 1988. The percentage of aluminum cans recycled in the United States increased from 54.6% of aluminum cans shipped in 1988 to 60.8% of can shipments in 1989.

Alcan Aluminum announced the opening of its new UBC recycling plant in Berea, KY. The company anticipated that the production from the 120,000-ton-per-year plant would be sent to the company's can sheet rolling mills in Henderson, KY, and Oswego, NY.

International Mill Service Inc. (IMS) reported that its UBC recycling plant in Hauser, ID, was operational. The plant reportedly had the capacity to convert at least 80 million pounds of UBC's and 40 million pounds of aluminum scrap per year into secondary metal, which could then be transported to Kaiser Aluminum's rolling facility in nearby Trentwood, WA. In addition, the IMS plant reportedly had the capability of processing 50 million pounds of aluminum dross annually.

Golden Aluminum Co. announced plans to construct a new continuous casting and rolling mill in San Antonio, TX. The plant reportedly would convert UBC's into 200 million pounds per year of beverage can body stock.

Secondary Aluminum Smelters Inc. announced the opening of a new 36-million-pound-per-year secondary smelter in Chattanooga, TN. Culp Industries Inc. announced the sale of its secondary smelter in Steele, AL, to Legett & Platt Inc., a producer of aluminum die-cast components for the home furnishing industry. In December, Apex International Alloys Co., a secondary aluminum smelter in Cleveland, OH, reported that the company had filed under Chapter 11 of the U.S. Bankruptcy Code.

American Recovery Technology Systems Inc. announced the completion of a closed-loop system for recycling secondary aluminum dross and salt cakes. Capacity of the system was reported to be 6 million pounds per month. The company said that the facility was designed to recover the salt flux and produce an exothermic flux for use by the steel industry and remelt secondary ingot producers.

Metal Mark Inc. announced plans to startup an aluminum dross processing plant late next year. The new company, to be located near Chicago Heights, IL, and to be named Columbia Aluminum Recycling Ltd., would reportedly become the fifth plant owned by Metal Mark.

Alcan Aluminium reported the development of a process for recycling aluminum dross that reportedly eliminated the use of salt fluxes employed in conventional treatment methods. The process reportedly used plasma-torch technology provided by Plasma Energy Corp. of Raleigh, NC. Alcan Aluminium announced that the company would begin industrial-scale testing of this process at its plant in Jonquiere, Quebec, in 1990.

Consumption

The container and packaging industry remained the largest domestic consumer of aluminum products. The Can Manufacturers Institute reported that about 83 billion aluminum beverage cans were shipped in 1989, representing almost 97% of the total metal beverage can shipments.

Reynolds Metals announced plans to begin commercial marketing of aluminum composite panels for use by the architectural industry. The panel combined a solid thermoplastic compound core with two sheets of aluminum. The panel reportedly was intended to serve a wide range of architectural applications, including designs where fire resistance was critical. The panel, called Reynobond, would be produced at the company's architectural products plant in Eastman, GA.

TABLE 22

U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,[1] BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1988			
Secondary smelters	871,484	725,881	781,813
Primary producers	1,025,107	860,494	921,725
Fabricators	229,868	200,978	214,988
Foundries	71,499	59,297	63,755
Chemical producers	36,854	36,854	36,854
Total	2,234,812	1,883,504	2,019,135
Estimated full industry coverage	2,348,000	1,979,000	2,122,000
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

[1] Excludes recovery from other than aluminum-base scrap.

TABLE 23

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1989

(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	36,556	125,781	156,300	6,037
Borings and turnings	4,551	119,472	119,155	4,868
Dross and skimmings	2,396	20,808	21,574	1,630
Other[3]	5,347	84,836	87,865	2,318
Total	48,850	350,897	384,894	14,853
Old scrap:				
Castings, sheet, clippings	15,450	244,310	246,723	13,037
Aluminum-copper radiators	1,083	8,523	9,061	545
Aluminum cans	3,897	[4]107,015	[4]109,401	1,511
Other[5]	1,085	33,519	34,309	295
Total	21,515	393,367	399,494	15,388
Sweated pig	2,352	19,723	20,607	1,468
Total secondary smelters	72,717	763,987	804,995	31,709
Primary producers, foundries, fabricators, chemical plants:				
New scrap:				
Solids	15,132	476,764	479,678	12,218
Borings and turnings	204	32,075	32,136	143
Dross and skimmings	1,012	10,036	9,389	1,659
Other[3]	3,595	158,580	158,849	3,326
Total	19,943	677,455	680,052	17,346
Old scrap:				
Castings, sheet, clippings	1,296	120,767	120,911	1,152
Aluminum-copper radiators	39	1,411	1,396	54
Aluminum cans	18,182	561,127	542,157	37,152
Other[5]	1,474	—	1,474	—
Total	20,991	683,305	665,938	38,358
Sweated pig	1,154	22,601	23,004	751
Total primary producers, etc.	42,088	1,383,361	1,368,994	56,455
All scrap consumed:				
New scrap:				
Solids	51,688	602,545	635,978	18,255
Borings and turnings	4,755	151,547	151,291	5,011
Dross and skimmings	3,408	30,844	30,963	3,289
Other	8,942	243,416	246,714	5,644
Total new scrap	68,793	1,028,352	1,064,946	32,199
Old scrap:				
Castings, sheet, clippings	16,746	365,077	367,634	14,189
Aluminum-copper radiators	1,122	9,934	10,457	599
Aluminum cans	22,079	668,142	651,558	38,663
Other	2,559	33,519	35,783	295
Total old scrap	42,506	1,076,672	1,065,432	53,746
Sweated pig	3,506	42,324	43,611	2,219
Total of all scrap consumed	114,805	2,147,348	2,173,989	88,164

[r] Revised.

[1] Includes imported scrap. According to reporting companies, 6.04% of total receipts of aluminum-base scrap, or 129,795 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 24

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1988		1989	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	107,626	108,475	97,970	97,305
380 and variations	326,011	323,698	348,160	349,471
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	19,063	18,849	18,451	18,850
No. 12 and variations	W	W	W	W
No. 319 and variations	53,971	53,921	60,542	60,068
F-132 alloy and variations	6,945	6,781	6,826	6,763
Al-Mg alloys	224	222	49	68
Al-Zn alloys	2,390	2,296	1,913	2,170
Al-Si alloys (0.6% to 2.0% Cu)	6,933	6,737	9,710	9,837
Al-Cu alloys (1.5% Si, maximum)	1,189	1,176	350	449
Al-Si-Cu-Ni alloys	933	943	1,121	1,123
Other	3,672	3,626	1,209	1,237
Wrought alloys: Extrusion billets	108,052	108,052	126,482	124,714
Miscellaneous:				
Steel deoxidation	8,605	8,903	7,967	7,994
Pure (97.0% Al)	—	—	—	—
Aluminum-base hardeners	1,904	1,933	1,813	1,777
Other[2]	44,307	43,318	31,091	31,226
Total	691,825	688,930	713,654	713,052
Less consumption of materials other than scrap:				
Primary aluminum	46,939	—	55,731	—
Primary silicon	38,344	—	36,981	—
Other	5,405	—	3,536	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[3]	601,137	XX	617,406	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.

Topy Corp., which has been manufacturing steel wheels since 1986, announced the completion of a new manufacturing facility for aluminum wheels. The new facility reportedly would have an annual production capacity of 800,000 units. Topy was the U.S. subsidiary of Topy Industries Ltd. of Japan.

A-Mold Corp., a newly established U.S. subsidiary of Ube Industries Ltd. of Japan, announced plans to construct an aluminum wheel manufacturing plant in Mason, OH. The company expected the plant to have an annual production capacity of 1 million units and to be completed in 1991.

Stocks

Inventories of aluminum ingot, mill products, and scrap at reduction and other processing plants, as reported by the U.S. Department of Commerce, decreased from the revised figure of about 1.88 million tons at yearend 1988 to about 1.82 million tons at yearend 1989.

Prices

The monthly average U.S. market price for primary aluminum ingot trended downward during the year as supply and demand came into a more balanced position. 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. In January 1989, the LME changed the basis of its price quotes for aluminum ingot from standard-grade (99.5%-pure aluminum) to high-grade (99.7%-pure aluminum). This change more accurately reflects the material traded in the world market.

The following table summarizes various average monthly and annual aluminum prices during the year, in cents per pound:

	COMEX 1[1]	COMEX 2[1]	COMEX 3[1]	LME (cash)	U.S. market	U.S. transaction
1988: Annual average	111.13	106.57	88.13	[2]115.88	110.09	112.24
1989:						
January	106.91	107.67	94.23	108.75	107.73	108.89
February	96.32	97.40	89.61	99.02	99.58	100.95
March	92.15	93.05	84.06	94.06	95.78	97.53
April	93.70	93.70	85.90	96.42	96.38	97.61
May	97.15	96.27	88.76	102.48	97.80	99.18
June	88.74	86.34	81.82	86.83	87.66	89.30
July	82.55	80.78	77.85	79.65	80.40	81.45
August	81.28	80.78	79.07	81.57	81.37	82.34
September	78.23	78.18	76.75	77.92	78.30	79.05
October	79.23	78.64	78.43	82.56	79.76	80.30
November	76.16	75.70	75.85	78.75	75.81	76.25
December	72.85	73.30	73.98	74.08	73.56	74.22
Annual average	87.10	86.82	82.19	88.51	87.84	88.92

[1] COMEX delivery positions: 1-within 1 month; 2-within 3 months; and 3-within 12 months.
[2] Average for 11 months.

Source: Metals Week.

Purchase prices for aluminum scrap, as quoted by the American Metal Market (AMM), also decreased during the year. The purchase price for mixed low-copper-content aluminum clips, which began the year near 80 cents per pound, closed at a low 50-cent-per-pound level. Purchase prices for old sheet and cast aluminum, as well as clean, dry, aluminum turnings, decreased from the mid 60-cent-per-pound level to a mid 40-cent-per-pound level by the end of the year.

Prices for UBC's fluctuated during the year but also followed a general downward trend. Aluminum producers' buying prices for processed and delivered UBC's decreased from a range of 74 to 77 cents per pound in late January and early March to a price range of 50 to 53 cents per pound at the end of the year.

TABLE 25

U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1985	1986	1987	1988[r]	1989
Primary production	3,500	3,037	3,343	3,944	4,030
Change in stocks:[1] Aluminum industry	+312	+108	+341	+11	+61
Imports	1,420	1,967	1,850	1,620	1,470
Secondary recovery:[2]					
New scrap	912	989	1,134	1,077	1,043
Old scrap	850	784	852	1,045	1,011
Total supply	6,994	6,885	7,520	7,697	7,615
Less total exports	908	753	917	1,247	1,613
Apparent aluminum supply available for domestic manufacturing	6,086	6,132	6,603	6,450	6,002
Apparent consumption[3]	5,174	5,143	5,469	5,373	4,959

[r] Revised.
[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).

Secondary aluminum ingot prices, as quoted by AMM, also followed a downward trend. The yearend price ranges for selected secondary aluminum ingots were as follows: Alloy 380 (1% zinc content), 73 to 76 cents per pound; alloy 360 (0.6% copper content) and alloy 413 (0.6% copper content), 78 to 80 cents per pound; and alloy 319, 76 to 78 cents per pound.

Changes in aluminum metal prices from 1850–1988 and a brief analysis of the factors that influenced the changes were included in a Bureau of Mines report on nonferrous metal prices.[11]

Foreign Trade

For the third consecutive year, exports of all forms of aluminum from the United States increased substantially from those of the previous year. Total exports in 1989 were more than double those of 1986. Japan and Canada continued to be the major recipients of U.S. aluminum materials in 1989. Japan received three-fourths of the U.S. exports of crude metal and about one-half of the total exports of aluminum materials during the year. Exports of UBC's, which were included in the scrap category, totaled 17,354 tons in 1989, more than 4 times the quantity exported in 1988. Japan continued to be the principal destination of UBC's exported, accounting for more than one-half of the total in 1989.

Imports for consumption of aluminum decreased slightly compared with those of 1988. Canada remained the major shipping country to the United States, supplying three-fourths of the total U.S. imports in 1989.

U.S. tariff rates in effect in 1989 for selected aluminum products from countries with most-favored-nation status were as follows:

Item	HTS No.	Import duty
Unwrought metal (in coils)	7601.10.30	2.6% ad valorem.
	7601.20.30	Do.
Unwrought (other than Si-Al alloys)	7601.10.60	Free
	7601.20.90	Do.
Waste and scrap	7602.00.00	Free.

TABLE 26

DISTRIBUTION OF END-USE SHIPMENTS OF ALUMINUM PRODUCTS IN THE UNITED STATES, BY INDUSTRY

Industry	1987		1988		1989[p]	
	Quantity (thousand metric tons)	Percent of grand total	Quantity (thousand metric tons)	Percent of grand total	Quantity (thousand metric tons)	Percent of grand total
Containers and packaging	2,052	27.8	2,036	26.7	2,104	26.6
Building and construction	1,441	19.5	1,316	17.2	1,296	16.4
Transportation	1,500	20.3	1,536	20.1	1,515	19.1
Electrical	620	8.4	671	8.8	679	8.6
Consumer durables	576	7.8	588	7.7	554	7.0
Machinery and equipment	401	5.4	435	5.7	443	5.6
Other markets	223	3.1	269	3.5	266	3.3
Total to domestic users	6,813	92.3	6,851	89.7	6,857	86.6
Exports	569	7.7	787	10.3	1,060	13.4
Grand total	7,382	100.0	7,638	100.0	7,917	100.0

[p] Preliminary.

Source: The Aluminum Association Inc.

TABLE 27

U.S. NET SHIPMENTS[1] OF ALUMINUM WROUGHT AND CAST PRODUCTS, BY PRODUCERS

(Metric tons)

	1988	1989[p]
Wrought products:		
Sheet, plate, foil	3,779,789	3,899,451
Rod, bar, pipe, tube, and shapes	1,336,657	1,280,301
Rod, wire, cable	334,118	338,888
Forgings (including impacts)	75,264	71,724
Powder, flake, paste	40,941	42,369
Total	5,566,769	5,632,733
Castings:		
Sand	115,351	NA
Permanent mold	201,334	NA
Die	699,897	NA
Other	37,934	NA
Total	1,054,516	1,095,508
Grand total	6,621,285	6,728,241

[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 28

DISTRIBUTION OF WROUGHT PRODUCTS IN THE UNITED STATES

(Percent)

	1988[r]	1989[p]
Sheet, plate, foil:		
Nonheat-treatable	58.4	58.2
Heat-treatable	3.9	3.9
Foil	7.3	7.1
Rod, bar, pipe, tube, shapes:		
Rod and bar (rolled and extruded)	1.7	1.2
Pipe and tube (extruded and drawn)	2.3	2.4
Extruded shapes	18.7	19.1
Rod, wire, cable:		
Rod and bar wire	.7	.5
Cable and insulated wire	5.1	5.5
Forgings (including impacts)	1.2	1.3
Powder, flake, paste	.7	.8
Total	100.0	100.0

[p] Preliminary. [r] Revised.

Source: U.S. Department of Commerce.

TABLE 29

TARIFF CODES FOR U.S. EXPORTS OF ALUMINUM

Material	1988	1989
	TSUS[1]	HTS[2]
Metals and alloys, crude	618.0300	7601.10.0000
	618.0630	7601.20.9030
	618.0670	7601.20.9045
	618.4500	7601.20.9500
Plates, sheets, bars, etc.:		
Plates, sheets, bars, strips, etc.	618.1520	7604.10.1000
	618.1540	7604.10.3010
	618.1700	7604.10.3050
	618.2810	7604.10.5030
	618.2830	7604.10.5060
	618.2850	7604.21.0000
	618.2870	7604.29.1000
	618.2890	7604.29.3010
		7604.29.3050
		7604.29.5030
		7604.29.5060
		7606.11.3030
		7606.11.3060
		7606.11.6000
		7606.12.3030
		7606.12.3070
		7606.12.6000
		7606.91.0010
		7606.91.0050
		7606.91.0070
		7606.91.0090
		7606.92.0010
		7606.92.0050
		7606.92.0070
		7606.92.0090
Castings and forgings	657.4320	7616.90.0060
	657.4342	7616.90.0070
Semifabricated forms, n.e.c.	618.4620	7608.10.0030
	618.4640	7608.10.0090
	618.4900	7608.20.0030
	688.3600	7608.20.0090
	688.3710	7609.00.0000
Scrap	618.1020	7601.20.9075
	618.1060	7602.00.0030
	618.1080	7602.00.0090
Foil and leaf	644.0720	7607.11.3000
	644.0740	7607.11.6000
		7607.11.9000
		7607.19.0000

See footnotes at end of table.

TABLE 29—Continued

TARIFF CODES FOR U.S. EXPORTS OF ALUMINUM

Material	1988 TSUS[1]	1989 HTS[2]
Powders and flakes	618.4000	7603.10.0000
	618.4200	7603.20.0000
Wire and cable	618.2100	7605.11.0030
		7605.11.0090
		7605.19.0000
		7605.21.0030
		7605.21.0090
		7605.29.0000

[1] Tariff Schedules of the United States Annotated.
[2] Harmonized Tariff System of the United States.

Source: Bureau of the Census.

On January 1, 1989, the Harmonized Tariff System went into effect. This system was designed to bring the trade classifications used in the United States closer to those used in the rest of the world. Tables 29 and 32 provide listings of the tariff codes used by the Bureau of Mines to prepare trade data before January 1 and those that were used under the new Harmonized System.

World Review

World aluminum demand slowed from levels reached during the past few years but remained strong. Inventories in market economy countries increased slightly over last year's levels but remained at historically low levels. Many of the world's producers of aluminum continued to operate their primary smelters at or near rated capacity levels.

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, increased slightly from 1.482 million tons at yearend 1988 to 1.576 million tons at yearend 1989. IPAI reported that total metal inventories, including secondary aluminum, increased from 3.085 million tons at yearend 1988 to 3.231 million tons at yearend 1989.

Capacity.—The data in table 35 are rated annual capacity for plants producing primary aluminum metal 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.

Greenfield smelter expansions were planned for areas of the world that had low energy and/or labor costs, most notably Canada and the Persian Gulf area.

Algeria.—A Dubai-based consortium, Industrial Development Corp. of Dubai, and the Algerian Public National Enterprise announced plans to build a 220,000-ton-per-year smelter and related facilities, including a powerplant and port, on the western coast of Algeria. Work on the facility, to be named Medial, was expected to start in late 1990 and take 3 years to complete. Members of the consortium were reported to be Caradel Investments Inc., George Wimpey Plc., Asea Brown Boveri, and the Marc Rich organization.

Australia.—Kaiser Aluminium announced the sale of its 20% interest in the Boyne Island smelter at Gladstone to Austria Metall AG.

Tomago Aluminium Co. Pty. Ltd. announced that it was investigating the possibility of constructing a third potline at its 230,000-ton-per-year smelter in New South Wales that would increase capacity to 360,000 tons per year. Startup of the additional potline reportedly depended on the signing of a power contract with the New South Wales Electricity Commission.

Comalco announced that a prefeasibility study for a 198,000-ton-per-year expansion at the Boyne Island smelter had been completed. Comalco reportedly was investigating the possible purchase of the Gladstone power station to ensure the power required for the planned expansion.

Bahrain.—Kaiser Aluminum announced the sale of its 17% interest in Aluminium Bahrain (Alba) to the Government of Bahrain. The sale increased the Government's share in the 205,000-ton-per-year primary smelter to 75%. Alba also announced expansion plans for the smelter that would increase capacity to 460,0000 tons per year by 1992.

Brazil.—Reynolds Metals announced the sale of all but a 35% interest in

TABLE 30

U.S. EXPORTS OF ALUMINUM, BY CLASS[1]

Class	1988 Quantity (metric tons)	1988 Value (thousands)	1989 Quantity (metric tons)	1989 Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	400,057	$925,572	593,048	$1,260,638
Scrap	486,615	774,277	574,170	767,573
Plates, sheets, bars, strip, etc.[2]	334,395	995,767	416,241	1,195,015
Castings and forgings	16,964	111,168	20,480	128,975
Semifabricated forms, n.e.c.	9,306	50,669	9,368	55,075
Total	1,247,337	2,857,453	1,613,307	3,407,276
Manufactures:				
Foil and leaf	52,307	78,912	39,334	73,708
Powders and flakes	4,445	19,472	3,262	15,949
Wire and cable	4,160	15,823	4,553	19,087
Total	60,912	114,207	47,149	108,744
Grand total	1,308,249	2,971,660	1,660,456	3,516,020

[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.
[2] Includes "strip" with plates, sheets, bars, etc. in 1989.

Source: Bureau of the Census.

TABLE 31

U.S. EXPORTS OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc.[1]		Scrap		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:								
Belgium	5,243	$13,541	809	$4,253	4,094	$7,332	10,146	$25,126
Brazil	252	573	1,884	11,958	746	924	2,882	13,455
Canada	29,756	83,720	210,524	607,678	30,689	33,306	270,969	724,704
Colombia	199	574	1,929	5,095	47	86	2,175	5,755
Dominican Republic	372	773	389	957	12	11	773	1,741
France	176	707	1,923	16,059	12,814	22,628	14,913	39,394
Germany, Federal Republic of	1,227	5,087	4,437	23,923	4,280	6,360	9,944	35,370
Hong Kong	1,023	2,078	11,513	31,940	922	1,496	13,458	35,514
Italy	77	281	2,611	18,470	8,575	11,711	11,263	30,462
Japan	303,120	673,326	15,281	62,234	268,846	441,645	587,247	1,177,205
Korea, Republic of	10,108	25,197	17,532	57,582	35,663	75,627	63,303	158,406
Mexico	13,966	32,038	31,176	86,608	29,859	37,703	75,001	156,349
Netherlands	10,434	26,966	2,957	13,801	13,150	26,980	26,541	67,747
Panama	82	836	605	1,756	193	439	880	3,031
Singapore	10,328	25,175	642	9,829	1,705	3,718	12,675	38,722
Spain	24	78	1,170	6,040	330	482	1,524	6,600
Taiwan	7,054	16,762	8,903	28,006	65,823	87,946	81,780	132,714
Trinidad[2]	163	462	173	738	14	57	350	1,257
United Kingdom	1,391	3,328	8,027	45,339	1,993	3,610	11,411	52,277
Other[r]	5,062	14,070	38,180	125,338	6,860	12,216	50,102	151,624
Total	400,057	925,572	360,665	1,157,604	486,615	774,277	1,247,337	2,857,453
1989:[3]								
Belgium	2,944	6,889	1,129	5,191	4,851	6,239	8,924	18,319
Brazil	127	988	2,430	13,833	3,642	4,606	6,199	19,427
Canada	28,491	76,163	260,718	689,586	36,854	41,335	326,063	807,084
Colombia	439	927	1,510	3,940	31	47	1,980	4,914
Dominican Republic	130	354	1,143	3,025	58	126	1,331	3,505
France	265	1,635	3,274	23,817	16,522	20,602	20,061	46,054
Germany, Federal Republic of	723	3,050	5,719	23,876	9,669	12,558	16,111	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	488,503	806,618	1,506,526
Korea, Republic of	25,012	51,054	19,010	63,480	13,983	18,916	58,005	133,450
Mexico	19,188	44,076	40,721	139,115	26,509	38,150	86,418	221,341
Netherlands	14,619	29,433	2,726	12,168	11,503	17,250	28,848	58,851
Panama	394	877	910	2,719	35	73	1,339	3,669
Singapore	5,566	9,784	1,673	19,021	453	565	7,692	29,370
Spain	179	1,602	985	5,665	1,292	1,605	2,456	8,872
Taiwan	26,706	50,985	15,301	37,099	75,429	77,768	117,436	165,852
Trinidad and Tobago[2]	203	588	364	1,156	30	28	597	1,772
United Kingdom	2,137	4,898	8,303	40,937	5,122	6,619	15,562	52,454
Other	18,171	37,595	38,629	141,858	16,874	15,396	73,674	194,849
Total	593,048	1,260,638	446,089	1,379,065	574,170	767,573	1,613,307	3,407,276

[r] Revised.

[1] Includes castings, forgings, and unclassified semifabricated forms.

[2] For 1989, Trinidad and Tobago combined, data not available to separate; 1988 data for Trinidad only.

[3] Because of the implementaion of the Harmonized Tariff System beginning in Jan. 1989, export categories for 1988 are not necessarily comparable with those in 1989.

Source: Bureau of the Census.

TABLE 32

TARIFF CODES FOR U.S. IMPORTS OF ALUMINUM

Material	1988 TSUS[1]	1989 HTS[2]
Metals and alloys, crude	618.0100	7601.10.3000
	618.0200	7601.10.6000
	618.0400	7601.20.3000
	618.0610	7601.20.6000
	618.0630	7601.20.9030
	618.0650	7601.20.9045
	618.4500	7601.20.9090
Plates, sheets, bars, etc.:		
Plates, sheets, bars, strips, etc., n.e.c.	618.1700	7606.11.3030
	618.2520	7606.11.3060
	618.2550	7606.11.6000
	618.2560	7606.12.3030
	618.2563	7606.12.3060
	618.2580	7606.12.3090
	618.2720	7606.12.6000
	618.2740	7606.91.3030
	618.2760	7606.91.3060
	618.2765	7606.91.3075
	618.2900	7606.91.3090
		7606.91.6020
		7606.91.6040
		7606.91.6060
		7606.91.6080
		7606.92.3030
		7606.92.3060
		7606.92.3075
		7606.92.3090
		7606.92.6020
		7606.92.6040
		7606.92.6060
		7606.92.6080
		7616.90.0060
		7616.90.0070
Pipes, tubes, etc.	618.4700	7608.10.0030
	618.4800	7608.10.0090
		7608.20.0030
		7608.20.0090
		7609.00.0000
Rods and bars	618.1520	7604.10.1000
	618.1540	7604.10.3010
	618.2540	7604.10.3050
		7604.10.5030
		7604.10.5060
		7604.21.0000
		7604.29.1000
		7604.29.3010

See footnotes at end of table.

TABLE 32—Continued

TARIFF CODES FOR U.S. IMPORTS OF ALUMINUM

Material	1988 TSUS[1]	1989 HTS[2]
Rods and bars—Continued		7604.29.3050
		7604.29.5030
		7604.29.5060
Scrap	618.1000	7601.20.9075
		7602.00.0030
		7602.00.0090
Foil and leaf	644.0600	7607.11.0000
	644.0800	7607.11.3000
	644.0900	7607.11.6000
	644.1100	7607.11.9000
	644.1200	7607.19.1000
	644.2600	7607.19.3000
	644.6400	7607.19.6000
	644.6800	
	644.7200	
	644.7600	
Flakes and powders	618.4000	7603.10.0000
	618.4200	7603.20.0000
Wire	618.2000	7605.11.0000
	618.2200	7605.11.0030
		7605.11.0090
		7605.19.0000
		7605.21.0030
		7605.21.0090
		7605.29.0000

[1] Tariff Schedules of the United States Annotated.
[2] Harmonized Tariff System of the United States.
Source: Bureau of the Census.

Latasa, its aluminum can manufacturing plant that came on-stream this year, to three Brazilian banks.

Canada.—A six-member consortium announced the signing of an agreement to construct a 215,000-ton-per-year primary smelter at Sept Iles, Quebec. The members of the consortium were VAW, 20%; Austria Metall, 20%; Hoogovens Groep BV, 20%; Société Generale de Financement, 20%; Kobe Steel Ltd., 13.3%; and Marubeni Corp., 6.7%. The smelter to be called Alouette reportedly was scheduled to come on-stream in 1992.

Alumax announced plans to construct a 215,000-ton-per-year greenfield aluminum smelter at Deschambault, Quebec. Completion of the project was scheduled for 1992.

Reynolds Metals announced plans to add a 120,000-ton-per-year potline to its smelter at Baie Comeau, increasing capacity to 400,000 tons per year. The company expected the potline to be fully operational by 1991. In June, workers at the Baie Comeau smelter ratified a new 3-year labor contract that was set to expire on June 30, 1992.

Alcan Aluminium announced the purchase of a 20% stake in Moli Energy Ltd. of Vancouver, British Columbia, and the signing of an agreement to blend the technologies of Alcan's aluminum-air battery and Moli's rechargeable lithium battery. Alcan reported that the joint venture could lead to the development of a lightweight power source for an electric vehicle that could also involve the company's aluminum-structured-vehicle technology.

China.—The Government announced plans to add 80,000 tons per year of capacity to its 110,000-ton-per-year smelter at its Guizhou complex. Officials expected the expansion to be completed by 1991.

The China International Trust & Investment Corp. reportedly canceled the contract to buy a mothballed smelter in Sakata, Japan, from Sumitomo Metal Industries Ltd.

Dubai.—Dubai Aluminium Co. (Dubal) announced that construction had begun on a new potline that would increase the smelter's capacity to 235,000 tons per year by 1991.

Indonesia.—The Asahan Development Authority announced plans to build a second hydroelectric powerplant for the Inalum smelter in Sumatra. The plant, with a capacity of 180 megawatts, reportedly was scheduled for completion in 1990.

Korea, Republic of.—Aluminium of Korea Ltd. announced plans to build a 100,000-ton-per-year rolling mill. The company planned commissioning of the plant in 1992.

Netherlands.—Hoogovens Groep BV announced that it would merge its aluminum operations into a new subsidiary, Hoogovens Aluminium BV.

Norway.—Soer-Norge Aluminium A/S announced plans to expand capacity at its 66,000-ton-per-year smelter at Husnes to 100,000 tons per year. The

company noted that the project, which could take 3 to 5 years to complete, hinged on the signing of power supply contracts.

Saudi Arabia.—The Minister of Industry and Electricity reported that approval had been granted for the construction of a 220,000-ton-per-year primary smelter at Yanbu. Alujain Corp., formed by Saudi interests, reportedly would hold a 60% interest in the smelter. Gove Aluminium Ltd. reported the signing of an agreement with Alujain to supply 100,000 tons per year of alumina to the smelter. The Alusa smelter was expected to begin production in 1992.

South Africa, Republic of.—General Mining Union Corp. Ltd. (Gencor) announced that it had purchased a 30.7% interest in the Alusaf Pty. Ltd. primary aluminum smelter at Richards Bay.

Switzerland.—Swiss Aluminium Ltd. (Alusuisse) announced that the company would be renamed Alusuisse Lonza Holdings effective January 1, 1990.

Taiwan.—Ball Corp. of Muncie, IN, and Hong Kong-based Lam Soon Ltd. announced the formation of a joint venture to construct an aluminum beverage can plant in Hsin Chu County, south of Taipei. Ball reportedly would own 30% of the venture called Lam Soon-Ball International. The company expected the plant to be operational early next year and to produce 1,600 cans per minute for the local beer and soft drink market.

U.S.S.R.—Reynolds Metals, Fata European Group of Italy, and a group of U.S.S.R. organizations announced plans to build an aluminum foil production and converting operation in Siberia. The plant was expected to have a capacity of 47,000 tons per year and to be located in the town of Sajanogordsk. Six U.S.S.R. entities would own 70% of the plant, while Reynolds Metals and Fata would each own 13.5%, and the remaining 3% would be held by the San Paolo Bank of Italy.

United Kingdom.—British Alcan Aluminium Plc. announced plans to build a UBC recycling plant at Latchford Locks in northwestern England. The company expected the plant to have an annual capacity of 50,000 tons and to come on-stream in 1991.

Venezuela.—Aleaciones Ligeras SA (Alisa) reported the signing of an agreement with Davy McKee for the construction of a 120,000-ton-per-year primary aluminum smelter. Alisa is a wholly Venezuelan-owned project. Corporacion Venezolana de Guyana (CVG) reportedly owned 30% of the project, and Ripesa, an investment group, held the remaining 70%. The new startup date given by the company was 1993.

TABLE 33

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY CLASS[1]

Class	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value thousands)
Crude and semicrude:				
Metals and alloys, crude	1,027,246	$2,197,785	923,030	$1,898,132
Plates, sheets, strip, etc., n.e.c.[r 2]	341,508	898,386	315,564	867,222
Pipes, tubes, etc.	3,838	18,205	2,808	20,363
Rods and bars	47,113	111,622	22,012	63,331
Scrap	200,517	318,015	206,610	309,122
Total	1,620,222	3,544,013	1,470,024	3,158,170
Manufactures:				
Foil[3]	33,058	144,643	25,832	123,223
Leaf[3]	(4)	299	(3)	(3)
Flakes and powders	2,869	6,799	2,259	6,916
Wire	5,452	18,331	23,446	68,683
Total	41,379	170,072	51,537	198,822
Grand total	1,661,601	3,714,085	1,521,561	3,356,992

[r]Revised.

[1] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, import categories for 1988 are not necessarily comparable with those in 1989.

[2] Includes plates, sheets, circles, and disks.

[3] Combining foil and leaf in 1989.

[4] 1988—aluminum leaf not over 30.25 square inches in area 5,235,781 leaves, and aluminum leaf over 30.25 square inches in area, 771,966,360 square inches.

Source: Bureau of the Census.

Current Research

Golden Aluminum published a brief description of the continuous cast process used by the company to produce can body stock at its Fort Lupton, CO, facility. The paper described chemical composition control, surface quality, internal structure, gauge, and casting parameters, as well as the operating practices required to obtain these quality levels.[12]

The Bureau of Mines studied the effects of aluminum additions on the sulfidation resistance of iron-chromium-nickel (Fe-Cr-Ni) alloys. A series of Fe-Cr-Ni alloys with and without additions of 4% aluminum were tested in a wet sulfur vapor atmosphere at 677° C. Aluminum-containing alloys formed a compact, tightly adherent layer of scale that reduced corrosion rates by a factor of 3 to 10 compared with that of aluminum-free alloys. The thin, adherent aluminum-containing scale limited inward diffusion of sulfur and oxygen to the base metal and outward diffusion of nickel from the base metal.[13]

Outlook

World supply and demand should be in fairly good balance over the next few years. Growth in world aluminum demand has slowed from the rapid growth rates of the late 1980's but should show an average growth rate of about 2% per year over the next few years. Increased attention, both domestically and abroad, to waste disposal problems should provide steady growth in the secondary aluminum industry.

TABLE 34

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc.[1]		Scrap		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:								
Argentina	25,088	$39,581	9,763	$23,231	—	—	34,851	$62,812
Australia	13,358	28,440	5,182	10,996	662	$1,281	19,202	40,717
Belgium	89	504	33,616	86,617	231	233	33,936	87,354
Canada	794,786	1,704,106	117,984	286,102	135,061	219,793	1,047,831	2,210,001
France	130	657	25,926	78,609	422	660	26,478	79,926
Germany, Federal Republic of	1,229	6,908	11,814	40,428	3,474	4,462	16,517	51,798
Ghana	50,543	126,417	723	1,596	—	—	51,266	128,013
Hong Kong	227	465	2,924	7,625	112	172	3,263	8,262
Israel	9	37	1,165	5,064	76	109	1,250	5,210
Jamaica	209	289	—	—	1,049	1,567	1,258	1,856
Japan	558	2,782	40,062	108,508	234	642	40,854	111,932
Mexico	7,085	15,538	5,882	17,164	17,180	21,148	30,147	53,850
Netherlands	2,167	3,581	8,978	40,750	3,224	4,332	14,369	48,663
Panama	348	342	19	21	3,967	4,739	4,334	5,102
U.S.S.R.	267	485	—	—	16,877	29,118	17,144	29,603
United Kingdom	2,000	5,524	7,063	29,739	3,955	6,284	13,018	41,547
Venezuela	52,829	106,448	36,641	81,206	8,644	15,865	98,114	203,519
Yugoslavia	431	981	12,684	31,214	—	—	13,115	32,195
Other[r]	75,893	154,700	72,033	179,343	5,349	7,610	153,275	341,653
Total	1,027,246	2,197,785	392,459	1,028,213	200,517	318,015	1,620,222	3,544,013
1989:[2]								
Argentina	12,173	23,046	6,889	17,302	—	—	19,062	40,348
Australia	5,764	12,084	11	70	666	1,588	6,441	13,742
Belgium	76	467	29,993	83,693	101	116	30,170	84,276
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	11,518	41,914
Germany, Federal Republic of	579	7,766	10,745	42,165	872	1,295	12,196	51,226
Ghana	8,924	21,805	278	651	—	—	9,202	22,456
Hong Kong	10	10	2,558	7,157	123	213	2,691	7,380
Israel	—	—	1,227	7,786	20	31	1,247	7,817
Jamaica	100	168	—	—	1,875	2,919	1,975	3,087
Japan	941	2,657	20,788	68,291	310	891	22,039	71,839
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	5,078	24,734
Panama	481	638	—	—	3,539	4,285	4,020	4,923
U.S.S.R.	100	226	—	—	5,845	10,054	5,945	10,280
United Kingdom	356	1,789	11,470	41,960	541	1,077	12,367	44,826
Venezuela	59,552	90,694	16,454	36,612	4,747	7,800	80,753	135,106
Yugoslavia	19	50	13,289	31,320	—	—	13,308	31,370
Other	43,536	96,866	55,708	154,127	6,010	7,927	105,254	258,920
Total	923,030	1,898,132	340,384	950,916	206,610	309,122	1,470,024	3,158,170

[r] Revised.

[1] Includes circles, disks, rods, pipes, tubes, etc.

[2] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, import categories for 1988 are not necessarily comparable with those in 1989.

Source: Bureau of the Census.

TABLE 35

ALUMINUM: WORLD ANNUAL PRIMARY METAL PRODUCTION CAPACITY, BY COUNTRY[1]

(Thousand metric tons)

Continent and country	1987	1988	1989[p]
North America:			
Canada	1,577	1,594	1,594
Mexico	66	66	66
United States	3,895	3,960	4,016
South America:			
Argentina	150	160	160
Brazil	869	869	869
Suriname	30	30	30
Venezuela	430	460	666
Europe:			
Austria	92	92	92
Czechoslovakia	60	60	60
France	346	346	346
German Democratic Republic	85	85	85
Germany, Federal Republic of	733	733	733
Greece	145	145	145
Hungary	76	76	76
Iceland	86	86	86
Italy	276	276	276
Netherlands	266	266	266
Norway	834	843	851
Poland	110	110	110
Romania	250	250	250
Spain	344	344	344
Sweden	91	91	91
Switzerland	72	72	72
U.S.S.R.	2,590	2,590	2,640
United Kingdom	287	287	287
Yugoslavia	357	367	377
Africa:			
Cameroon	80	80	80
Egypt	170	170	170
Ghana	200	200	200
South Africa, Republic of	172	172	172
Asia:			
Bahrain	180	180	205
China	[r]695	875	975
India	472	472	472
Indonesia	225	225	225
Iran	50	50	50
Japan	64	64	64

See footnotes at end of table.

TABLE 35—Continued

ALUMINUM: WORLD ANNUAL PRIMARY METAL PRODUCTION CAPACITY, BY COUNTRY[1]

(Thousand metric tons)

Continent and country	1987	1988	1989[p]
Asia—Continued			
Korea, North	20	20	20
Korea, Republic of	18	18	18
Taiwan	50	50	50
Turkey	60	60	60
United Arab Emirates: Dubai	149	159	170
Oceania:			
Australia	1,012	1,177	1,177
New Zealand	244	250	250
Total	[r]17,978	18,480	18,946

[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, Bureau of Mines, Bldg. 20, Federal Center, Denver, CO, 80225. Part 1 of "Primary Aluminum Plants, Worldwide" details location, ownership, and production capacity for 1985–92 and sources of energy and aluminum raw materials for foreign and domestic primary aluminum plants, including those in centrally planned economies. Part 2 summarizes production capacities for 1985–92 by smelter and country.

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 ($Al_2O_3 \cdot H_2O$), the monohydrates.[14] 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%. In dried bauxite, most of the free moisture is removed by heating crude bauxite in rotary drying kilns at about 315° C. Calcined bauxite is produced by heating bauxite to 925° to 1,040° C to reduce total volatile matter, including chemically combined water, to less than 1%. 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 costs 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 39.

New aluminum-base scrap, generated in the production of intermediate and end products of aluminum metal, may be pure (unalloyed), segregated (one alloy type), or mixed (two or more alloys). It

includes solids, such as new casting scrap; clippings or cuttings of new sheet, rod, wire, and cable; borings and turnings from the machining of aluminum parts; and residues, drosses, skimmings, spillings, and sweepings.

New scrap is further defined as either "runaround" (home) scrap or purchased scrap. Runaround or home scrap is new scrap that is recycled by the same company that generates it; such scrap by definition never leaves the company generating it and, therefore, is never marketed as scrap. Purchased scrap is new scrap that is purchased, imported, or treated on toll by secondary smelters, the original aluminum product suppliers, or others. New aluminum scrap that is purchased from manufacturers of end products may be referred to as consumer scrap. Purchased scrap is sometimes referred to as prompt industrial scrap.

Old scrap, all of which is considered as purchased, comes from discarded, used, and worn out products. It includes aluminum pistons or other aluminum engine or body parts from junked cars, aluminum UBC's and utensils, and old wire and cable. Sweated pig is scrap that has been sweated or melted into a pig or ingot form for convenience and economy in shipping and storage. Obsolete scrap is new, unused, but technologically obsolete aluminum end products, outdated inventory materials, production overruns, and spare parts for machines and equipment no longer being used. In the United States, both sweated pig and obsolete scrap are considered old scrap.

Geology-Resources

Bauxite is formed by the weathering of aluminum-bearing rocks under conditions conducive to the chemical breakdown of minerals in the parent rock. In the weathering process, the aluminum is retained as hydrated aluminum oxide minerals and other constituents are leached from the parent rock. Conditions favorable for the formation of bauxite existed in areas and geological periods that provided warm wet climates, parent aluminous rocks with high permeability and readily soluble minerals, good subsurface drainage, and long periods of tectonic stability that permitted deep weathering and preservation of land surfaces.

The major deposits in central Arkansas were formed by weathering of

TABLE 36

ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina	136	148	153	154	155
Australia	851	882	1,004	1,150	[2]1,244
Austria	94	93	93	95	[2]93
Bahrain	176	178	180	[e]182	[2]184
Brazil	549	757	843	874	[2]935
Cameroon	90	84	79	87	86
Canada	1,282	1,355	1,540	1,535	[2]1,555
China[e]	410	410	615	800	825
Czechoslovakia	32	33	32	32	30
Egypt	209	175	179	173	173
France	293	322	323	328	[2]335
German Democratic Republic[e]	60	61	62	[r]61	60
Germany, Federal Republic of	745	765	738	744	[2]742
Ghana	49	125	150	161	[2]169
Greece[3]	125	[r]124	127	151	[2]145
Hungary	74	74	76	75	75
Iceland	73	76	85	82	[2]89
India[3]	260	257	265	375	375
Indonesia[3]	217	219	202	185	222
Iran[e]	43	40	40	40	40
Italy	224	243	233	222	220
Japan[4]	227	140	41	35	[2]35
Korea, North[e]	10	10	10	10	10
Korea, Republic of[3]	18	19	22	18	17
Mexico[3]	43	[r]37	65	71	72
Netherlands	251	266	276	278	[2]274
New Zealand	241	[r]236	252	264	[2]260
Norway	743	726	806	864	[2]859
Poland[5]	47	48	48	48	47
Romania[6]	247	269	260	[e]260	250
South Africa, Republic of	165	170	171	172	170
Spain	370	350	341	323	[2]352
Suriname	29	[r]29	2	10	10
Sweden	84	[r]78	81	99	[2]97
Switzerland	73	80	73	72	[2]71
Turkey	54	60	42	57	57
U.S.S.R.[e]	2,200	2,300	2,400	2,400	2,400
United Arab Emirates: Dubai	153	155	155	162	160
United Kingdom	275	276	294	300	[2]297
United States	3,500	3,037	3,343	3,944	[2]4,030
Venezuela	396	[r]424	440	455	500
Yugoslavia[e 3]	280	282	244	260	260
Total	15,398	[r]15,413	16,385	17,608	17,980

[e] Estimated. [p] Preliminary. [r] Revised.

[1] The 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 23, 1990.

[2] Reported figure.

[3] Primary ingot.

[4] Excludes high-purity aluminum containing 99.995% or more as follows, in metric tons: 1985—4,783; 1986—8,140; 1987—12,099; 1988—13,628; and 1989—15,600 (estimated).

[5] Primary unalloyed ingot plus secondary unalloyed ingot.

[6] Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

TABLE 37

TYPICAL SPECIFICATIONS FOR GRADES OF BAUXITE

(Weight-percent, maximum content unless otherwise specified)

Constitutent	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.

TABLE 38

CELL-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-Bureau of Mines Alumina Miniplant Steering Committee recommended specifications, May 1979.

nepheline syenite intrusives during late Paleocene and early Eocene time.[15] The predominant aluminum oxide mineral in the bauxite is the trihydrate form, gibbsite. Some deposits are residual on the igneous rock and clay, while others are the result of transportation and accumulation of eroded deposits. Most of the deposits were subsequently covered by sand and clay beds. Bauxite ore ranges in thickness from a few feet to 65 feet and is overlain by a 40- to 150-foot overburden. The composition of the ore mined in Arkansas varies widely within a range of 40% to 52% Al_2O_3, 7% to 17% SiO_2, and 6% to 12% Fe_2O_3.

The bauxite deposits in the coastal plain of Alabama and Georgia are found as lenses within flat-lying beds of kaolinitic clay, which are overlain by sand and clays of early Tertiary age. Average ore thickness is 10 feet, though locally 33-foot ore has been encountered. Overburden, especially in the Alabama sinkhole deposits, can exceed 120 feet in thickness. The grade of the bauxite is 48% to 56% Al_2O_3, 12% to 16% SiO_2, and less than 2.5% Fe_2O_3. The low iron oxide content permits this ore to be used in refractories and chemicals.

In Jamaica, the bauxite deposits fill sinkholes and channels and blanket uneven depressions in the karst surface of a limestone of middle Tertiary age. Individual ore bodies range from pockets containing a few hundred tons of bauxite to basins containing millions of tons. The soil overburden is only 1 to 2 feet thick. Jamaican bauxite is largely gibbsitic, although mixtures containing up to 20% monohydrate alumina occur. Ore grade is 45% to 49% Al_2O_3, 0.8% to 8% SiO_2, 17% to 22% Fe_2O_3, and 2.5% TiO_2. The bauxite deposits in the Dominican Republic and Haiti are similar in grade, age, and genesis, and are identified as "Jamaica-type" bauxites.

Bauxite deposits in Suriname and Guyana are scattered throughout a narrow belt extending along the contact between the Precambrian crystalline rocks of the Guyana Shield and the sedimentary beds of Tertiary or later age that form the coastal plain. These deposits usually rest on kaolinitic clay and range from exposed outcrops to ore bodies overlain by as much as 200 feet of sand and clay, although the average overburden is around 60 feet. Other deposits of bauxite and laterite occur in these countries at higher elevations south of the coastal belt. The alumina mineral is gibbsite and the ore is high grade; typically 55% to 60% Al_2O_3, 2% to 5% SiO_2, and less than 3% Fe_2O_3. Both countries have been exporters of refractory and abrasive-grade bauxite.

In the large deposits discovered in northern Brazil since 1967, the bauxite occurs as a residual capping on dissected plateaus several hundred feet above the Amazon or other nearby rivers. The ore has developed on unconsolidated Tertiary sediments and is covered by 12 to 30 feet of kaolinitic clay. Ore thickness averages about 16 feet. The approximate grade after washing is 55% Al_2O_3, 3.5% SiO_2, and 11% Fe_2O_3. Bauxites in northern Brazil and Venezuela are of the gibbstic type and contain little monohydrate alumina.

The Weipa bauxite deposit in Queensland, Australia, occurs in the upper portion of a flat-lying laterite that extends for more than a hundred miles along the west coast of the Cape York Peninsula. The bauxite ranges in thickness from a few feet to 30 feet and is covered by a soil overburden 1 to 3 feet thick. Average ore thickness is about 14 feet. The ore is basically gibbsitic, but some of the alumina is also present in the form of boehmite. The deposits are associated with Tertiary kaolinitic

sands, from which they were probably derived. The grade of the beneficiated bauxite is 53% to 58% Al_2O_3, 4% to 7% SiO_2, and 12% Fe_2O_3.

The Darling Range bauxite deposits in Western Australia occur as a residual capping on Precambrian granites, gneiss, and intrusive crystalline rocks. A thin 1.5-foot blanket of soil mixed with loose pisolites covers the deposits. The top of the ore is characterized by a ferruginous hardcap about 6 feet in thickness. The deposits are characterized by a low alumina and a high quartz sand content; however, the reactive silica is typically less than 2%. General composition is 38% to 46% Al_2O_3, 10% to 23% SiO_2, 11% to 16% Fe_2O_3, and about 4% TiO_2.

In Guinea, the large Sangaredi bauxite deposits occur as laterite caps on inland plateaus at elevations of 900 feet or more above sea level. The deposits have been dissected by stream valleys. Most of the bauxite is believed to have formed through weathering of schists and sandstones of Devonian or Post-Devonian age. The thickness of the Sangaredi bauxite ore averages more than 65 feet and exceeds 130 feet in some places. Overburden, where present, consists of a thin topsoil. Typical ore contains 57% to 60% Al_2O_3, less than 1% SiO_2, and 2% to 4% Fe_2O_3. The upper zone of the Sangaredi deposit contained only a few percent boehmite, but mining has progressed to lower benches where the monohydrate content has increased to nearly 10%.

Many of the European bauxite deposits are associated with pockets and depressions in the karst weathering surface of Mesozoic limestone beds that have been buried, folded, and faulted subsequent to the development of the bauxite. European bauxites are composed predominantly of monohydrate alumina minerals, although some gibbsitic deposits are mined in Hungary and a few other countries.

Historically, the commercial production of primary aluminum has been based almost entirely on the use of bauxite. However, deposits containing aluminum in the other mineral forms are widespread and virtually inexhaustible. The average aluminum content of the Earth's crust has been estimated at 8.3% (15.7% on an Al_2O_3 basis), and deposits containing more than 13% aluminum (25% Al_2O_3) are common.

Information on bauxite reserves and

TABLE 39

COMPOSITION LIMITS AND USES OF SOME ALUMINUM WROUGHT AND CASTING ALLOYS[1]

(Weight-percent)

Aluminum Association designation	Aluminum	Copper	Manganese	Magnesium	Silicon	Other constitutents	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]	1.9-1.2	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- .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.	Automative 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 constitutents, 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.

resources varies from reports based on thorough exploration for some deposits to reports giving only a total quantity estimate based on unspecified fieldwork for other deposits. The reserve and reserve-base estimates in table 40 are the result of evaluating data and information obtained from many sources. The quality of bauxite deposits cannot be assessed by the alumina content alone because the mineralogical form in which the alumina occurs, its extractability in the Bayer process, the quantity of reactive silica present, iron content, including the ratio of ferric to ferrous iron, and other chemical and physical properties all affect the process cost and the alumina recoverable from a given bauxite. The classification of undeveloped bauxite deposits as either reserves or subeconomic resources also is a matter of judgment because many factors other than grade influence the economics of mining, transporting, and processing the bauxite to alumina. The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."[16]

Past estimates of world bauxite reserves were about 1 billion metric tons in 1945, nearly 3 billion tons in 1955, 6 billion tons in 1965, and about 21 billion tons in 1985. In 1989, they were estimated at about 22 billion tons. Guinea and Australia together have about one-half of the world's reserves. More than 25% occurs in the Western Hemisphere, principally in Brazil, Jamaica, Guyana, and Suriname. Estimates of additional bauxite classified as subeconomic, hypothetical, or speculative resources bring the total world resources of bauxite to 55 to 75 billion tons. Growth in reserves has roughly paralleled the expansion of world bauxite production capacity. Major new discoveries are the primary factor in reserve increases; however, production economies resulting from technological advances and large-scale operations have also permitted the inclusion of lower grade bauxite previously considered subeconomic.

The principal domestic deposits of bauxite are in central Arkansas, where reserves are estimated to be about 33 million metric tons. An additional 2 to 5 million tons of bauxite reserves in Alabama and Georgia are the source of domestic refractory and chemical bauxites.

The resources of bauxite in the United States, other than the present reserves, are chiefly in (1) large low-grade deposits containing substantial quantities of clay minerals and deeply buried and thin deposits in Arkansas, Alabama, and Georgia; (2) ferruginous bauxite deposits in Oregon and Washington; and (3) deposits of low-grade ferruginous bauxite in soils and weathered basalts on Kauai and Maui, Hawaii. Inclusion of these low-grade resources increases the total estimated bauxitic resource in the United States to 300 to 325 million tons. The mining of some of these deposits may be restricted or prohibited because of environmental considerations such as their proximity to populated or scenic areas.

Nonbauxitic aluminum-bearing deposits in the United States that have received the most attention as potentially economic sources of aluminum include kaolinitic clays, anorthosite, and alunite. Other types of clays, shales, schists, nepheline syenite, and sapprolite are also potential aluminum raw materials. In addition, the production of certain other minerals yields aluminous materials that may be considered potential sources of metal. These include coal ash and coal mining refuse, copper leach solutions, aluminum phosphate rock, and dawsonite if produced in conjunction with the mining of oil shales.

TABLE 40

WORLD BAUXITE RESOURCES, DECEMBER 1989

(Million metric tons of bauxite)

Continent and country	Reserves[1]	Reserve base[1]
North America and Caribbean Islands:		
Dominican Republic	30	45
Haiti	10	14
Jamaica	2,000	2,000
United States	38	40
South America:		
Brazil	2,800	2,900
Guyana	700	900
Suriname	575	600
Venezuela	320	350
Europe:		
France	30	40
Greece	600	650
Hungary	300	300
Italy	5	5
Romania	50	50
Spain	5	5
U.S.S.R.	300	300
Yugoslavia	350	400
Africa:		
Cameroon	680	1,000
Ghana	450	560
Guinea	5,600	5,900
Mozambique	2	2
Sierra Leone	140	160
Zimbabwe	2	2
Asia:		
China	150	1,450
India	1,000	1,200
Indonesia	750	805
Malaysia	15	20
Pakistan	20	20
Turkey	25	30
Oceania: Australia	4,440	4,600
Other	200	200
Total[2]	22,000	25,000

[1] Resource Reserve Definition. Geological Survey Circular 831, 1980.

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

Technology

Exploration.—The first stage of planning a bauxite exploration program usually entails a thorough study of regional geology, physiography, and any previous reports on exploration or mining operations within the area of interest. The initial regional appraisal should include a review of topographic maps (rarely available for remote tropical areas), aerial photographs, satellite images, and mosaics prepared from aerial side-looking radar (SLR) surveys. In the Amazon Basin of Brazil, where the dense rain forest canopy completely masks stream valleys, scarps, and plateaus, SLR methods have proven effective in revealing the hidden topography. Geobotanical techniques using real or false color air photos and satellite images have been used to identify vegetation types associated with aluminous laterites. Airborne radiometric surveys are useful in delineating exposed laterites by their typically evaluated levels of radioactivity.

After specific target areas have been

defined, reconnaissance by helicopter or fixed-wing aircraft can provide valuable logistics information. Surface prospecting for float samples in stream valleys has long been a reliable guide in the discovery of bauxite deposits. Vertical channel sampling of indurated resistant outcrops exposed in stream valleys can often provide the first positive identification of the presence of bauxite. Detailed evaluation and development require drilling, pitting, or trenching to provide samples for chemical analysis. Surface mapping is essential to document drill collar and pit locations and elevations.

Bauxite minerals are difficult to identify visually and require sophisticated laboratory techniques for quantitative analysis. Because of this requirement, exploration samples and development samples are often shipped to the company's main laboratory for analysis. The most important determinations are for alumina and silica content. Both "total alumina" and "available alumina" (alumina recoverable by both low- and high-temperature Bayer processes) are normally determined. In addition to "total silica," it is important to analyze for "reactive silica" because the latter combines with alumina and soda in the Bayer process to form sodium aluminum silicates that are lost in the red mud wastes. Iron oxides, titania, and loss on ignition are also routinely determined.

Mining.—Open pit mining accounted for all of the bauxite mined within the United States in recent years and for about 95% of the world bauxite production. Restoration of the land surface of depleted bauxite mines is being practiced in many areas of the world by preserving the topsoil after stripping for later replacement.

In Arkansas, draglines, scrapers, shovels, and trucks are used in stripping operations. Stripping ratios as high as 13 feet of over-burden to 1 foot of ore have been employed, and some surface pits in Arkansas have reached depths of about 200 feet. The pit walls of unconsolidated sand and clay are relatively stable; however, some slumping does occur. In the past, a deeper flat-lying ore was recovered by room-and-pillar mining along a retreating cave line. Underground bauxite mining ceased in 1976, and the remaining surface mining operations in Arkansas are scheduled for permanent closure in 1990.

In Jamaica, the bauxite deposits lie closer to the surface, and the overburden of vegetation and topsoil is easily stripped. The ore usually requires no blasting. Shovels, draglines, and scrapers are used to load the ore. Haulage is by truck, railroad, or aerial tramline to the alumina plants and port facilities. In Suriname and Guyana, up to 200 feet of overburden is stripped by draglines, scrapers, bucket wheel excavators, or hydraulicking. The ore is broken by blasting and loaded into ore cars or trucks with power shovels, backhoes, or draglines.

At Weipa, Australia, bulldozers and scraper loaders remove the few feet of overburden. Front-end loaders, each mining in excess of 500 tons per hour, then load the uncemented pisolitic ore into trucks for a short haul to a beneficiating plant for sizing and washing. At the deposits in the Darling Range of Western Australia, forest clearing of vegetation and overburden removal are followed by blasting of the hardcap that comprises the top few feet of the bauxite deposits. Front-end loaders load dump trucks for haulage to a mobile crushing plant. Bauxite is carried from the crusher to an alumina plant by conveyer belt.

The deposits mined for the Boké project in Guinea have little overburden, but require blasting. Loosened ore is loaded by electric shovels directly onto railcars for shipment 85 miles to a treatment plant and port at Kamsar.

Underground mining accounts for much of the Greek, French, and Hungarian bauxite production and is widely used in other parts of Europe, including the U.S.S.R. Room-and-pillar and various stoping methods are used. Underground water problems are common —especially in the Hungarian mines where bauxite deposits are associated with the weathering of limestone. Here dewatering of underground workings accounts for 10% to 15% of the mining cost.

Beneficiation.—Bauxite treatment is usually confined to crushing, washing, and drying operations. Most of the bauxites that are mined do not require the more costly beneficiation techniques used on some other metal ores. Moreover, most impurities such as iron, silicon, and titanium are frequently so finely dispersed in the bauxite that they cannot be readily separated by physical methods. Many bauxites are upgraded, however, by washing or wet screening to remove sand and some of the clay minerals.

Metallurgical and chemical grades of bauxite that must be transported appreciable distances are normally dried before shipment. Drying facilitates the handling of some bauxites, and the degree to which a specific bauxite is dried depends in part on its handling and dusting characteristics. Because crude bauxite may contain 10% to 30% free moisture, drying results in savings in freight that may more than offset drying costs. Suriname and Guinea bauxite is dried to 3% to 6% moisture, whereas Jamaican bauxite is shipped with about 15% moisture. Bauxite for use in refractories and abrasives is calcined to remove both free moisture and chemically combined water.

Alumina Production.—Virtually all commercially produced alumina from bauxite is obtained by a process patented by Karl Bayer in 1888 (German Patent 43,977), although research on aluminum extraction from other mineral raw materials has continued for many years. The Bayer process involves a caustic leach of the bauxite at elevated temperature and pressure, followed by separation of the resulting sodium aluminate solution and selective precipitation of the aluminum as the hydrated aluminum oxide ($Al_2O_3 \cdot 3H_2O$).

The actual processing conditions such as the leach temperature, holding time, and caustic concentration, as well as the costs, are influenced by the type of bauxite to be processed. As a result, a Bayer alumina plant is designed to treat a specific bauxite and, in general, cannot use a bauxite that is too different from the one the plant was designed to use without major plant modifications.

The Bayer process is initiated by mixing crude bauxite with preheated spent leach solution. Lime is added during this initial step to control the phosphorus content and to increase the solubility of alumina. The resulting slurry, containing 40% to 50% solids, is pumped with additional caustic leach solution to pressurized digesters where high-pressure steam is used to raise the temperature. Alumina and some of the silica are dissolved during this step,

soluble sodium aluminate is formed, and a complex sodium aluminum silicate is precipitated.

Digestion, in tanks 10 to 15 feet in diameter and up to 90 feet high, takes up to 5 hours. Leaching temperatures range from about 105° C to about 290° C, with corresponding pressures ranging from about 60 pounds per square inch (psi) to more than 1,000 psi. The lower temperature ranges are used for bauxites in which nearly all of the available alumina is present as gibbsite. The higher temperatures are needed to digest bauxite having a large percentage of boehmite. Caustic concentration of the spent leach solution, expressed as grams per liter of sodium carbonate (Na_2CO_3), averages about 200 grams per liter for gibbsitic bauxite and about 300 grams per liter for bauxites with a high-boehmite content.

The resulting slurry of sodium aluminate solution and insoluble red mud from the digesters is cooled to atmospheric boiling temperature, and a coarse sand waste fraction is removed by gravity separators or wet cyclones. The fine solids in the red mud are then separated by decantation of the overflow in settling tanks measuring about 15 feet in depth and 50 to 125 feet in diameter. A flocculant such as starch is added to increase the settling rate of the red mud particles. The overflow from the settling tanks containing the alumina in solution is clarified by filtration and placed into precipitating tanks ranging in size from 25 to 30 feet in diameter and up to 80 feet high.

The clarified sodium aluminate liquor is cooled until it becomes supersaturated, then seeded with fine crystals of alumina trihydrate. The alumina is precipitated as the trihydrate, separated by sedimentation or filtration, and washed. The spent leach solution containing caustic soda is regenerated in the precipitation step, and together with the alumina remaining in solution, is recycled to the digesters. The filtered and washed alumina trihydrate is calcined for use in making metal. A portion of the washed alumina may be left in the trihydrate form for chemical uses or it may be further processed under controlled conditions to produce a variety of chemical aluminas, such as activated or tabular alumina for uses other than metal production.

Two forms of calcined alumina are used to produce aluminum. European Bayer plants have traditionally produced a fine-grained, highly calcined, floury alumina while North American Bayer plants have always produced a coarser grained, porous, sandy alumina that has not been totally calcined to the alpha alumina stage (artificial corundum). The relatively large surface area of the sandy alumina particles compared with the floury alumina particles permits their use as an absorbent in dry scrubber units at the smelter. Fluorine in the gases emitted by the potlines is trapped by the alumina and is later recycled when the alumina is used as feed for the cell. Pressure from environmental regulations and improved economics through recovery of fluoride have been important factors in the conversion of world alumina plants to produce a sandy rather than a floury alumina product.

The red mud contains Fe_2O_3, TiO_2, the sodium aluminum silicate complex, and small quantities of other metal oxides. Because the complex represents a loss of both alumina and soda, a low reactive silica content in the bauxite is desirable. Reactive silica contents of more than 8% are usually uneconomic for treatment by the Bayer process because approximately 1.1 units (weight unit) of alumina and 1.2 units of soda are lost for each unit of reactive silica in the ore. The loss of soda is made up by adding caustic soda or soda ash and lime to the spent leach solution to bring it up to the appropriate caustic concentration before it is recycled.

Bauxite with 8% to 15% silica may be treated by the combination process developed by Alcoa. In this process, the bauxite is first subjected to a Bayer leach. The resulting red mud, containing sodium aluminum silicate, is sintered with limestone and soda ash and then leached with water to recover alumina and soda. Alumina produced by the combination process is of relatively high purity and commands a premium price. The insoluble residue (brown mud) resulting from leaching the sintered materials has a composition somewhat similar to that of portland cement.

The upper limit of silica for use in the combination process is about 15%. However, in practice, bauxite containing some clay and as much as 25% silica is mined and blended with low-silica ore in proportions that will give a feed material approximately 12% to 13% silica. The combination process is currently used in one plant in Arkansas, which has been scheduled for permanent closure in 1990, and reportedly in several plants within the U.S.S.R.

In the U.S.S.R., alumina is extracted from nepheline [$(Na,K)AlSiO_4$] flotation concentrates and other nonbauxitic materials containing about 30% alumina. Nepheline syenite has been mined at Belogorsk in Siberia and obtained as a byproduct of apatite recovery from syenite deposits in the Kola Peninsula. The process used involves sintering the nepheline with lime followed by leaching. Alumina reportedly is also produced from alunite [$KAl_3(OH)_6(SO_4)_2$] in the Azerbaijan S.S.R.

Historically, a small tonnage of alumina has been extracted commercially in Norway from high-iron bauxites by the Pedersen process. In this process, bauxite, limestone, coke, and iron ore are smelted in an electric furnace to produce pig iron and calcium aluminate slag containing 30% to 50% alumina. The slag is leached with sodium carbonate solution, and alumina trihydrate was precipitated by carbon dioxide. During World War II, the process was also used at a Swedish plant to treat andalusite (Al_2SiO_5).

Smelting

Primary Aluminum Production.— Primary aluminum is produced by the reduction of alumina by electrolysis in a molten bath of natural or synthetic cryolite (Na_3AlF_6), which serves as an electrolyte and as a solvent for the alumina. The reduction cells or pots containing the bath are about 10 to 15 feet wide, 20 to 40 feet long, and about 3 to 4 feet deep, lined with carbon, and connected in electrical series of 100 to 240 cells to form a potline. From 800 to 3,000 pounds of aluminum are produced per day in each pot. The carbon lining is in contact with the molten aluminum metal and serves as the cathode. It usually must be replaced after 3 to 4 years.

Cryolite and aluminum fluoride are added to the electrolyte to maintain the desirable ratio of sodium and aluminum fluoride and to replace fluorine lost from the cell in pot linings or

through volatilization. The melting point of the bath is lowered by the addition of small quantities of fluorspar or, in some instances, lithium compounds. The carbon anode, which is consumed during the operation, is replaced using the Soderberg continuous method or the prebaked method.

In the Soderberg method, a reinforced rectangular steel shell, approximately 3 to 5 feet high and open at the top and bottom, is suspended above the furnace. The carbon mass of paste or briquets of coke and pitch within the shell forms the anode and is added periodically as the anode is consumed. Current enters the anode through rows of pins inserted into the carbon mass either vertically or horizontally. The heat of the bath and the heat resulting from the electrical resistance of the carbon bake the anode mass so that it becomes a hard monolithic mass from the surface of the electrolyte to a point approximately 20 inches above the bath. As the carbon anode is consumed and additional carbon descends through the rectangular steel shell and is consumed, the lowest pins are withdrawn and replaced at higher levels in the carbon mass. The optimum anode-cathode distance is maintained by raising or lowering the cathode mass via the pins, which become baked into the lower part of the carbon block.

In the prebaked anode system, sets of 16 to 24 prebaked carbon blocks are used for the anode. The size of the blocks varies from plant to plant; typical blocks are about 20 inches wide, about 30 inches long, and 12 to 18 inches high. They weigh 400 to 600 pounds. Steel stubs or rods, which suspend the block in the bath and conduct the current to the carbon, are sealed in the anode block by pouring molten iron around the rod and allowing it to solidify. The blocks are raised or lowered separately to maintain proper position with respect to the bath and are replaced individually as they are consumed.

The Soderberg system requires less labor and, except for moving the steel pins, is a continuous method of feeding anode carbon. The prebaked system results in better electrical efficiency in the reduction cell but requires separate anode fabricating and rodding facilities not required in the Soderberg system. The prebaked system permits efficient collection of the cell offgases for subsequent treatment to remove fluorine; the offgases from a Soderberg cell are difficult to collect, necessitating fluorine recovery from a larger volume of gas than that required in prebaked systems.

The molten bath or electrolyte may be as deep as 14 inches, but the anode is usually only 2 inches from the pad of molten aluminum collecting on the carbon cathode. The optimum operating temperature is between 950° to 985° C. At this temperature range, the alumina content of the bath ranges from 3% to 10%. When the alumina concentration drops to about 2%, the electrical resistance of the cell increases sharply, chiefly because of a gas film that envelops the anode, and the voltage drop across the cell increases from 5 volts to 30 to 40 volts. The phenomenon is known as the "anode effect," and as soon as it occurs, the crust of frozen cryolite on top of the bath is broken and more alumina is added to the cell, which then returns to normal operating condition.

Every 1 or 2 days the molten aluminum is removed from the bottom of the cell by a vacuum siphon technique. Thermally insulated cast-iron pots with airtight lids and downward-sloping spouts are used to withdraw the molten metal. The pot is evacuated, and the molten metal is sucked into the cast-iron pot. The molten metal is blended in a holding furnace with other batches and alloyed and cast into various solid forms or transported molten to fabricating plants as far as 300 miles away.

Utilizing direct current, cells operate at 65,000 to 150,000 amperes; the majority of plants have 80,000- to 100,000-ampere cells. Anode current densities range from 600 to 800 amperes per square foot. The voltage drop across a single cell is 4.5 to 5.0 volts; across a potline, it may be as high as 1,000 volts.

The larger cells require less labor per pound of aluminum produced, but special problems are encountered in cells designed to operate at 100,000 or more amperes. The larger currents cause powerful magnetic fields in the molten aluminum metal and the bath, resulting in violent agitation. This agitation causes aluminum to be dispersed in the bath, increasing the possibility of reversing the reduction reaction. Another detrimental effect is that the molten metal piles up toward the negative leads, causing a variation in the anode-cathode spacing. Moreover, localized thermal effects may distort the carbon lining.

Production cells normally have current efficiencies ranging from 85% to 93%. Metal losses are principally caused by reoxidation of aluminum in the electrolyte and by physical loss of metal through vaporization from the bath or spillage. The resistance of the bath is sufficient to maintain the operating temperature. However, heat energy is lost by radiation, thermal conductance through electrode connections, in exhaust gases and tapped metal, and in electrodes removed from the cells.

To prevent atmospheric pollution, fumes evolved from the cells during electrolysis are removed from plant offgases by a collection and wet-scrubbing system or by a dry process whereby the fluorine is absorbed by alumina and recycled.

Superpurity Aluminum Processing.—The production of superpurity aluminum, 99.99+% purity, requires special procedures, such as a continuous electrorefining of commercially pure aluminum in a Hoopes cell. This cell employs three molten layers of metals or bath materials of different densities. The bottom layer is the anode, a relatively impure aluminum alloyed with copper to increase its density. The intermediate layer is molten cryolite electrolyte with alkaline earth metal fluorides added to give the desired density, always greater than pure aluminum. The top layer, which serves as the cathode, is the molten superpurity aluminum that floats on the electrolyte layer.

Recycling.—In recycling, aluminum-base scrap is usually melted in gas- or oil-fired reverberatory furnaces of 30,000 to 100,000 pounds capacity, sometimes with primary ingot metal. The furnaces have one or two charging wells separated from the main bath by a refractory wall that permits only molten metal into the main bath. The principal refining of aluminum-base scrap is the removal of magnesium by treating the molten metal with chlorine or with various fluxes such as aluminum chloride, aluminum fluoride, or mixtures of sodium and potassium chlorides and fluorides. To facilitate handling, a significant proportion of the old aluminum scrap, and in some

cases new scrap, is simply melted to form a solid ingot called "sweated pig," which must be further treated to produce specification-grade ingot.

Aluminum drosses containing about 30% metallics are usually crushed and screened to bring the metallic content up to about 60% to 70%. They are then melted in a reverberatory furnace, with the molten aluminum metal collecting on the bottom of the furnace. Salt slags containing less than 30% metallics may be leached with water to separate the metallics.

Economic Factors[17]

Aluminum production costs at aluminum mining and primary processing facilities were affected by internal factors such as variations in bauxite type and quality, stripping ratios, caustic soda consumption rates, and energy and alumina costs. In addition, external factors such as foreign exchange rates, inflation, and world market prices for products affected aluminum producers. The Bureau's Minerals Availability Program (MAP) monitors these factors to determine variations in the industry and changes in the cost competitiveness of major aluminum producing countries.

Table 41 summarizes the principal production costs of aluminum for selected countries in average 1988 U.S. dollars. The wide spread in electric power costs among primary aluminum operations was a principal reason for large variations in aluminum ingot production costs among producing nations. As a result, many energy-intensive plants have closed since 1980, and operating facilities have implemented energy-conserving technology. Countries with lower energy costs appeared to have a cost advantage over other producers.

Extreme variations in inflation relative to foreign exchange rates were another factor affecting production costs in countries such as Brazil. Although energy was abundant and labor and supply costs in Brazil traditionally have been low, extreme inflation in 1988 and 1989 made Brazil a higher-cost producer when costs were reported in U.S. dollars.

In terms of relative costs competitiveness in 1988, Australia and Canada were the lowest cost aluminum producers, principally because of low-cost energy and lower alumina and supply costs. Latin American countries such as Brazil have traditionally been low-cost producers; Brazil's costs, in the midcost range, reflected the high inflation rates present in that country in 1988. The U.S. aluminum industry also fell in the middle of the cost range, indicative of the domestic aluminum industry's recent efforts in cost reduction and restructuring. European aluminum producers appeared to be the highest cost operations.

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TABLE 41

ALUMINUM PRODUCTION POTENTIAL AND COSTS FOR SELECTED COUNTRIES

(Average 1988 U.S. cents per pound of aluminum)

Country	Annual production[1] (thousand metric tons)	Operating costs			Overhead	Transport to smelter	Net operating cost[2]	Recovery of capital	0% DCFROR[3]		15% DCFROR[3]		
		Labor	Supplies/ alumina	Energy					Taxes	Total cost	Taxes[4]	Return on investment	Total cost[5]
Producing operations:													
Australia	2,318	8.4	23.4	12.4	4.2	0.8	49.2	3.2	0.3	52.7	5.2	5.9	63.5
Brazil	2,407	5.0	28.3	18.0	4.9	.4	56.6	4.4	.4	61.4	2.0	8.9	71.9
Canada	3,057	11.2	25.8	5.4	3.9	.6	46.9	3.3	.5	50.7	8.7	5.9	64.8
France	639	13.4	34.2	20.5	7.0	.4	75.5	4.5	.3	80.3	5.0	6.1	91.1
Germany, Federal Republic of	1,518	17.9	33.1	25.4	8.4	1.1	85.9	3.7	.4	90.0	7.1	5.8	102.5
India	610	14.6	29.3	33.1	8.4	NA	85.4	2.4	.1	87.9	3.6	4.0	95.4
Italy	499	18.7	34.0	21.2	8.0	.3	82.2	4.3	.4	86.9	4.7	5.5	96.7
Norway	1,624	17.5	30.4	11.3	6.4	1.2	66.8	3.1	.2	70.1	5.6	5.3	80.8
Spain	681	10.3	38.0	25.7	7.6	.1	81.7	3.6	.1	85.4	2.2	5.2	92.7
Switerland	126	18.6	25.8	15.0	7.4	2.2	69.0	6.2	.3	75.5	2.9	7.4	85.5
United Kingdom	571	13.4	37.2	21.7	7.5	.9	80.7	3.2	.2	84.1	2.9	5.3	92.1
United States	579	12.8	21.5	20.7	6.5	.7	62.2	1.7	.7	64.6	2.5	3.7	70.1
Total or average[6]	26,840	11.2	25.4	16.5	5.6	.7	59.4	3.0	.6	63.0	5.2	5.6	73.2
Nonproducing operations:													
Total or average[6]	2,410	9.9	28.6	10.4	4.7	.4	54.0	.2	3.2	57.4	30.8	26.7	111.7
All operations:													
Total or average[6]	29,250	11.1	25.6	16.0	5.6	.7	59.0	2.8	.8	62.6	7.1	8.5	77.4

NA Not available.

[1] Based on total recovered aluminum divided by life of smelter.

[2] Costs may not total because of individual rounding.

[3] Discounted Cash Flow Rate of Return.

[4] Taxes at 15% reflect higher revenues needed to obtain 15% return on investment.

[5] Total cost (15%) = Total cost (0%) + (taxes (15%) − taxes (0%) + return on investment.

[6] Reported figures are totals or weighted averages of all operations considered in this study. Other countries include Argentina, Austria, Bahrain, Greece, Iceland, Indonesia, Iran, Mexico, the Netherlands, New Zealand, Qatar, Suriname, Turkey, the United Arab Emirates, and Venezuela.

Source: Bureau of Mines, Minerals Availability Field Office, Denver, CO.

BERYLLIUM

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Nonferrous Metals. She has covered beryllium for 6 years. Domestic survey data were prepared by Ruth A. Hough and Lura M. Nightlinger, Nonferrous Metals Data Section. International data were prepared by W. Zajac, International Data Section.

Softness in the defense, semiconductor, and computer markets resulted in lower domestic beryllium production and consumption. Concern about health hazards associated with beryllium oxide ceramic components resulted in a decrease in their use in some defense applications. Although total beryllium demand decreased, beryllium alloys, such as Alloy 174, gained new uses in automotive electronics components, and new alloys were introduced for use as molds for injection-molded plastics.

Brush Wellman Inc. remained the sole U.S. mine producer of beryllium ores and the only company with the facilities to process ore into alloys, metal, and oxide. Because of a drop in profits, the company planned to consolidate or sell some of its metals businesses to reduce costs.

LEGISLATION AND GOVERNMENT PROGRAMS

The National Defense Stockpile (NDS) acquired 6 metric tons of hot-pressed beryllium billets in 1989, under a contract awarded to Brush Wellman in 1988. Of the 27 tons purchased and delivered under the 1988 contract, 21 tons must be tested before it is accepted in the NDS. Total NDS inventories and goals for beryl ore, beryllium-copper master alloy, and metal are shown in table 2.

In September, the Environmental Protection Agency issued a final ruling on the criteria to evaluate mineral processing wastes for exclusion from regulation under subtitle C of the Resource Conservation and Recovery Act (RCRA). Barren filtrate, raffinate, and bertrandite thickener sludge from primary beryllium processing operations were candidates for exclusion under the original criteria established in 1988. To be excluded from regulation under RCRA, waste streams must pass high-volume and low-toxicity criteria established in the final ruling. Barren filtrate and raffinate waste streams did not pass the high-volume criteria and were no longer excluded from RCRA. Bertrandite thickener slurry was reclassified as a beneficiation waste and was to be regulated under the subtitle D+ program.[1]

TABLE 1

SALIENT BERYLLIUM MINERAL STATISTICS

(Metric tons of beryllium metal equivalent unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Beryllium-containing ores:					
Mine shipments	209	237	220	212	184
Imports for consumption, beryl[1]	60	54	83	35	24
Consumption, reported	287	288	323	243	217
Price, approximate, per short ton unit BeO, imported cobbed beryl at port of exportation	$87	$88	$84	$93	$90
Yearend stocks	181	177	164	158	153
World: Production[1]	326	r330	317	p332	e303

e Estimated. p Preliminary. r Revised.

[1] Based on a beryllium metal equivalent of 4% in beryl.

TABLE 2

STOCKPILE STATUS, DECEMBER 31, 1989

(Metric tons, beryllium content)

Material	Goal	Inventory
Beryllium ore	653	653
Beryllium-copper master alloy	287	268
Beryllium metal	363	269

The U.S. Department of Commerce planned to investigate reports that Degussa AG of the Federal Republic of Germany shipped a small quantity of high-purity beryllium metal to India without obtaining an export license. International shipment of beryllium metal is strictly controlled because of the metal's applications in nuclear weapons. Commerce officials indicated that an application for shipment of beryllium would have been denied because India did not sign the nuclear nonproliferation treaty.

PRODUCTION

Mine shipments of beryllium concentrates declined, continuing a 2-year trend. Production of beryllium metal, beryllium oxide, and beryllium-copper master alloy also decreased. Brush Wellman remained the sole ore processor in the United States, treating bertrandite, imported beryl, and small quantities of domestically produced beryl at its plant in Delta, UT.

To provide faster service to customers with small orders, Brush Wellman completed a $5 million expansion program at its beryllium-copper rolling facility in Reading, PA. New equipment installed at the plant included a 10-inch-wide cluster mill with computerized feed control, a

strand annealing furnace, and a chemical cleaning line. The company expected to provide its customers with shorter response times, larger coils, and improved thickness control.

Late in 1989, Brush Wellman announced that it would consolidate and sell a few of its metal businesses to reduce costs and streamline operations. Specifically, the company planned to sell the unrelated custom rolling business of its subsidiary, Metals Engineering Co., and consolidate the remainder of its metals systems operations at the Lincoln, RI, location of its Technical Materials Inc. subsidiary. In addition, Brush Wellman planned to seek a partner or buyer for its clad metal systems business in Japan because of losses in 1988 and 1989. The company expected that the restructuring plan would affect about 10% of Brush Wellman's 2,200 employees.[2]

CONSUMPTION AND USES

Because of softness in defense, semiconductor, and computer markets, demand for beryllium products declined in 1989. In addition, concern about the potential health hazards of beryllium oxide ceramic components led to a decline in their use in some defense-related applications.

Although overall beryllium demand decreased, the use of Alloy 174, a lower cost beryllium-copper alloy, continued to increase in automotive electronics. Brush Wellman also introduced two new beryllium-copper alloys for use as molds for injection-molded plastics for automotive, industrial, and consumer applications.

PRICES

Metals Week quoted a price of beryl ore at a range of $78 to $85 per short ton unit (20 pounds) of contained beryllium oxide throughout 1989. At yearend, American Metal Market quoted the following prices, in dollars per pound, for beryllium and beryllium alloys; beryllium-copper master alloy was quoted in dollars per pound of contained beryllium:

Vacuum cast ingot, 98.5% pure	$225
Metal powder, in 1,000- to 4,999-pound lots and 98.5% pure	196
Beryllium-copper master alloy	160
Beryllium-copper casting alloy	$5.52- 6.30
Beryllium-copper in rod, bar, wire	9.85
Beryllium-copper in strip	8.90
Beryllium-aluminum alloy, in 100,000-pound lots	260
Beryllium oxide powder	65.65

Changes in beryllium metal prices from 1932 to 1988 and a brief analysis of the factors that influenced the changes were included in a Bureau of Mines report on nonferrous metals prices.[3]

FOREIGN TRADE

In 1989, the United States implemented the Harmonized Tariff System (HTS), which resulted in changes in classifications for some materials. Some data that were aggregated under one category in the Tariff Schedule of the United States (TSUS) classification system were separated under the HTS, and some data that were separated in the TSUS system are aggregated in the HTS. Consequently, trade data that can be identified specifically with one commodity may have changed, and data for 1989 were not comparable to that of 1988 and previous years. For beryllium, data on exports of metal and waste and scrap in 1989 were not exactly comparable to 1988 export data, and import data for beryllium metal and compounds differed from those in previous years.

Exports of beryllium-copper alloys could not be separately identified in the Bureau of the Census data. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provided some information on these exports. According to PIERS, 300,678 kilograms (gross weight) of beryllium-copper alloys was exported from the United States, with almost 80% of the material shipped to France. In addition, 29,508 kilograms (gross weight) of beryllium-copper master alloy was exported, with 63% shipped to France, 33% to the Federal Republic of Germany, and 4% to Brazil.

WORLD REVIEW

Capacity data for beryllium mining operations are presented in table 7. Beryl mining operations outside the United States employ manual labor to separate beryl crystals from the host rock, and capacity data for such operations represent average production figures. Output from many operations, particularly those in Africa, was dependent largely on the economic and political situation within the country.

Hecla Mining Co. announced that it would withdraw from its joint venture with Highwood Resources Ltd. to develop a beryllium-containing deposit in the Northwest Territories, Canada. Although a processing design was developed, the company encountered difficulties in marketing the product. Highwood Resources planned to assess other alternatives for the project.

OUTLOOK

Although total beryllium demand has declined each year since 1987, this trend is not expected to continue over the next few years. The consumption of beryllium is influenced largely by the requirements for beryllium-copper alloys, which represents more than one-half of the total demand. Increased use of beryllium alloys in automotive electronic components was expected to be an important factor in alleviating the downturn in demand. In addition, applications for Alloy 174 were expected to expand because of its lower cost compared with traditional beryllium-copper alloys, and its superior performance relative to the materials it can replace.

BACKGROUND

Products For Trade and Industry

A wide variety of applications use beryllium in one of three forms—metal, oxide, and alloys. Beryllium-copper alloys are the principal form, averaging about 65% of annual consumption on a beryllium metal equivalent basis. These alloys, most of which contain approximately 2% beryllium, are used because of their high electrical and thermal con

TABLE 3

U.S. EXPORTS OF BERYLLIUM ALLOYS, WROUGHT OR UNWROUGHT, AND WASTE AND SCRAP,[1] BY COUNTRY

Country	1988		1989	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Angola	—	—	31	$9
Australia	—	—	72	9
Belgium	—	—	277	40
Brazil	118	$3	—	—
Canada	2,102	331	3,415	524
China	173	38	37	50
France	5,604	2,271	1,954	784
Germany, Federal Republic of	4,944	1,145	910	353
Hong Kong	4	11	—	—
India	73	10	—	—
Ireland	359	7	80	9
Israel	—	—	200	156
Italy	109	4	353	55
Japan	2,277	808	716	285
Korea, Republic of	552	15	79	12
Malaysia	32	7	—	—
Mexico	75	17	1,014	14
Netherlands	1,290	138	7,741	190
Peru	304	7	—	—
Singapore	18	8	—	—
Sweden	—	—	46	7
Switzerland	298	159	937	248
Taiwan	15,301	135	138	27
Tanzania	—	—	8,825	11
United Kingdom	3,965	1,778	7,435	1,062
Other	1	2	1	2
Total	37,599	6,894	34,261	3,847

[1] Consisting of beryllium lumps, single crystals, powder; beryllium-base alloy powder; and beryllium rods, sheets, and wire.

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF BERYL, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Brazil	664	$677	526	$572
China	122	161	35	44
France	58	10	—	—
Hong Kong	30	55	—	—
Madagascar	10	8	—	—
Morocco	—	—	22	20
Zimbabwe	—	—	18	19
Total	884	911	601	655

Source: Bureau of the Census.

ductivity, high strength and hardness, good corrosion and fatigue resistance, and nonmagnetic properties. Beryllium-copper strip is manufactured into springs, connectors, and switches for use in applications in automotive, aerospace, radar and telecommunications, factory automation, computer, home appliances, and instrumentation and control systems. The principal use of large-diameter beryllium-copper tubing is in oil and gas drilling equipment and bushings and bearings in aircraft landing gear and heavy machinery. Connectors in fiber optic telecommunications systems are the main application for beryllium-copper rod, and small pluggable sockets for joining integrated circuits to printed circuit boards is the main use for beryllium-copper wire. Beryllium-copper bar and plate are used in resistance-welding parts, components for machinery and materials-handling systems, and for molds to make metal, glass, and plastic components.

Beryllium also is used in small quantities in nickel- and aluminum-base alloys. Miniature electronic connector components that operate at high temperatures are the main use for beryllium-nickel alloys. Beryllium-aluminum alloys are used as castings in the aerospace industry. Addition of small quantities of beryllium to magnesium alloys inhibit oxidation. Beryllium metal, which averages about 20% of annual domestic demand, is used principally in aerospace and defense applications. Its high stiffness, light weight, and dimensional stability over a wide temperature range make it useful in satellite and space vehicle structures, inertial guidance systems, military aircraft brakes, and space optical system components. Because metallic beryllium is transparent to X-rays, it is used in X-ray windows. In nuclear reactors, beryllium also serves as a canning material, as a neutron moderator, in control rods, and as a reflector. The metal has been used as a triggering device in nuclear warheads. Other applications for metallic beryllium include high-speed computer components, audio equipment components, and mirrors. In the U.S. space shuttles, several structural parts and brake components used beryllium.

Beryllium oxide (beryllia) is an excellent heat conductor, with high hardness and strength. This material also acts as an electrical insulator in some applica-

TABLE 5

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

Source: Bureau of the Census.

TABLE 6

U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1989	Non-MFN Jan. 1, 1989
Ore and concentrate	2617.90.0030	Free	Free
Unwrought beryllium	8112.11.6000	8.5% ad val.	25.0% ad val.
Beryllium, wrought	8112.19.0000	5.5% ad val.	45.0% ad val.
Beryllium waste and scrap	8112.11.3000	Free	Free
Beryllium-copper master alloy	7405.00.6030	6.0% ad val.	28.0% ad val.
Beryllium oxide or hydroxide	2825.90.1000	3.7% ad val.	25.0% ad val.

tions. Beryllium oxide, averaging about 15% of U.S. demand, serves mainly as a substrate for high-density electronic circuits for high-speed computers, automotive ignition systems, lasers, and radar electronic countermeasure systems. Because it is transparent to microwaves, microwave communications systems and microwave ovens may use beryllium oxide.

Because of its high cost compared with that of other materials, beryllium is used in applications in which the properties are crucial. Steel, titanium, or graphite composites substitute for beryllium metal in some applications, and phosphor bronze substitutes for beryllium-copper alloys, but these substitutions would result in substantial loss in performance.

Industry Structure

Although beryllium is a constituent of over 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.

The United States is the only market economy country that can process beryllium ore and concentrates into beryllium products. Brush Wellman mines bertrandite and converts this ore, along with beryl, to beryllium hydroxide at its facility in Delta, UT. Beryllium hydroxide is shipped to the company's plant in Elmore, OH, where it is converted into beryllium alloys and metal. Brush Wellman also produces beryllium oxide from the hydroxide at a plant in Tucson, AZ. At a plant in Reading, PA, NGK Metals Corp. produces beryllium alloys from beryllium hydroxide produced by Brush Wellman, under a tolling agreement.

Production from labor-intensive beryl mining operations outside the United States is sporadic, except for the largest producers, Brazil, China, and the U.S.S.R. Two properties being developed in North America may provide additional beryllium ore supplies. A bertrandite mine near El Paso, TX, is being developed by Cyprus Minerals Co., and a deposit containing phenacite (a beryllium mineral) and rare-earth minerals is awaiting development by Highwood Resources Ltd.

Technology

Outside the United States, where the principal beryllium mineral mined is beryl, the main method used is pick-and-shovel mining of weathered pegmatites. After mining pegmatite ore, beryl crystals are hand-picked from the waste material.

In Utah, Brush Wellman mines bertrandite by open pit methods. Unlike beryl, in which the mineral can be identified by color and crystal structure, bertrandite mineralization cannot be recognized with the naked eye. Consequently, Brush Wellman conducts a geological and geochemical evaluation on a specific area, followed by a drilling program to determine if an economic ore body exists.

After delineating an ore body, overburden is removed within 7 feet of the ore body by a local earth-moving contractor during the winter and spring. This stripping operation requires about 9 months for completion. In the 7-foot cover remaining, drill benches are con-

TABLE 7

WORLD ANNUAL BERYL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(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.

TABLE 8

BERYL: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina	31	50	46	39	40
Brazil	877	[r]225	250	913	900
Madagascar[e 2]	50	50	50	([3 4])	([4])
Mozambique	[e]6	[r]1	([5])	([5])	—
Portugal	2	—	4	4	4
Rwanda (concentrate, gross weight)	27	—	—	—	—
South Africa, Republic of	5	3	([4])	([4])	—
U.S.S.R.[e]	1,900	1,900	[r]2,000	[r]2,000	2,000
United States[6] (mine shipments)	5,205	5,927	5,499	5,313	[3]4,592
Zimbabwe (concentrate, gross weight)	38	103	83	33	50
Total	8,141	[r]8,259	7,932	8,302	7,586

[e] Estimated. [p] Preliminary. [r] Revised.

[1] In addition to the countries listed, China produced beryl and Bolivia, Namibia, and Nepal may also have produced beryl, but available information is inadequate to formulate reliable estimates of production. Table includes data available through Apr. 27, 1990.

[2] Includes ornamental and industrial products.

[3] Reported figure.

[4] Less than 1/2 unit of measure; for Madagascar, production for 1988 and 1989 was 3 kilograms and 3 kilograms (estimated), respectively and for the Republic of South Africa, production for 1987 and 1988 was 135 kilograms and 72 kilograms, respectively.

[5] Revised to zero.

[6] Includes bertrandite ore, calculated as equivalent to beryl containing 11% BeO.

structed on 25-foot centers to take samples of the ore body at 2-foot intervals. Information obtained from analyzing the samples allows cross-sectional and contour maps to be produced. These maps are used to plan the mining and processing operations.

After the maps are prepared, the remainder of the overburden is removed, and the ore is mined, typically with a self-loading scraper. Because of the irregular ore-grade distribution in the ground, the ore is mined from predetermined areas and placed in a stockpile in layers to obtain a homogeneous blend. Drilling, sampling, and assaying the stockpiled ore generate a map that identifies ore-grade distribution throughout the stockpile. Stockpiled ore is trucked to the mill, which is about 50 miles away, for further processing.

Beryllium is commercially recovered from two ores—bertrandite and beryl. Brush Wellman is the only company in market economy countries with facilities to extract the beryllium values from both ores. Because of the difference in beryllium content of bertrandite and beryl, the ores are treated separately until the beryllium is dissolved, then the two solutions are combined.

Bertrandite is crushed, screened, and then leached with a sulfuric acid solution at about 95° C to dissolve the beryllium, forming a beryllium sulfate solution. In contrast, after crushing, beryl ore is heated to 1,700° C and quenched rapidly in water to form a frit. Heat treating the frit at 1,000° C, crushing, and then leaching with a concentrated sulfuric acid solution dissolves the contained beryllium, forming a beryllium sulfate solution.

After separating the solids from both beryllium sulfate solutions, the sulfate solutions are combined. Solvent extraction is used to remove additional impurity elements that were extracted with the beryllium. In solvent extraction, the beryllium sulfate solution contacts an organic solution, which does not mix with water. Beryllium is selectively dissolved in the organic solution, which is then mixed with an ammonium carbonate solution to form an ammonium beryllium carbonate solution.

In addition to beryllium, the solvent extraction step dissolves iron, aluminum, and fluoride. Hydrolysis with steam removes most of these impurities. Two additional hydrolysis steps to remove the ammonia and carbon dioxide result in the formation of beryllium hydroxide, the intermediate product used for production of beryllium metal, oxide, and alloys.

To produce beryllium-copper master alloy, beryllium hydroxide, electrolytic copper, and carbon are combined in an electric arc furnace. The resultant melt containing about 4% beryllium is cast into ingots. Remelting master alloy ingots with additional copper and other alloying elements yields the desired beryllium-copper alloy, which is then cast into slabs or billets. Slabs of beryllium-copper alloys are further processed to strip or plate, and billets are extruded into tube, rod, bar, and wire products.

Beryllium oxide powder is produced by dissolving beryllium hydroxide in sulfuric acid. The resulting beryllium sulfate solution is concentrated by evaporation and cooled to yield beryllium sulfate tetrahydrate crystals. Calcining these crystals at temperatures up to 1,430° C yields beryllium oxide powder.

To produce beryllium metal, beryllium hydroxide is dissolved in an ammonium bifluoride solution and evaporated to yield an ammonium beryllium fluoride salt. Decomposing the salt at 700° C to 900° C produces molten anhydrous beryllium fluoride, which is reacted with magnesium to produce metallic beryllium and magnesium fluoride. Cooling the mixture produces a solid cake that contains beryllium metal pebbles, magnesium fluoride, and unreacted beryllium fluoride. Crushing this mixture followed by water leaching, yields beryllium metal and magnesium fluoride. After separating the magnesium fluoride, which is recycled, the pebbles are vacuum melted to remove any slag trapped in them and cast into ingots.

Vacuum-cast ingots may be further processed into a powder produced by machining the ingot into chips. Grinding in a ball mill, impact grinding, or attrition grinding reduces the size of the chips. Each of these methods produces a different particle size powder. Beryllium powder is formed into billets by vacuum hot-pressing, hot-isostatic pressing, or cold isostatic pressing, depending on the end use of the material.[4]

Because of the toxic nature of beryllium dust and fines, the industry must maintain careful control on the cleanliness of the workplace. Personal protection equipment for the workers, medical monitoring programs, and source collection of dust, fumes, and mists are

TABLE 9

BERYLLIUM SUPPLY-DEMAND RELATIONSHIPS, 1979–89

(Metric tons of beryllium content)[1]

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION											
Mine production:											
United States	W	270	266	197	242	219	209	237	220	212	184
Rest of world	e112	103	119	121	119	141	117	93	97	p120	e119
Total	W	373	385	318	361	360	326	330	317	p332	e303
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines	W	270	266	197	242	219	209	237	220	212	184
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports, metal	1	W	1	8	8	32	51	19	50	12	14
Imports, beryl	38	62	78	96	80	48	60	54	83	35	24
Industry stocks, Jan. 1[2]	W	W	49	81	185	255	205	181	177	164	158
Total U.S. supply	W	367	394	382	515	554	525	491	530	423	380
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	W	49	81	185	255	205	181	177	164	158	153
Exports, metal and alloy	33	26	35	61	17	18	54	36	77	37	34
Government accessions	—	—	—	—	—	28	27	—	—	—	6
Industrial demand	275	292	278	136	243	303	263	278	289	228	187
U.S. DEMAND PATTERN											
Nuclear reactors	54	57	54	29	52	73	65	45	41	18	10
Aerospace	50	53	51	25	46	46	39	41	44	51	44
Electrical	103	109	101	49	87	105	91	108	109	66	36
Electronic components	44	47	46	24	41	53	46	62	68	80	88
Other	24	26	26	9	17	26	22	22	27	13	9
Total U.S. demand	275	292	278	136	243	303	263	278	289	228	187

e Estimated. p Preliminary. W Withheld to avoid disclosing company proprietary data.
[1] Beryllium content of material classified as ores is considered to be 4%.
[2] Beryl ore.

employed in all stages of beryllium processing to minimize harmful effects.

[1] Federal Register. Environmental Protection Agency. Mining Waste Exclusion. V. 54, No. 169, Sept. 1, 1989, pp. 36592-36642.

[2] Regan, J. G. Brush Wellman to Restructure. Am. Met. Mark., v. 97, No. 251, Dec. 28, 1989, p. 5.

[3] Bureau of Mines. Nonferrous Metal Prices in the United States Through 1988. Spec. Publ., 1989, pp. 13-15.

[4] National Materials Advisory Board. Beryllium Metal Supply Options. Natl. Acad. Sci., Washington, DC, NMAB-452, 1989, 124 pp.

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BISMUTH

By Stephen M. Jasinski

Stephen M. Jasinski is a physical scientist with the Branch of Nonferrous Metals. He has been the bismuth commodity specialist for 2 years. Domestic survey data were prepared by Tony E. Morris, Nonferrous Metals Data Section. International data were prepared by Harold Willis, International Data Section.

Owing largely to reduced use in alloys and steel, domestic consumption of bismuth declined. Bismuth was produced in the United States as a byproduct of lead refining. One company accounted for all primary production. Pharmaceutical and industrial compounds and pigments continued as the major chemical uses. Fusible alloys and additives to aluminum, malleable iron, and steel were the major metal uses. U.S. dealer prices for bismuth fell during the year due to the increased availability resulting from record-high imports and lower consumption.

TABLE 1

SALIENT BISMUTH STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Consumption	1,199	1,324	1,597	1,531	1,352
Exports[1]	122	42	38	147	122
Imports for consumption	907	1,129	1,581	1,641	1,880
Price, average, domestic dealer, per pound	$5.18	$3.25	$3.65	$5.78	$5.76
Stocks, Dec. 31: Consumer	230	346	294	433	440
World:					
Mine production (metal content)[2]	r4,407	3,457	2,886	p2,767	e2,762
Refinery production[2]	4,325	r4,367	4,290	p3,567	e3,595

e Estimated. p Preliminary. r Revised.
[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	1985	1986	1987	1988	1989
Chemicals[1]	601	663	748	679	659
Fusible alloys	277	290	334	332	272
Metallurgical additives	303	350	494	493	396
Other alloys	10	13	11	12	11
Other[2]	9	8	10	15	14
Total[3]	1,199	1,324	1,597	1,531	1,352

[1] Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.
[2] Includes experimental.
[3] Data may not add to totals shown because of independent rounding.

LEGISLATION AND GOVERNMENT PROGRAMS

In April, a Department of Defense study recommended reducing the goal for bismuth in the National Defense Stockpile from the current 997,903 kilograms to 480,808 kilograms over an 8-year period. If approved, disposal would begin at 57,924 kilograms annually in 1990 and 1991. The stockpile inventory on December 31, 1989, was 944,087 kilograms.

DOMESTIC PRODUCTION

Production at the ASARCO Incorporated refinery in Omaha, NE, decreased slightly in 1989. Data are not published to avoid disclosing company proprietary information. Several firms produced small quantities of secondary bismuth, primarily from fusible alloy scrap.

CONSUMPTION AND USES

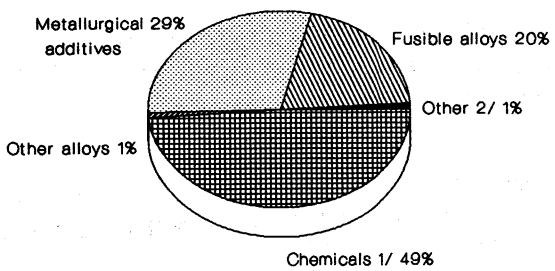
The use of bismuth in metallurgical additives fell due to reduced production of free-machining steel. Chemical usage rose and accounted for almost one-half of total domestic consumption for the first time since 1986. Major chemical uses included compounds for treating digestive tract ailments, pearlescent pigments for cosmetics and plastics, and varistors and ceramic capacitors.

PRICES

The range of dealer price quotations for bismuth, as reported in Metals Week,

FIGURE 1

BISMUTH METAL CONSUMED IN THE UNITED STATES IN 1989



1/ Includes industrial and laboratory chemicals, cosmetics, and pharmaceuticals.
2/ Includes experimental.

TABLE 3

U.S. EXPORTS OF BISMUTH, BISMUTH ALLOYS, AND WASTE AND SCRAP, BY COUNTRY

Country	1988		1989	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Argentina	25	$2	—	—
Belgium	741	10	8,382	$14
Canada	23,205	401	15,554	263
Chile	—	—	54	2
France	381	5	787	20
Germany, Federal Republic of	20,191	27	17,914	26
Greece	136	3	—	—
Hong Kong	—	—	18,696	10
India	—	—	300	2
Israel	136	2	1,964	16
Jamaica	113	2	—	—
Japan	26,291	175	18,755	50
Korea, Republic of	2,086	49	50	6
Mexico	399	5	121	4
Netherlands	162	2	—	—
New Zealand	34	2	—	—
Panama	702	4	—	—
Saudi Arabia	233	3	—	—
Singapore	470	8	220	11
Sri Lanka	—	—	100	4
Sweden	—	—	55	14
Switzerland	133	2	46	2
Taiwan	1,080	42	1,455	39
United Kingdom	69,813	462	37,278	55
Venezuela	454	7	440	4
Total[1]	146,784	1,213	122,171	540

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

Source: Bureau of the Census.

decreased gradually throughout the year from a high of $6.75 to $6.85 per pound in January to $4.40 to $4.50 per pound in December. The decline in price was mainly attributed to excessive world stock levels.

FOREIGN TRADE

U.S. imports for consumption of bismuth metal reached a record level, up 15% from 1988. Belgium was the largest source of refined bismuth.

Effective January 1, 1990, the import duty for bismuth articles, including waste and scrap (Harmonized code 8106.00.0000), was free for most favored nations (MFN) and 7.5% ad valorem for non-MFN.

WORLD REVIEW

Bismuth was recovered mainly as a byproduct of processing lead and copper ores and only in Bolivia was it mined as the principal product. World mine and refinery production remained nearly the same as 1988. Mexico led in both mine and refinery production for the third consecutive year.

TABLE 4

	1988	1989
Production	524	502
Imports	325	408
Exports	69	16
Consumption[1]	511	464
Producer stocks, Dec. 31	78	120

[1] Reported shipments from smelters. Does not include imports.

Source: MITI (Trade data), Bismuth Institute.

The United States and Japan were the largest consumers of bismuth and were also the only countries for which published data on end uses were available. The demand for bismuth has been growing rapidly in Japan since 1987, mainly for varistors and ceramic capacitors, although reported consumption dropped slightly in 1989.

TABLE 5

JAPAN—CONSUMPTION BY USE

(Metric tons)

Use[1]	1988	1989
Catalysts	5	8
Ferrites[2]	265	242
Fusible alloys	72	35
Metallurgical additives	95	82
Pharmaceuticals	25	22
Other	49	75
Total	511	464

[1] Reported shipments from smelters. Does not include imports.
[2] Includes varistors and capacitors.

Source: Bismuth Institute.

CURRENT RESEARCH

An organic bismuth compound was developed that makes plastics detectable to X-rays. The compound, triphenylbismuth, is heat-stable, moisture-resistant, and flame-retardant. Plastic explosives and weapons containing the additive would be detectable in airport security systems.[1]

The Bismuth Institute Information Center (47, rue de Ligne, B. 1000—Brussels, Belgium) collects detailed information on the uses of bismuth. It publishes a bulletin several times a year with articles on current research and lists new patents issued in the world involving bismuth.

OUTLOOK

World reserves and production capacity are sufficient to meet foreseeable demand for bismuth into the next century. Domestic consumption is expected to grow slowly in the next decade. Bismuth has the advantage of being nontoxic. It is expected to remain important in pharmaceutical applications and as a substitute for lead in free-machining steel and pigments.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF METALLIC BISMUTH, BY COUNTRY

Country	1988		1989	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Belgium	340,157	$3,781	835,675	$9,722
Bolivia	—	—	32,001	418
Canada	82,057	889	23,120	333
China	204,310	2,315	35,082	500
Germany, Federal Republic of	278	11	62,717	897
Hong Kong	22,801	280	700	10
Italy	5,083	56	—	—
Japan	13,163	96	1,068	543
Korea, Republic of	38,861	417	12,000	161
Mexico	448,540	5,048	390,815	4,028
Netherlands	20,090	240	6,161	115
Peru	188,942	2,096	271,444	2,379
Switzerland	17,997	167	—	—
United Kingdom	259,147	2,958	209,538	2,481
Total[1]	1,641,426	18,354	1,880,321	21,586

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

Source: Bureau of the Census.

[1] Advanced Materials & Processes. Textiles, Plastics Gain Unusual Properties, v. 135, No. 6, June 1989, p. 12.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications.

Bismuth. Reported quarterly in Mineral Industry Surveys.

Bismuth. Ch. in Mineral Commodity Summaries, annual.

TABLE 7

WORLD ANNUAL BISMUTH PRODUCTION CAPACITY, DECEMBER 31, 1989

(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
United Kingdom	—	400
United States	700	500
U.S.S.R.[e]	100	100
Yugoslavia[e]	150	150
World total	8,200	7,700

[e] Estimated.

TABLE 8

BISMUTH: WORLD MINE AND REFINERY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	Mine output, metal content					Refined metal				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Australia[e 3]	1,400	1,000	350	400	400	—	—	—	—	—
Belgium[e]	—	—	—	—	—	610	1,000	865	795	750
Bolivia	159	43	1	13	20	—	—	—	—	—
Canada[4]	201	153	165	181	164	[e]180	212	218	225	272
China[e]	260	260	260	275	275	260	260	260	275	275
France	70	95	[e]90	[e]90	90	—	—	—	—	—
Germany, Federal Republic of	—	—	—	—	—	[e]400	[e]400	[e]400	—	—
Italy	—	—	—	—	—	54	66	44	32	45
Japan[5]	[e]195	[e]190	[e]165	[e]160	150	642	640	546	524	500
Korea, Republic of[5]	[e]135	[e]136	[e]145	[e]140	140	135	136	145	[e]140	140
Mexico[5]	[e]970	[e]790	[e]1,065	[r e]1,005	1,050	925	749	1,012	958	1,000
Mozambique	1	([6])	—	—	—	—	—	—	—	—
Peru	785	605	412	[e]330	300	738	569	387	[e]310	290
Romania[e]	80	80	75	65.	60	80	80	75	65	60
U.S.S.R.[e]	83	84	85	85	85	83	84	85	85	85
United Kingdom[e]	—	—	—	—	—	150	150	180	135	150
United States	W	W	W	W	W	W	W	W	W	W
Yugoslavia	[e]68	[e]21	[e]73	23	[7]28	68	21	73	23	[7]28
Total	[r]4,407	3,457	2,886	2,767	2,762	4,325	[r]4,367	4,290	3,567	3,595

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] Table includes data available through Mar. 30, 1990. 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, the German Democratic Republic, 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] It is believed that bismuth-rich residues were stockpiled at the mine site during the period 1983–85 and released into the world market in subsequent years.

[4] Figures listed under mine output are reported in Canadian sources as production of refined metal and bullion plus recoverable bismuth content of exported concentrate.

[5] Mine output figures have been estimated based on reported metal output figures.

[6] Less than 1/2 unit.

[7] Reported figure.

BORON

By Phyllis A. Lyday

Mrs. Lyday has covered boron for 11 years. Domestic survey data were prepared by Pamela Shorter, mineral data assistant, Industrial Mineral Data Section. International data prepared by G. Jacarepaqua, international data assistant, Geographic Data Section.

U.S. production and sales of boron minerals and chemicals decreased during the year. Domestically, glass fiber insulation was the largest use for borates, followed by sales to 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 Bureau of Mines from two separate, voluntary surveys of U.S. operations. Of the three operations to which a production survey request was sent, all responded, representing 100% of the total boron sold or used shown in tables 1 and 7. A Bureau canvass of the three U.S. producers also collected data on domestic consumption of boron minerals and compounds shown in tables 2 and 3.

LEGISLATION AND GOVERNMENT PROGRAMS

The House of Representatives introduced legislation to provide a separate tariff classification and a temporary duty suspension on opal borosilicate glassware imported from Mexico and distributed nationwide by Crisa Corp. of Laredo, TX. The proposed legislation would permanently reduce the duty to 7.2% and temporarily suspend the duty entirely on opal borosilicate glassware imported in sets. Opal borosilicate glassware is sold exclusively door-to-door to low- to moderate-income consumers. At yearend, no action had been taken on the proposal.[1]

The House Mining and Natural Resource Subcommittee, on June 23, 1987, held an oversight hearing on how well the Mining Law of 1872 serves the Nation and the mining industry. Sodium borate minerals, which are excluded from the Law, are included under the Mineral Leasing Act of 1920, as amended and supplemented.

TABLE 1

SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[1]	1,151	1,135	1,256	1,149	1,114
Boron oxide (B_2O_3) content	577	571	625	578	562
Value	$404,775	$426,086	$475,092	$429,667	$429,806
Exports:					
Boric acid:[2]					
Quantity	44	38	61	56	42
Value	$21,598	$23,562	$34,180	$35,301	$32,613
Sodium borates:					
Quantity[3]	565	566	552	546	646
Value[e]	$151,000	$161,000	$243,600	$240,800	$361,000
Imports for consumption:[4]					
Boric acid:					
Quantity	5	5	2	3	3
Value	$5,121	$3,824	$2,900	$2,020	$2,197
Colemanite:					
Quantity	30	15	7	17	15
Value	$24,620	$8,770	$2,763	$7,790	$4,202
Ulexite:					
Quantity	28	38	47	31	27
Value	$11,120	$17,766	$20,597	$7,480	$1,552
Consumption: Boron oxide (B_2O_3) content	327	307	335	356	315
World: Production	2,505	[r]2,510	[p]2,699	[e]2,761	[e]1,114

[e] Estimated. [p] Preliminary. [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, and 7,257 tons in 1989.

ISSUES

Boron mining in the southwest desert areas could be adversely affected by the recent declaration of the Fish and Wildlife Service granting "emergency endangered status" for the Mojave desert tortoise.[2]

PRODUCTION

The majority of the boron production continued to be from Kern County, CA, and the rest was from San Bernardino County.

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.

United States Borax & Chemical Corp., a part of RTZ Borax 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 U.S. Borax's extensive kernite ore reserves. The boric acid was produced to compete with imported colemanite used in glass manufacture. The majority of material was shipped to U.S. Borax's storage, Wilmington, CA. Products made at Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate.

During 1989, U.S. Borax signed a 15-year contract with Mojave Pipeline Company for 100% of the natural gas used in the co-generation operations. The 386-mile pipeline is proposed from the Arizona-California border to Kern County.[3]

Corona Corp. purchased the remaining 20% interest held by Mountain States Mineral Enterprise Inc. in the Fort Cady colemanite property in California and renamed the project the Fort Cady Minerals Corp. This gave Corona 100% control of the project. Corona was in the process of negotiating with a number of commercial banks for $85 million of production financing. The design production of 81,000 tons of boric acid per year was planned. The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on bromine in units most consistent with international usage, will henceforth report data in kilograms (kg) and metric tons (mt) unless otherwise noted. An engineering contract was awarded to Kilborn International Ltd. Canada. Plant construction was expected to be completed in 1992. Reserves were estimated at 147 million tons of ore grading 6.4% boron oxide.

CONSUMPTION AND USES

U.S. consumption of borates decreased. Glass fiber insulation and glass fiber primarily used as reinforcement for plastics continued to be the largest consuming industries.

The use of borates in glass fiber thermal insulation, primarily used in new construction, was the largest area of demand for borates, but decreased over that reported in 1988. Cellulosic insulation, the seventh largest area of demand, increased.

During 1989, PPG Industries Inc. sold its 50% interest in Fiberglas Canada for $200 million to its partner Owens-Corning Fiberglas. Fiberglas Canada produced fiberglass mainly for insulation, but PPG's interest in the material was for use in plastic reinforcements and circuit boards. Fiberglas Canada had six plants near the Canadian border.[4]

The second major market for borates, manufacturing high-tensile-strength glass fiber materials for use in a range of products, showed a decrease in demand.

A fiberglass reinforced wheel utilizing a vinyl ester compound won an award in 1989 for the most innovative use of plastics. The award was given to Chrysler Motors Corp. by the Society of Plastics Engineers.[5]

The construction of the first glass-fiber, wide-band digital cable was across the Atlantic Ocean. The ocean cable can transmit more than 30,000 telephone calls and communication services at the same time. The cable stretches from Tuckerton, NJ, on the East Coast of the United States, some 6,000 kilometers across the Atlantic to Denmark, France, and Widemouth, England.[6]

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 and assisted with fiber formation during processing and allowed for thermal expansion.

After almost 16 years of research and design and 5 years of construction, the U.S. Department of Energy was close to finishing the Nation's largest and most technically complex nuclear-waste processing plant. The $930 million Defense Waste Processing Facility at the Savannah River Plant in Aiken, SC, will convert high-level nuclear waste from weapons production into solid forms from a glass process used in France since 1978. The facility planned to immobilize 34 million gallons of highly radioactive liquid, sludge, and salt that have been accumulating in carbon steel storage tanks since 1954. An in situ salt treatment involves adding a boron compound to salt tanks to separate radioactive cesium. The waste cesium in a molten glass mixture is poured into a stainless steel canister 2 feet in diameter and 10 feet high.[7] The canisters will be stored in a waste-storage building. Because of delays in the Nevada repository, a second storage building will be built at the Savannah River site.

Boron compounds in cleaning and bleaching were the fourth major end use. Oxygen systems may replace chlorine systems. In the oxygen system, activators produce acids in the wash water. These acids can react with sodium perborate to generate a bleach. Lever Bros. (USA) and Kao Corp. (Japan) are working with perborate activators that also generate softeners. Proctor & Gamble's Tide With Bleach

is the only major commercial U.S. detergent to use a boron activator system and is the first multifunctional detergent on the U.S. market.[8] About 60 million pounds of perborates are consumed in detergent applications as compared with about 90 to 100 million pounds 20 years ago. Europe consumed about 1 billion pounds annually because of the higher temperature used in wash water.[9]

Boron compounds continued to find application in the manufacture of biological growth control chemicals for use in water treatment, algicide, fertilizers, herbicides, and insecticides. Boron can be applied as a spray, and incorporated in herbicides, fertilizers, and irrigation water.

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. Steel containing less than 4.75% boron can be forged, and steels with up to 6% boron can be cast. An addition of boron to low-carbon steels reduces the amount of nickel, chromium, or molybdenum required. Boron-containing steels do not require some of the heat-treating steps required in other alloys, which results in significant energy savings. Boron can also be diffused into the surface of metal (boronizing) to make a corrosion-and abrasion-resistant metal.

Boron is used in neodymium-iron magnets to give a one-directional crystal structure that provides the magnet with one-directional strength. There are two basic methods for manufacturing NdFeB magnetic material: sintering and melt spinning.[10]

Allied Signal Inc. began production of a rapid-solidification amorphous metal ribbon, Metglas. The ribbon was produced at a site in Conway, SC, with capacity of 60,000 tons per year. Transformers made from Metglas, a boron, iron, rare-earth material, offer utilities energy savings of up to 70%.[11]

Experiments by the Australian Defenses Science and Technology Organization's Aeronautical Research Laboratories in Melbourne, Australia, have used boron fibers surrounded by an epoxy matrix to repair metal structures since about 1975. The material supplier is Textron Specialty Materials, formerly Avco Specialty Materials, which has been supplying boron material for use on military aircraft, for 20 years. Annual sales are reported at about $20 million worth of boron a year. The technique, originally developed for use on military aircraft, is being considered for repair of civil applications. Boron-epoxy patches are about five times stronger and six times stiffer than aluminum alloys. The patches can be applied in thinner layers to achieve the same amount of reinforcement, which is important on aerodynamic surfaces.[12]

Union Carbide Corp., Advanced Ceramics Division, Cleveland, OH, offered a titanium diboride powder for use in ceramic armor, cutting tools, bearings or bearing liners, and crucibles. The new compound can be sintered to more than 97.5% of theoretical density without pressure.[13]

Modern manufacturing techniques and higher volume production have lowered the cost of boron nitride. Hexagonal boron nitride is synthesized into low purity powder. Further processing via chemical or thermal techniques yields larger crystals of higher purity and greater stability. Hexagonal boron nitride powder is a raw material for producing cubic boron nitride. The powder is heated under pressure in the presence of a solvent and catalyst.[14]

TABLE 2

U.S. CONSUMPTION OF BORON MINERALS AND COMPOUNDS, BY END USE

(Metric tons of boron oxide content)[1]

End use	1988	1989
Agriculture	14,362	14,583
Borosilicate glasses	34,136	30,600
Enamels, frits, glazes	9,923	8,149
Fire retardants:		
Cellulosic insulation	11,167	11,920
Other	641	509
Glass-fiber insulation	103,355	91,736
Metallurgy	5,175	3,040
Miscellaneous uses	28,824	14,729
Nuclear applications	679	611
Soaps and detergents	26,446	25,145
Sold to distributors, end use unknown	75,352	73,460
Textile-grade glass fibers	45,420	40,499
Total	355,480	314,981

[1] Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 3

U.S. CONSUMPTION OF ORTHOBORIC ACID, BY END USE

(Metric tons of boron oxide content)[1]

End use	1988	1989
Agriculture	209	231
Borosilicate glasses	5,019	4,862
Enamels, frits, glazes	1,519	1,383
Fire retardants:		
Cellulosic insulation	1,769	1,683
Other	641	509
Insulation-grade glass fibers	702	1,081
Metallurgy	366	278
Miscellaneous uses	8,596	9,779
Nuclear applications	510	494
Soaps and detergents	183	57
Sold to distributors, end use unknown	27,271	23,379
Textile-grade glass fibers	23,082	22,493
Total	69,867	66,229

[1] Includes imports.

PRICES

Prices for domestic borax compounds and colemanite increased significantly. Industrial Minerals Magazine (London) reported Turkish colemanite c.i.f. to Europe was $290 to $325 per ton. Prices obtained often vary widely according to type, source, quality, quantity purchased, and application. Hence, the quotations can only serve as a guide to prices by producers and dealers. Boron compounds and ore were also 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 only to serve as a guide to yearend price levels.

Prices for European borates published by Metal Bulletin 1989 per ton were as follows: Anhydrous borax $1,000 to $1,204; decahydrate borax, $550 to $762; pentahydrate borax, $510 to $846; and boric acid $846 to $1,354.

FOREIGN TRADE

The majority of material from the U.S. Borax facility in Boron, CA, was

TABLE 4

YEAREND 1989 PRICE FOR BORON MINERALS AND COMPOUNDS PER METRIC TON[1]

Product	Price Dec. 31, 1989 (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]	322
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, U.S. Borax & Chemical Corp., high-purity anhydrous, 99% B_2O_3, 100-pound bags, carlots	2,717
Colemanite, Turkish, 40%–42% B_2O_3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC[3]	485

[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. 236, No. 26, Dec. 25, 1989, pp. 26-34.
[3] American Borates Co.

shipped to storage, loading, and shipping facilities at Wilmington, CA. A large part of the output was exported to Western Europe from Wilmington to Botlek, Netherlands.

Exports to the United States from Turkey for 1988, as reported by the Istanbul Minerals Exporter's Union, of boron material or minerals and value were as follows: Colemanite 97,000 tons, $19 million; ulexite 11,000 tons, $15 million; boric acid 24 tons, $3,000; and refined borax 12,000 tons, $3 million.[15]

WORLD REVIEW

Capacity

The data in table 7 are rated capacity for mines and refineries as of December 31, 1989. 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. Any restrictions to capacity utilization related to legal, political, or environmental restraints have been footnoted.

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

Borax production exceeded 200,000 tons during 1988. Production at Boroquimica S.A.M I.C.A F., a subsidiary of RTZ Corp., at a tincal deposit at Tincalayu, north-central Salar del Hombre Muerto in Salta Province, was 30,000 tons of boron oxide equivalent.[16] Industrial Quimicas Baradero S.A. also had significant production. Installed processing capacity of 37,700 tons was at plants in Campo Quijano and Tincalayu, in the Province of Salta. Exports reached 26,500 tons in 1988.[17]

Boro Sur S.A. operated a boric acid plant in Buenos Aires Province approximately 25 kilometers from Buenos Aires. Production was reported as 120 tons monthly with a planned increase to 160 tons in the first quarter of 1990. Production of 300 tons per month was planned by yearend 1990. The ore is colemanite from a mine in Salta Province.[18]

Bolivia

Lithium Corp. of America (Lithco) signed a preliminary agreement with the Ministry of Mines to explore and produce lithium and other elements from brines in the Salar de Uyuni. Under the same contract, Lithco was authorized to mine ulexite found within the salt crust and clay sediments bordering the river Rio Grande of Lipez.[19]

Chile

Jacobs Engineering Group Inc., CA, was awarded the feasibility study on the development of 30,000 tons per year of boric acid at the Salar de Atacama. The contract award was made by Sociedad Minera Salar de Atacama Ltda. (Minsal), a consortium of AMAX Exploration Inc. (63.75%), Corfo (25%), and Molibdenos y Metales (Molymet, 11.23%).

Commercial production from the $300 million project was scheduled for mid-1992. The Salar de Atacama is one of about 74 arid salt basins in the Chile-Bolivia-Argentina border region. The salt nucleus covers more than 1400 square kilometers of which the top 40 meters is porous and filled with concentrated brine.

At capacity, the project will also produce 500 tons per year of potassium chloride, 230 tons of potassium sulfate, and up to 14 tons of lithium salts. 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.

Minsal products would be transported from the plant by rail to a ship bulk-loading dock at Jejillones. Containers of boron and lithium could be shipped from Antofagasta.

AMAX was developing a financial package and negotiating the use of debt-equity exchanges with the Government before deciding to proceed with the project.[20]

Reserves are adequate for 30 years of production. The reserves contain about 47 million tons of potassium chloride equivalent, 117 million tons of lithium, and 4 million tons of boric acid equivalent. Brine products can be separated and recovered without further processing. Two sets of evaporation pans will

TABLE 5

U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1988			1989		
	Boric acid[1]		Sodium borates[2] (metric tons)	Boric acid[1]		Sodium borates[2] (metric tons)
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	1,572	$899	7,250	1,338	$982	8,271
Bangladish	—	—	110	—	—	168
Belgium-Luxembourg	1,412	481	975	—	—	1,290
Brazil	88	63	1,503	141	133	2,831
Canada	5,840	2,952	[3]49,059	4,822	2,927	50,966
Chile	—	—	5	1	2	1,310
China	196	112	4,160	—	—	8
Colombia	130	92	1,708	237	132	1,241
Costa Rica	5	4	1,373	17	15	90
Dominican Republic	—	—	87	128	20	37
Ecuador	—	—	748	—	—	847
Egypt	—	—	—	—	—	1,380
El Salvador	—	—	24	—	—	5
France	—	—	77	—	—	222
Germany, Federal Republic of	1,293	798	248	313	138	12
Guatemala	—	—	31	28	17	39
Haiti	—	—	544	20	2	130
Honduras	—	—	38	—	—	82
Hong Kong	2,154	1,226	7,937	270	199	3,536
India	—	—	3,351	26	10	6,593
Indonesia	286	182	7,231	380	279	5,681
Israel	53	36	227	87	65	168
Jamaica	15	6	—	3	6	5
Japan	25,940	16,328	57,676	20,270	15,512	46,593
Korea, Republic of	2,507	1,358	22,244	1,863	1,563	15,651
Malaysia	133	78	3,978	56	48	5,645
Mexico	3,157	1,729	[3]28,840	2,662	1,824	23,187
Netherlands	3,850	4,011	300,920	3,647	4,620	404,474
New Zealand	1,126	676	2,325	1,363	857	2,817
Pakistan	—	—	953	—	—	152
Panama	10	4	43	24	14	28
Papua New Guinea	96	57	160	32	24	32
Peru	22	15	127	57	22	92
Philippines	113	69	2,205	135	108	1,933
Romania	280	176	—	—	—	—
Saudi Arabia	28	19	830	42	30	389
Singapore	413	249	4,090	62	40	1,507
South Africa, Republic of	105	75	1,577	65	58	1,751
Spain	—	—	12,249	—	—	35,642
Sri Lanka	—	—	—	9	7	16
Taiwan	3,361	2,093	16,900	3,082	2,332	17,561
Thailand	410	291	2,012	400	329	2,267
United Kingdom	64	73	238	27	48	181
Venezuela	1,728	1,130	1,600	336	241	704
Other	27	19	303	10	8	63
Total	56,412	35,301	545,956	41,953	32,613	645,597

[1] Bureau of the Census.
[2] The Journal of Commerce Port Import/Export Reporting Service.
[3] U.S. exporters of sodium borates.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	82	$70	7	$5
Chile	707	300	1,084	492
France	—	—	7	11
Germany, Federal Republic of	21	53	19	37
Italy	1,923	1,580	1,627	1,471
Japan	—	—	35	82
Netherlands	—	—	65	42
Taiwan	—	—	1	1
United Kingdom	16	17	53	56
Total	2,749	2,020	2,898	2,197

[1] U.S Customs declared values.

Source: Bureau of the Census.

receive high potassium and high sulfate brine, respectively. Sequential precipitation will produce sodium chloride, mixed sodium, potassium chlorides, lithium, and sulfates in a variety of compounds. Boron will remain in solution until extraction before discharge back into the salt basin.[21]

Chile's National Geological and Mining Service studied a large deposit at Salar de Surire, Arica Province, northern Chile. Surveys of the area revealed 34.5 million tons of ulexite ore bearing more than 4.5% boron. Brines containing lithium and potassium were also part of the deposit.

Minero del Boro had produced ulexite concentrates and boric acid since 1984. Deposits mined were Salar de Pintados, the Salar de Cariquima, and the Salar de Quillagua, in Tarapaca Province. The company had recently completed an expansion in capacity and further expansion was planned.[22]

Quimica e Industrial del Borax Ltda. (Quiborax) had completed a $3 million plant to treat 1,000 tons per month of ulexite to produce boric acid at Lluato. Mined production was from the Salar de Surire in Arica Province. Quiborax also owned the mineral rights to another ulexite deposit in the Salar de Ascotan, which is north of Salar de Surire.

TABLE 7

WORLD BORON ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY[1]

(Thousand metric tons of boron oxide content)

	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	472
Total	477
World total	[2]1,300

[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.

China

The Ministry of Chemical Industry mines and processes minerals used as chemical feed-stocks, such as borates. The processing of boron as the mineral Szaibelyite in Lioning Province was estimated to be 100,000 metric tons per year. Many minerals of high unit-value, including boron, are of current or potential importance in world trade. China has a rich and varied mineral resource base and all the requisite conditions that tend to stimulate production and utilization of industrial minerals: a large, growing population, rapidly increasing living standards, an expanding industrial base, a growing need for export earnings, facilities for rail and water transport, and abundant low-cost labor.[23]

Netherlands

Botlek can receive 10 40,000-ton shipments per year from the United States. Bulk carriers unload over a 5-day period at the rate of 8,000 tons per day. European consumption of borates is about 350,000 tons per year. At Botlek, bulk products from U.S. Borax that are not required in bulk are packed into 50-kilogram bags or 1-ton "superbags." Specialty products from Wilmington are usually repackaged into 25- or 50-kilogram paper bags which are then stretch-wrapped.[24]

Peru

Production of ulexite used to produce boric acid was estimated at 2,000 tons of boron oxide equivalent.[25]

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.

Borate deposits are in two different zones in northeast-southwest-trending basins in Turkey. In the Bigadic district, borate minerals formed in two distinct lower and upper zones separated by thick volcanic beds. Colemanite and ulexite are predominant in both zones. Other borates, including howlite, probertite, and hydroboracite, are found in the lower borate zone; whereas inyoite, meyerhofferite, pandermite, terschite, hydroboracite, howlite, tunellite, and rivadavite are found in the upper borate zone. The average colemanite and ulexite ore grades are 30% and 20%, respectively.[26]

United Kingdom

Borax Holdings Ltd. changed its name to Borax Consolidated Ltd. Borax Consolidated Ltd. was formed as an Anglo-American joint venture. Borax Consolidated purchased the remaining borax interest in 1913. The

Borax group joined RTZ Corp. PLC in a merger in 1968. The name change was to reflect the more active role of borax in the production and marketing.

Borax celebrated its 90th year of operation and was actively making improvements during 1989. Five small refining operations in Europe were merged into one large automated facility in Coudekerque, northern France. Capacity was expanded at the bulk terminal and depot in Botlek, near Rotterdam, Netherlands. New warehousing was brought into operation in Humberside, United Kingdom, and two new facilities in Valencia and Castellon, Spain, were scheduled to open in 1990.

Borax's European network now incorporates Borax Francais SA, Deutsche Borax GmbH, Compagnie des Borates SA, Borax NV, and La Productora de Borax y Articulos Quimicos SA.[27]

CURRENT RESEARCH

Air Products and Chemicals Inc., under a Department of Energy, Office of Industrial Programs grant of $366,000, was working to improve the process economics and energy efficiency of glass melting.[28]

Chemists at Kyoto University, Japan, have developed new boron-containing polymers. Boron is a neutron absorber used in nuclear-shielding applications that could benefit from the new process. The research also included a description of the group's conversion of polyboranes to polyalcohols and polyketones.

In addition, a combination of organic boron compounds produced a polymer of steadily increasing molecular weight until the polymer gelled. A polymer of molecular weight of 24,000 was produced. Unlike pure boranes, which are explosive, the resins produced were completely stable in air. The polyborane resins could be decomposed to low-molecular-weight products by bubbling air through their solutions in organic solvent, thus making borane processing safe.[29]

Chemists announced the preparation and characterization of the first example of boron-containing compounds named boratirenes. The compounds were prepared by the photochemical rearrangement of metal salts of a borate ion. The compound exhibits a yellow to orange color even in solution.[30]

Boron-doped synthetic diamond layers is believed to be a very useful material for electronics. A process for the deposition of boron-doped semiconducting diamond by a depositional process was demonstrated by Case Western Reserve University. Natural diamond crystals containing small amounts of boron are generally blue. The famous Hope diamond is an outstanding example of this type of diamond. Boron is responsible for the color and the semiconducting properties. The properties of high-temperature stability, low dielectric constant, and high electrical-field breakdown voltage make doped diamond a good material for high frequency, high-power semiconducting devices. Research is continuing toward electronic applications of diamond technology.[31]

General Electric Co. developed a resin that can be produced in powder form and packed into a carbon or glass matrix that varies fabrication process time. The powder triggers a catalyst upon heating that causes the molten resin to harden. The process allows the resin to fill all voids, thus increasing the strength of the composite.[32]

TABLE 8

BORON MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina	158	192	185	257	200
Chile	5	6	13	32	30
China[e]	27	27	27	27	27
Peru	[e]10	23	23	[r e]15	18
Turkey	954	928	[e]1,000	[e]1,200	1,400
U.S.S.R.[e]	200	200	200	200	200
United States[2]	1,151	1,135	1,256	1,149	[3]1,114
Total	2,505	2,511	2,704	2,880	2,989

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through May 11, 1990.
[2] Minerals and compounds sold or used by producers, including both actual mine production and marketable products.
[3] Reported figure.

OUTLOOK

Production and consumption of boron minerals and compounds have decreased between 1980 and 1989. There are several factors that may give to misleading outlooks in consumption. One is that production and imports reported in 1 year may be utilized over a period of years. In addition, environmental concerns may change the demand for boron significantly in a short period. The regulation of the use of fire retardants in products has resulted in changes in boron usage as a fire retardant.

Agriculture

Boron usage in agriculture declined to a low in 1982 and has declined during the last decade. The primary reason for the decline was attributed to the decrease in the number of operating farms during this period. Farming exports were showing increased strength, and demand for boron usage in agriculture was expected to increase 8% per year for the next 5 years.

Ceramics and Glass

Boron usage in ceramics and glass increased over the decade, reaching a peak in 1984 that was a 36% increase over the prior year. This spike was probably a demand to balance the sharp 41% decline in 1982. Ceramics and glass have both faced competition with polymers. Consumption was expected to continue to increase at the rate of 4% per year for the next 5 years.

Coatings and Plating

Boron usage has experienced a decline as a protective coating for steel products and as a glazing on ceramic tiles. This decline was a result of the demand for polymers that substituted for boron in

the coatings and platings. Demand was expected to remain at 1988 levels.

Fabricated Metal Products

Boron usage decreased in metal products during the last decade. Many traditional metals 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 has declined, primarily as chlorine bleaches and cold water washes have replaced boron soap powders. Recent concern for environmental effects of chlorine have reversed that 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 for the next 5 years.

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 as marketed is usually in excess of 40%.

Tincal, 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. U.S. Borax discontinued the production of a "crude" borax pentahydrate for foreign customers, but began production of textile-fiberglas-grade (TFG) boric acid for domestic use.

Boric acid is a white, odorless, crystalline solid sold in technical national formulary and special quality grades as granules or powder. Boron oxide is a hard, brittle, colorless solid resembling glass that is ground and marketed most often under the name anhydrous boric acid.

Elemental boron is a dark-brown powder in the amorphous form and a yellowish-brown, hard, brittle solid in the monoclinic crystalline form. Boron is marketed in grades from 90% to 99% purity.

Ferroboron is a name given to a variety of boron-iron alloys, containing 0.2% to 24% boron, used primarily to introduce small quantities of boron into specialty steels.

The boron hydride series contains diborane, a gas; pentaborane, a liquid; and decaborane, a solid. These compounds range from 31,200 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 to temperatures up to 650° C. Boron nitride produced in fibrous form equals glass fibers in strength and modulus 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 the reaction of carbon and boric acid, 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 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 U.S.S.R. 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.

TABLE 9

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 (borocalcite)	$Ca_2B_6O_{11.5}H_2O$	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)	$NaCaB_5O_9{\cdot}5H_2O$	49.6
Sassolite (natural boric acid)	H_3BO_3	56.3
Szaibelyite (ascharite)	$MgBO_2(OH)$	41.4
Tincal (native decahydrate borax)	$Na_2B_4O_7{\cdot}10H_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O_7{\cdot}5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9{\cdot}8H_2O$	43.0

[1] Parentheses include common names.

TABLE 10

TIME-PRICE RELATIONSHIPS FOR BORAX PENTAHYDRATE[1]

Year	Average annual U.S. producer price, dollars per metric ton	
	Actual prices	Based on constant 1988 dollars
1970	83	217
1971	83	205
1972	83	196
1973	88	196
1974	108	220
1975	116	215
1976	121	211
1977	130	213
1978	141	212
1979	184	258
1980	186	239
1981	205	240
1982	222	244
1983	222	235
1984	229	234
1985	236	234
1986	243	234
1987	249	234
1988	249	226

[1] Borax pentahydrate, technical, granular, 99.5%, bulk, carlots, works.

Operating Factors

Toxicity.—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.

In the 1950's, when the boranes (B_xH_y), a class of manufactured boron compounds, were undergoing research as high-energy aircraft fuels, a few cases of acute poisoning through inhalation occurred in industrial workers. Boranes are highly toxic and produce severe irritation to the central nervous system. Boron trifluoride presents a hazard to workers.

Because small quantities of boron are essential for all plant life, it 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.

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BROMINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the Bureau of Mines, has been the commodity specialist for bromine for 11 years. Domestic survey data were prepared by Gail Mason, mineral data assistant; and international data tables were prepared by Peter Roetzel, international data assistant.

Of the 423 million kilograms of bromine produced worldwide in 1989, the United States produced 41%, followed by Israel, 28%; the U.S.S.R., 15%; the United Kingdom, 6%; and other countries, 10%. The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on bromine in units most consistent with international usage, will henceforth report data in kilograms (kg) and metric tons (mt) unless otherwise noted. 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 a major producer. The quantity of bromine sold or used in the United States was about 175 million kilograms valued at $189 million. Exports of bromine compounds amounted to 29 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, as a scavenger for lead in gasoline, and in oil and gas well fluids. International concern over the use of halons brought 44 countries together, including the United States, to agree on proposals to protect the Earth's ozone shield from destruction.

DOMESTIC DATA COVERAGE

Domestic production data for bromine was developed by the 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 47% of total elemental bromine sold or used. The other operations were estimated by using quantity of brine produced and estimated bromine concentration.

LEGISLATION AND GOVERNMENT PROGRAMS

The Underground Injection Control (UIC) program was established under Part C of the Safe Drinking Water Act to protect underground sources of drinking water from endangerment by subsurface emplacement of fluids through wells.

The Environmental Protection Agency (EPA) was required to identify a list of States for which UIC programs may be necessary, to approve or disapprove programs submitted by the listed States, and to develop programs and regulate injection activities in States that do not have approved UIC programs.

Of the 57 States and jurisdictions identified, 35 have primary enforcement authority, or primacy, over all injection practices; 5 share primacy with EPA; and 17 have federally administered programs. In 1987, approximately 300,000 injection wells were regulated nationally by UIC programs. Seventy-three percent of these wells are regulated by States with primacy programs. Arkansas reported 66 wells as Class V and Michigan reported 2,941.[1] A well used to reinject spent brine into the same formation from which it was drawn after production of bromine, is included as a Class V well (text table below).

The EPA incinerated all leftover stocks of the pesticide fumigant ethylene dibromide (EDB). The disposal included 328,000 gallons of EDB stored at various locations around the country.

In July, the first restrictions on the manufacture of fully halogenated chlorofluorocarbons (CFC) went into effect. Output of halons, which are fluorocarbons that can contain bromine, was to be limited in 1992 to 1986 levels. The EPA set up a quota system that allocates future production of the controlled chemicals based on each U.S. producer's share of the 1986 market for halons. Halons 1211, 1301, and 2402, which are used in fire extinguishers, are included in the quota system. New information identifies chlorine and bromine from CFC as primary factors in the seasonal loss of ozone at the South

INJECTION WELL CLASSIFICATION

Class I:	Wells used to inject hazardous wastes or dispose of industrial and municipal fluids beneath the lowermost Underground Sources of Drinking Water (USDW).
Class II:	Wells used to inject fluids associated with the production of oil and natural gas or fluids/compounds used for enhanced hydrocarbon recovery. These wells normally inject below the lowermost USDW except in cases where the USDW is hydrocarbon producing.
Class III:	Wells that inject fluids for the extraction of minerals.
Class IV:	Wells that dispose of hazardous or radioactive wastes into or above a USDW (BANNED).
Class V:	Wells not included in other classes generally inject nonhazardous fluid into or above a USDW.

If a well does not fit into one of the first four Classes and meets the definition of an injection well, it is considered a Class V well. It should be noted that not all Class V wells are used for disposal. Examples of Class V practices which are not disposal related include: Aquifer Recharge, Fossil Fuel Recovery, and Mineral Recovery.

TABLE 1

SALIENT BROMINE AND BROMINE COMPOUND STATISTICS

(Thousand kilograms and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Bromine sold or used:[1]					
Quantity	145,000	141,000	152,000	163,000	175,000
Value	$80,000	$93,000	$107,000	$144,000	$188,650
Exports:					
Elemental bromine:					
Quantity	[2]2,836	[3]8,119	[3]3,348	[3]4,328	3,557
Value	[e]$1,400	[3]$8,170	[3]$3,526	[3]3,379	$3,165
Bromine compounds:[4]					
Gross weight	27,669	12,701	21,908	13,925	35,914
Contained bromine	23,541	10,433	18,643	11,839	28,998
Value	$23,400	$23,900	$18,000	$13,000	$24,093
Imports:[3]					
Elemental bromine:					
Quantity	5	155	248	257	460
Value	$9	$87	$166	$194	$293
Compounds:					
Ammonium bromide:					
Gross weight	1,264	2,595	2,243	1,660	2,402
Contained bromine	1,031	2,117	1,830	1,354	1,960
Value	$1,593	$2,994	$2,257	$2,180	$3,471
Calcium bromide:					
Gross weight	2,310	2,820	3,663	4,286	7,770
Contained bromine	1,847	2,255	2,929	3,427	6,212
Value	$917	$741	$833	$1,360	$3,231
Potassium bromate:					
Gross weight	485	291	1,389	4,161	2,314
Contained bromine	232	139	665	1,991	1,107
Value	$899	$669	$849	$1,107	$3,401
Potassium bromide:					
Gross weight	439	316	866	848	590
Contained bromine	295	212	581	569	395
Value	$685	$486	$1,122	$1,278	$985
Sodium bromide:					
Gross weight	1,316	212	657	1,925	1,369
Contained bromine	1,022	165	510	1,495	1,063
Value	$1,108	$217	$507	$1,936	$1,922
Other:					
Gross weight	4,575	4,587	8,294	32,892	28,005
Contained bromine	3,113	3,631	3,762	14,919	19,787
Value	$5,863	$4,627	$13,669	$35,531	$42,589
World: Production	[r]381,960	[r]375,059	391,116	[p]408,792	[e]422,900

[e] Estimated. [p] Preliminary.

[1] Elemental bromine sold as such to nonproducers, including exports, or used in the preparation of bromine compounds by primary U.S. producers.

[2] The Journal of Commerce Port Import/Export Reporting Service.

[3] Bureau of the Census.

[4] Bureau of the Census. Includes methyl bromine and ethylene dibromide.

Pole known as the Antarctic "ozone hole." The fate of halon is uncertain, although the output of halons is small compared with CFC.[2]

At yearend, a law was passed to raise $5.6 billion in new revenues for fiscal 1990, including $489 million from taxes on five chlorofluorocarbons and three halons, namely, halons 1201, 1301, and 2402. The tax rates are based on the potential for depleting the ozone layer, compared with halon 1100, fluoromethane.[3]

The EPA amended the regulations for hazardous waste management under the Resource Conservation and Recovery Act for methyl bromide. Two wastes generated during the production of methyl bromide were also listed. The regulation would become effective on April 6, 1990.[4]

The U.S. Department of Agriculture was granted a Section 18 exemption by the EPA for methyl bromide used in pest control on imported chayotes, melons, and plantains. The exemption expires on April 17, 1992. The EPA stated that long-term toxicity data were being developed for methyl bromide and future exemption requests will depend upon the outcome of these studies.[5]

A relabeling of the bromine compound, Bromoxynil, produced by Rhône-Poulenc Inc. was approved by the EPA. Rhône voluntarily canceled and recalled the formulation because of high skin absorbent rate. New labeling would be required on all Bromoxynil containers.[6]

The EPA sought to limit the land disposal of certain hazardous wastes listed in 40 Code of Federal Regulations (CFR) 268.12. Seven hydrocarbon wastes containing bromine were included.[7]

The Interagency Testing Committee, a consortium of 15 Federal agencies, issued a report adding 13 chemicals to the list of substances under the Toxic Substances Control Act. These should be given priority consideration to promulgating test rules. The additions to the list included several bromine compounds.[8]

The Department of Health and Human Services performed toxicology and carcinogen studies on rats using tribromomethane, a chemical intermediate and solvent. Under the 2-year studies, there was some evidence of carcinogenic activity.[9]

On January 19, 1989, the Occupational Safety and Health Administration published amendments to its Air

Contaminants Standard, 29 CFR 1910.1000. The new standard includes a new Table Z-1-A to replace the Permissible Exposure Limits. An index alphabetically lists the 428 substances discussed. Bromine and several bromine compounds were included.[10]

Ethylene dibromide and dibromochloropropane were 2 of 17 pesticides and 21 other compounds added to the EPA drinking water contaminants list. The proposal to regulate drinking water contaminants was authorized by the 1986 amendments to the Safe Drinking Water Act, which was originally passed by Congress in 1974. The EPA standards generally apply to any water-supply system serving more than 25 people.[11]

STRATEGIC CONSIDERATIONS

Firefighters and safety engineers in Alaska were alarmed that halons may be banned by Congress. Halons were used to suppress explosions and extinguish fires at the eight pipeline pumping stations. Automatic halon systems installed at wells throughout Alaska's massive North Slope can extinguish fires in a fraction of a second.[12]

Allied-Signal Inc. reported that the U.S. Navy began substituting a fluoride compound in discharge testing of halon systems installed on approximately 275 ships. Although the compound is not a fire-extinguishing agent, it is a practical alternative for reducing halon emissions during testing of the system. Another 150 ships planned to install similar halon systems.[13]

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. The Arkansas plants accounted for about 97% of U.S. elemental bromine capacity at yearend 1989 and 100% of bromine sold or used. Elemental bromine plant capacity did not reflect production capacity, which was dependent upon brine supplies, concentration of the bromine in the brine, and individual plant extraction processes. In Arkansas, one supply and one disposal well were required for each 4.5 million 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 insure 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.

During 1989, the Arkansas Oil and Gas Commission reported that 63 bromine producing wells were in operation. A small amount of bromine produced as a byproduct of wells in Michigan was not of commercial quality and was reprocessed before consumption.

CONSUMPTION AND USES

The U.S. International Trade Commission (ITC) publication "Synthetic Organic Chemicals, 1988" 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.

Demand for EDB, primarily as a gasoline additive, was about 18% of total consumption. The ITC's "Synthetic Organic Chemicals, 1988" listed Great Lakes and Ethyl as the only producers of EDB used in gasoline additives during 1988.

Ethyl reported that 70% of the production of sodium bromide is produced from virgin bromine and hydrogen. The remaining 30% is produced as a coproduct from a new purification system completed in 1988 to recycle bromine.

Unusual circumstances occurred during 1987 and 1988 that affected the company's ability to enter large volume contracts with service companies for the sale of clear brine fluids, including sodium bromide. In 1987, Ethyl signed a consent decree with the Department of Justice requiring a large volume of inorganic bromides to be placed in reserve to supply Tetra Chlor Inc., a subsidiary of Tetra Technologies Inc.[14]

Fire retardants were estimated to be about 30% of consumption, primarily as tetrabromobisphenol-A and decabromodiphenyl oxide. About 25% of bromine consumption was in clear brine drilling fluids used in work-over and completion fluids. Agricultural uses, primarily as methyl bromide, were about 15% of consumption, principally as methyl bromide used as a soil fumigant. Bromine was also used in water treatment as a slime and biocidal control product and other uses accounted for an estimated 15% of consumption.

TABLE 2

BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 1989

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.

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.

TABLE 3

YEAREND 1989 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. 236 No. 26, Dec. 25, 1989, pp. 26–34.

FOREIGN TRADE

In October, the ITC held a hearing concerning the withdrawal of the generalized system of preferences 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.

WORLD REVIEW

A 3-day conference titled "Saving the Ozone Layer" was held in London during March. The basis for the concern was CFC's and halons that are attributed to depletion of the ozone layer in the stratosphere. Another meeting was held in Helsinki in May of the 44 countries that signed the Montreal protocol. The Montreal protocol that went into effect January 1, requires that production of CFC's be reduced to 50% of 1986 levels by mid-1990 and that halon output be limited to 1986 levels. There was support of an agreement to eliminate CFC's by the year 2000. There was disagreement concerning the fate of essential uses of halon.[15]

TABLE 4

BROMINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	1985	1986	1987	1988[p]	1989[e]
France[e]	20,000	19,000	18,500	18,000	18,000
Germany, Federal Republic of[e]	[3]3,077	2,500	2,500	2,500	3,000
India	1,083	1,229	1,182	1,242	1,500
Israel[e]	100,000	105,000	110,000	[r]118,000	120,000
Italy[e]	600	450	[r]450	[r]450	500
Japan[e]	12,000	15,000	15,000	15,000	15,000
Spain[e]	350	280	300	300	300
U.S.S.R.[e]	70,000	65,000	65,000	65,000	65,000
United Kingdom	29,850	26,000	26,184	[e]25,000	25,000
United States[4]	145,000	140,600	152,000	163,300	[3]174,600
Total	[r]381,960	[r]375,059	391,116	408,792	422,900

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through Apr. 18, 1990.
[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] Reported figure.
[4] Sold or used by producers.

Capacity

The data in table 4 are rated capacity for mines and refineries as of December 31, 1989. Rated capacity is the maximum quantity of product that can be produced in a period based 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 bromine is based on rated capacity as reported by the company, by another Government agency, or another published source.

France

Mines de Potasse d'Alsace, Mulhouse, a producer of bromine from the bitterns of potash production, resumed production following a strike that lasted a month. The workers feared the collapse of international potash prices would lead to closure of the mines.[16]

TABLE 5

WORLD BROMINE ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989, RATED CAPACITY[2]

(Thousand kilograms)

Country	Capacity
North America: United States	261,000
Europe:	
France	22,000
German Democratic Republic	3,500
Germany, Federal Republic of	2,500
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 total shown because of independent rounding.

Israel

Israeli Chemicals Ltd. (ICL) controlled 25 active subsidiaries, including 89% of Dead Sea Bromine, the second largest producer of bromine and bromine compounds in the world. A decision to sell a 50% portion of ICL, the Government's wholly owned subsidiary, was under consideration. The sale was to be handled by First Boston, an investment bank.

U.S.S.R.

The U.S.S.R. took the position, during the Helsinki meeting of May 1988, concerning the Montreal protocol, that all halon uses are essential. There was agreement of the need to eliminate CFCs by the year 2000.[17]

United Kingdom

Great Lakes completed a purchase of 52% of Octel Associates and its operating company, The Associated Octel Co., Ltd., for $180 million. The shares were purchased from BP Petroleum Development Ltd., Texaco Oil Co., and Mobil Oil Corp. with 36.5%, 10.65%, and 5.3%, respectively. The acquisition gave Great Lakes more than 30% of the global bromine compounds market. Octel was the largest producer of tetraethyl lead in the world. Total sales in 1988 were $400 million. Shell Oil Co. and Chevron Oil Co. retain 36.7% and 10.65%, respectively, in the company.[18] Octel Associates, headquartered in London, employed approximately 3,000 people throughout Europe. Directly or through affiliated companies, Octel had interest in manufacturing plants in France, the Federal Republic of Germany, Italy, and the United Kingdom. Octel sold its products to about 270 refineries in over 90 countries worldwide.

Ethyl established a sales office in Bracknell, Berkshire, at Ethyl Petroleum Additives Ltd. The office provided sales of industrial chemicals and bromine chemicals sold in the United Kingdom, including "Saytech" brand flame retardants and bromine derivative chemicals.[19]

CURRENT RESEARCH

Tetra Technologies Inc., Woodlands, TX, purchased the clear brine fluids portion of Dow Chemicals Co. in 1988. Tetra, a diversified chemicals and waste management company founded in 1981, obtained funding from such sources as T. Rowe Price and the Environmental Fund.[20] During 1989, Tetra was examining the possibility of selectively precipitating a zinc hydroxide from a heavy metal waste stream. If the process is successful, the zinc hyroxide could be used to produce zinc bromide for use in Tetra's oil well brine fluids business.[21]

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.

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 Economic 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

TABLE 6

WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES, DECEMBER 31, 1989

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:	Bleicherode	NA	Do.
Government	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 Savoia	900	Seawater bitterns from salt production.
Japan:			
Asahi Glass Co. Ltd.	Kitakyushu	4,000	Seawater bitterns.
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Do.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Seawater.
U.S.S.R.:			
Government	NA	73,000	Well brines.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Do.

NA Not available.
[1] Excludes U.S. production capacity. See table 2.

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

Usage of calcium bromide and zinc bromide in well-drilling fluids decreased during the 1980's as the domestic petroleum industry suffered a severe recession. Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on increases in petroleum demand. Senate bill 1630, the Clean Air Act, has an amendment that will require mobile sources, such as cars and trucks, to use the most effective technology possible to control toxicants.

BACKGROUND

Definition, 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 was marketed in a "purified" grade. Specification for this grade are as follows: specific gravity not less than 3.1 at 10° C to 20° C; bromine, not less than 99.7%; iodine, none; and chlorine, not more than 0.1%

Specifications for the various grades of bromine compounds include technical bromine, 99.5% pure, with the chief impurities consisting of chlorine, traces of moisture, and organic matter. Specifications of the United States Pharmacopoeia and the American Chemical Society Committee on Analytical Reagents allow 0.3% chlorine, 0.05% iodine, 0.0002% sulfur (0.006% as sulfate), and no more organic matter in 1 milliliter than will saturate 50 milliliters of 5% sodium hydroxide solution. The term "chemically pure" signifies a minimum of impurities.

Geology-Resources

Bromine is widely distributed in the Earth's crust, but in small quantities. By far the largest potential source of bromine in the world exists in the oceans. At a concentration of only 65 parts per million, an enormous amount of water must be processed to obtain the bromine.

Arkansas brines contained about 5,000 parts per million at depths of 7,500 feet in limestone of the Smackover Formation of Jurassic age. In Michigan, brines containing about 2,600 parts per million of bromine occur in the Sylvania Sandstone Formation of the Detroit River Group of Devonian age.

In Israel, bromine was produced as a byproduct of salt, sodium chloride, and potash production. The waste brines contain 14,000 parts per million bromine.

Technology

The Arkansas Geological Commission reported three east-west bromine-rich brine fields. Wells are drilled down to the brine level and a submersible pump was lowered to pump the liquid to the surface. Brine is separated by gravity from any residual gas at the surface and was pumped to one of six processing facilities.

At the processing facility, bromine was separated from the brine by a steaming-out process. The brine was pumped into the top of a tower constructed of granite that was filled with ceramic packing. As the brine falls through the packing material, it reacts with chlorine and steam that were injected at the bottom of the tower. One pound of chlorine is required to yield 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 was first acidified to a pH of 3.5. The chlorine replaces the bromine in the brine and the gaseous bromine rises with the steam out of the top of the tower; there it was condensed to a reddish-brown liquid. Bromine was separated from gases because it is heavy and can be tapped out of the bottom. 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 was pumped through a heat exchanger to a waste pond. Brine from the pond was reinjected into the same producing zone to maintain hydrostatic pressure.

Seawater contains about 60 to 70 parts per million (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 passes countercurrent to the descending brine. Air containing bromine passes to the absorption tower. In the absorption tower, bromine reacts with sulfur dioxide to form a hydrogen bromide. The bromine is separated by adding acid to the solution and is distilled by steam. The gaseous bromine was condensed, separated, and purified.

Economic Factors

Cost.—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 1989, brines produced in Arkansas required the payment of $2 per 1,000 barrels in severance taxes and capital equipment was subject to the payment of property taxes. Bromine produced in the United States was subject to Superfund taxes of $4.45 per ton. Bromine was manufactured using chlorine, which was also subject to a Superfund tax of $2.70 per ton of chlorine.

TABLE 7

TIME-PRICE RELATIONSHIPS FOR BROMINE

Year	Average annual U.S. producer price, cents per kilogram	
	Actual prices	Based on constant 1988 dollars
1970	38.1	110
1971	38.2	104
1972	36.3	95
1973	35.4	87
1974	60.0	79
1975	61.0	123
1976	49.4	95
1977	47.7	86
1978	46.8	79
1979	48.6	25
1980	54.8	78
1981	48.6	63
1982	59.5	72
1983	59.5	69
1984	74.4	84
1985	74.4	81
1986	74.4	79
1987	77.2	80
1988	98.1	98
1989[e]	98.1	94

[e]Estimated.

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.

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 per-

sonal injury. If bromine is spilled on paper, rags, wood shaving, etc., it will generate considerable heat, which may lead to spontaneous combustion. Bromine will react 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 can be neutralized with a solution of sodium thiosulfate. Gaseous bromine may be neutralized with controlled amounts of gaseous ammonia. All metal, such as electrical switches and connections, that may be exposed to bromine vapors should be made of corrosion-resistant materials and/or completely sealed from contact with the room air.

Employment.—The U.S. chemical industry employs directly an average of 20 personnel for each $1 million of sales. These employees are working 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.—The manufacturing cost of bromine is heavily dependent on chlorine and brine cost. Of the total brine cost, 46% is power related and 53% is maintenance cost. Brine cost is dependent on well maintenance cost and energy cost associated with well pumping. Approximately 14% of the bromine manufacturing cost is energy related.

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CADMIUM

By Thomas O. Llewellyn

Mr. Llewellyn is a physical scientist with the Branch of Nonferrous Metals. He has covered cadmium for 3 years. Domestic survey data were prepared by Lura Nightlinger, Nonferrous Metals Data Section. International data were prepared by Giovanni Jacarepaqua, International Data Section.

Domestic production of cadmium metal decreased in 1989. Four companies operating four plants produced all of the domestic cadmium. Imports for consumption of cadmium metal increased, but exports decreased significantly compared to the level of 1988. The New York dealer-price range of cadmium metal, at $8.45 to $8.65 per pound at the beginning of the year, declined to $5.25 to $5.35 per pound by yearend.

LEGISLATION AND GOVERNMENT PROGRAMS

The Agency for Toxic Substances and Disease Registry published a final version of "Toxicological Profile for Cadmium," required under section 110 of the Superfund Amendments and Reauthorization Act of 1986 (Public Law 99-499).[1]

In October 1989, the Environmental Protection Agency (EPA) denied a petition submitted by SCM Chemicals Inc. requesting removal of cadmium sulfide (CdS) and cadmium selenide (CdSe) from the list of toxic chemicals under 313 of the Emergency Planning and Community Right-To-Know Act of 1986. SCM contended that CdS and CdSe were not toxic and did not meet the section 313 criteria for listing; however, EPA's decision was based on available cancer data on CdS and other cadmium compounds.[2]

STRATEGIC CONSIDERATIONS

Cadmium was 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.

The NDS goal for cadmium metal was at 5,307 metric tons, unchanged since 1980. At the end of 1989, the NDS cadmium inventory was 2,871 tons.

DOMESTIC PRODUCTION

Primary cadmium was produced by ASARCO Incorporated, Denver, CO; Big River Zinc Corp., Sauget, IL; Jersey Minière Zinc Co., Clarksville, TN; and Zinc Corp. of America, Bartlesville, OK.

CONSUMPTION AND USES

In 1989, nickel-cadmium batteries were the principal market for cadmium, surpassing both coating and plating application, for the second consecutive year. Based on production, trade, and stock data, the apparent domestic consumption of cadmium in 1989 was higher

TABLE 1

SALIENT CADMIUM STATISTICS

		1985	1986	1987	1988	1989
United States:						
Production[1]	metric tons	1,603	1,486	1,515	1,885	1,550
Shipments by producers[2]	do.	1,791	2,030	1,916	2,074	2,015
Value	thousands	$2,436	$1,883	$1,861	$5,389	$2,282
Exports	metric tons	86	38	241	613	369
Imports for consumption, metal	do.	1,988	3,174	2,701	2,482	2,787
Apparent consumption	do.	3,720	4,385	4,178	3,620	4,096
Price, average per pound, in 1 to 5 short ton lots:						
New York dealer		$0.92	$1.07	$1.60	$6.91	$6.28
Producer		$1.21	$1.25	$1.99	[3]$7.90	—
World: Refinery production	metric tons	r18,924	r19,070	19,066	p21,899	e21,002

e Estimated. p Preliminary. r Revised.

[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] 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]
1985	477	1,021
1986	645	1,459
1987	540	1,511
1988	345	1,497
1989	267	1,451

[1] Includes cadmium lithopone and cadmium sulfoselenide.
[2] Includes plating salts and oxide.

than that of 1988. The increase was believed to reflect the continuing demand of the battery industry for the metal. An estimated apparent consumption pattern for 1989 was as follows: batteries, 35%; coating and plating, 30%; pigments, 15%; plastics and synthetic products, 10%; and alloys and other, 10%.

TABLE 3

SUPPLY AND APPARENT CONSUMPTION OF CADMIUM

(Metric tons)

	1987	1988	1989
Stocks, Jan. 1	923	720	854
Production	1,515	1,885	1,550
Imports for consumption, metal	2,701	2,482	2,787
Total supply	5,139	5,087	5,191
Exports	241	613	369
Stocks, Dec. 31	720	854	726
Consumption, apparent [1]	4,178	3,620	4,096

[1] Total supply minus exports and yearend stocks.

STOCKS

Total inventories of cadmium metal decreased about 32%, while inventories of cadmium compounds increased 7% compared with those of 1988.

PRICES

The New York dealer-price of cadmium at the beginning of 1989 ranged from $8.45 to $8.65 per pound, more than two and one-half times the price range quoted at the beginning of 1988. The range of cadmium metal prices followed a steep downtrend and by the end of August were quoted at $3.40 to $3.80 per pound. The price decline was attributed to slower growth of the nickel-cadmium battery industry, particularly in Japan. However, the U.S. cadmium price market improved during September and by the end of the month the price range was $5.95 to $6.25 per pound. The prices for cadmium metal during the last quarter of 1989 trended downward and closed the year in the range of $5.25 to $5.35 per pound.

TABLE 4

INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

	1988		1989	
	Cadmium metal	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	332	W	241	W
Compound manufacturers	128	372	77	399
Distributors	21	1	8	1
Total	481	373	326	400

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

FOREIGN TRADE

Exports of cadmium metal and cadmium in alloys, dross, flue dust, residues, and scrap decreased considerably from those of 1988, but imports of cadmium metal increased in 1989.

The Bureau of the Census reported that the United States imported 137 million nickel-cadmium batteries in 1989. Japan, Hong Kong, and Mexico supplied approximately 92% of the total battery imports.

Under the new Harmonized Tariff Schedule of the United States, which was in effect January 1, 1989, cadmium sulfide and pigments and preparations based on cadmium compounds from most favored nations (MFN) were 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, were duty free for MFN, whereas a statutory duty of 33 cents per kilogram was imposed on these materials for non-MFN.

TABLE 5

U.S. EXPORTS OF CADMIUM METAL AND CADMIUM IN ALLOYS, DROSS, FLUE DUST, RESIDUES, AND SCRAP

Year	Quantity (metric tons)	Value (thousands)
1987	241	$660
1988	613	3,697
1989	369	857

Source: Bureau of the Census.

WORLD REVIEW

Industry Structure

In 1989, the U.S.S.R. was thought to be the largest producer of refined cadmium, followed by Japan, Belgium, Canada, the United States, Mexico, the Federal Republic of Germany, and Australia. These eight countries accounted for an estimated 67% of the world's refined cadmium production. 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. Cadmium is also recovered from flue dust generated at lead and copper smelters, and at steelmaking mini-mills; however, the amount of production from these sources is not known.

Capacity

The data in table 7 represent rated annual production capacity for mines and refineries on December 31, 1989. Rated capacity was defined as the maximum quantity that could be produced on a normally sustainable long-term operating rate, based on the physical

TABLE 6

U.S. IMPORTS FOR CONSUMPTION[1][2] OF CADMIUM METAL, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	31	$331	—	—
Australia	309	4,462	173	$2,391
Belgium	19	44	120	1,045
Brazil	80	1,099	22	328
Canada	[3]858	9,816	947	11,042
China	25	360	40	840
Finland	[3]30	371	3	46
France	—	—	333	1,522
Germany, Federal Republic of	372	4,979	139	1,837
Italy	—	—	([4])	2
Japan	—	—	2	48
Korea, Republic of	—	—	21	334
Mexico	590	7,670	616	7,525
Namibia	5	40	24	337
Netherlands	26	113	132	559
Norway	—	—	35	415
Peru	5	39	59	755
Poland	12	75	—	—
South Africa, Republic of	([4])	2	—	—
Spain	55	465	17	192
Switzerland	—	—	12	190
Taiwan	42	68	41	229
United Kingdom	[3]23	1,147	46	470
Venezuela	—	—	([4])	4
Yugoslavia	—	—	5	49
Total	[3]2,482	31,081	2,787	[5]30,161

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable to those in 1988.
[2]General imports and imports for consumption were the same in 1988 and 1989.
[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.

TABLE 7

WORLD ANNUAL CADMIUM PRODUCTION CAPACITY, DECEMBER 31, 1989

(Metric tons, cadmium content)

	Mine	Refinery
North America:		
Canada	4,800	2,500
Mexico	2,000	1,500
United States	1,800	3,100
Total	8,600	7,100
Central America	300	—
South America:		
Peru	2,000	600
Other	750	200
Total	2,750	800
Europe	7,500	11,000
Africa	1,000	600
Asia:		
Japan	600	5,100
Other	2,600	1,300
Total	3,200	6,400
Oceania:		
Australia	2,350	1,300
World total	25,700	27,200

equipment of the plant and routine operating procedures for labor, energy, materials, and maintenance. Capacity included both operating plants and plants temporarily closed that, in the judgment of the author, could be brought into production within a short period of time with minimum capital expenditure.

Cadmium is principally a byproduct of zinc production. Therefore, cadmium mine capacity was estimated based on zinc mine capacity, and cadmium refinery was estimated based on rated zinc refinery capacity, discussions with officials from private industry, past and present production rates, and published capacity data.

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 530,000 tons. The world's largest reserves of cadmium were located in the United States and Canada.

France

Société d' Accumulateurs Fixés et de Traction (SAFT) of France bought from SAB-NIFE, a Swedish battery company, the rights to use its technology for recycling industrial wastes and discarded nickel-cadmium batteries. SAFT installed a recycling plant at its Nersac facility, near Angouleme, France. The plant capacity for cadmium recovery was rated at about 300 metric tons per year.[3]

Japan

Sanyo Electric Co. Ltd. planned construction and installation of a new nickel-cadmium sealed battery plant at Kokushima, Japan, during 1990. The plant's designed production capacity of 10 million batteries per month will increase Sanyo's production to 40 million sealed batteries from the current 30 million units per month.

CURRENT RESEARCH

The Cadmium Association, England; Cadmium Council Inc., New York; and the International Lead Zinc Research Organization Inc., North Carolina, held the Sixth International Cadmium Conference in Paris, France, April 19-21, 1989. Major topics of

TABLE 8

CADMIUM: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Algeria	128	124	102	55	80
Argentina	46	47	46	46	40
Australia	910	915	944	855	900
Austria	52	52	26	26	30
Belgium	1,252	1,374	1,308	1,836	1,790
Brazil	224	233	214	161	175
Bulgaria[e]	200	200	180	180	180
Canada	1,717	1,484	1,481	1,742	1,750
China[e]	540	650	680	[r]750	800
Finland	565	522	690	703	600
France	337	431	457	558	500
German Democratic Republic[e]	15	18	18	[r]20	15
Germany, Federal Republic of	1,095	1,218	1,125	1,159	1,190
India	194	[e]160	214	237	245
Italy	526	411	320	705	500
Japan	2,535	2,489	2,450	2,614	2,690
Korea, North[e]	100	100	100	100	100
Korea, Republic of	—	—	—	490	500
Mexico	[r]734	1,016	935	1,259	1,200
Namibia	58	61	51	106	90
Netherlands	594	557	517	655	350
Norway	159	154	147	169	200
Peru	[e]420	438	461	368	470
Poland[e]	600	600	600	600	600
Romania[e]	75	75	75	75	70
Spain	268	247	297	438	300
Turkey	32	6	11	22	22
U.S.S.R.[e]	3,000	3,000	3,000	3,000	3,000
United Kingdom	370	379	498	399	395
United States[2]	1,603	1,486	1,515	1,885	[3]1,550
Yugoslavia	279	259	305	405	400
Zaire	296	364	299	281	270
Total	[r]18,924	[r]19,070	19,066	21,899	21,002

[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. Table includes data available through Mar. 30, 1990.

[2] Includes secondary.

[3] Reported figure.

discussion covered various aspects of cadmium applications technology. Papers were presented in five categories: Regulating Cadmium; New Technologies and Markets—the Essential Uses of Cadmium; Health Effects I—Cadmium and the Kidney; Health Effects II—Cadmium and Cancer; and Controlling Cadmium in the Environment. Sponsoring organizations expected to have the conference proceedings published by mid-1990.

Developments in cadmium technology during the year were abstracted in Cadscan, a quarterly publication available through the Cadmium Association, 34 Berkeley Square, London, W1X 6AJ, England.

OUTLOOK

Most uses of cadmium are dissipative, therefore little scrap is generated. Exceptions are scrap generated during the recycling of some cadmium bearing alloys and storage batteries. Currently, cadmium is recovered from waste batteries in Sweden, France, Japan, and the Republic of Korea. In the next 3 to 5 years, recycling of nickel-cadmium batteries was expected to become an integral part of many battery manufacturing industries in Europe and North America, because of environmental and economic reasons.

The short-term demand for cadmium in the United States was expected to fall marginally below the level of 1989. 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 2 to 5 years. There was a strong possibility that the world demand for primary cadmium will follow the same trend, for the reasons mentioned above and also due to slower growth of the nickel-cadmium battery industry.

[1] Toxicological Profile for Cadmium (U.S. EPA contract 68-02-4228, Life Systems Inc.). Oak Ridge National Lab., Mar. 1989, 116 pp.

[2] Federal Register. Environmental Protection Agency. Cadmium Sulfide and Cadmium Selenide; Toxic Chemical Release Reporting; Community Right-To-Know. V. 54, No. 201, Oct. 19, 1989, pp. 42962-42964.

[3] Advanced Battery Technology. V. 25, No. 4, Apr. 1989, pp. 2-3.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Cadmium. Ch. in Mineral Commodity Summaries, annual.

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Other Sources

American Metal Market (daily paper).

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CALCIUM AND CALCIUM COMPOUNDS

By M. Michael Miller

Mr. Miller, a physical scientist with 12 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.

In 1960, an International System of Units was adopted by the 11th General Conference of Weights and Measures. This system is called the MKS system or metric system, and most countries of the world have adopted it as their official system of measurement. The Bureau of Mines, in an effort to provide statistical data on calcium and calcium compounds in units most consistent with international usage, will henceforth report data in kilograms (kg) and metric tons (mt) unless otherwise noted.

Calcium, the fifth most abundant element in the Earth's crust, is chemically very active and is found in a host of minerals that occur in nearly every geologic environment. The 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 calcium carbonate as either limestone, marble, calcareous marl, or shell. Information on these commodities can be obtained in the Bureau of Mines Minerals Yearbooks reports entitled "Fluorspar," "Gypsum," "Lime," "Phosphate Rock," "Crushed Stone," and "Dimension Stone." Other calcium compounds are discussed in the Yearbook reports concerning the element with which calcium is combined; for example, calcium bromide is covered in the "Bromine" report in the Minerals Yearbook. This "Calcium and Calcium Compounds" Minerals Yearbook report includes calcium metal, calcium chloride, and various other calcium compounds not covered elsewhere.

DOMESTIC DATA COVERAGE

The 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 10 operations polled, 9 responded, representing less than 35% of the total production shown in table 1. Production for the nonrespondent was estimated using published plant capacity and contacts within the industry.

STRATEGIC CONSIDERATIONS

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.

Pfizer produced commercial-grade 98.5% calcium in eight shapes and high-purity redistilled 99.2% metal in three shapes; other shapes were 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 and flake; Wilkinson marketed calcium chloride solutions only. National Chloride Co. of America, Cargill's Leslie Salt Co., and Hill Brothers Chemical Co. produced calcium chloride from dry-lake brine wells in San Bernardino County, CA. Hill Brothers Chemical also produced from a second operation near Cadiz Lake, CA.

Allied Signal Inc. recovered synthetic calcium chloride as a byproduct at its Baton Rouge, LA, plant using hydrochloric acid and limestone. Texas United Chemical Corp. produced synthetic calcium chloride for 2 months in 1989 from purchased hydrochloric acid and limestone at its plant near Lake Charles, LA. This plant was sold to the Tetra Chemicals Division of Tetra Technologies, Inc. on February 28, 1989. Tetra Chemicals produced calcium chloride from this plant and their liquids plant at Norco, LA. Occidental Chemical Corp. manufactured calcium chloride at Tacoma, WA, using limestone and hy-

drochloric acid.

Precipitated calcium carbonate (PCC) was produced by Pfizer Inc. at its lime plant in Adams, MA, and at 10 satellite plants for use at adjacent paper mills. Mississippi Lime Co. produced PCC at a facility adjoining its lime plant in Ste. Genevieve, MO. Continental Lime Inc. produced PCC at Tacoma, WA. In late 1989, Continental Lime Ltd., parent of Continental Lime Inc., sold the assets and technology for PCC production to Georgia Kaolin Co. They have been reorganized under a new company called GK Carbonate.

Calcium hypochlorite was produced by Olin Corp. at Charleston, TN, and PPG Industries Inc. at Natrium, WV. Sales were flat in 1989 due to a rainy summer. Total domestic calcium hypochlorite capacity was 96,600 mt.

was to melt snow and ice from roads. Calcium chloride was also used 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. Calcium chloride when used for deicing is more effective at lower temperatures than rock salt and was used mainly in the Northern and Eastern States. Because of its considerably higher price, it was used in conjunction with rock salt for maximum effectiveness and economy.

Precipitated calcium carbonate was used as a pigment for brightness and opaqueness in premium-quality coated papers and as a filler in uncoated papers. In coated paper, PCC was used in the coating to improve paper brightness and print clarity. In uncoated papers, it

TABLE 1

U.S. PRODUCTION OF CALCIUM CHLORIDE (75% $CaCl_2$ Equivalent)

(Thousand metric tons and thousand dollars)

Year	Natural		Synthetic		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1985	W	W	W	W	853	135,000
1986	W	W	W	W	708	109,000
1987[e]	W	W	W	W	[r]597	87,400
1988[e]	W	W	W	W	[r]663	86,700
1989[e]	W	W	W	W	873	148,000

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

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, tungsten, vanadium, uranium, thorium, 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.

The principal use of calcium chloride 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.[1]

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.

PRICES AND SPECIFICATIONS

The published price of calcium metal changed infrequently. According to the Metal Bulletin, the yearend published price range for calcium metal, minimum 98% purity, was $3.05 to $3.45 per pound, U.S. free market.[2] This was equivalent to $6.70 to $7.60 per kg. Calcium metal was 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.

Calcium metal was usually sold in the form of crowns, broken crown pieces or nodules, or billets, which were produced by melting crowns in an argon atmosphere. The metal purity in these forms was at least 98%. Higher purity metal was obtained by redistillation. Calcium metal was usually shipped in polyethylene bags under argon in airtight steel drums. Grades of calcium are shown in the text table.

Typical specification, parts per million					
Commercial		Melted		Redistilled	
Mg	5,000	Mg	5,000	Mg	4,000
N	500	N	9,000	N	70
Al	5,000	Al	5,000	Al	30
Fe	200	Fe	300	Fe	20
Mn	400	Mn	300	Mn	150
Cu	<10			Cu	<10
				C	150
Ca min. 98.8%		Ca min 98.0%		Ca min. 99.5%	

Source: Quigley Company Inc., a subsidiary of Pfizer Inc.

Calcium chloride was sold as flake or pellet averaging about 75% $CaCl_2$, or as a liquid concentrate averaging 40% $CaCl_2$. Although actual prices are nego-

tiated and usually discounted, yearend 1989 published prices and specifications are shown in the text table.

Product and specifications	Value per short ton	Value per metric ton
Calcium chloride concentrate, regular grade, 77% to 80%, flake, bulk, carload, works	$153	$169
100-pound bags, carload, same basis	196	216
Anhydrous, 94% to 97%, flake or pellet, bulk, carload, same basis	217	239
80-pound bags, carload, same basis	279	308
Brining grade, 80-pound bags	285	314
Calcium chloride, liquid, 100% 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. 237, No. 1, Jan. 1, 1990, p. 33.

FOREIGN TRADE

U.S. exports of calcium chloride increased by nearly 20% in 1989. A substantial portion of the increase went to Canada. The United States exported nearly 24,900 mt of commercial calcium hypochlorite in small quantities to 78 countries for an export value of more than $32,400,000. Nearly 1,490 mt of calcium carbide was exported to 20 countries for an export value of more than $730,000. Exports of 134 mt of calcium cyanamide went to Canada, Mexico, and Barbados.

Imports of calcium metal increased by slightly more than 2% from 1988. This was the fourth straight year that calcium metal imports have increased. The majority of shipments came directly from China, the U.S.S.R., and France.

WORLD REVIEW

Calcium metal was produced in China, France, the U.S.S.R., and the United States. Total world production was estimated to be 2,300 to 2,700 mt, and world production capacity was estimated to be as much as 5,500 mt. This excess capacity was due to the fact that some calcium metal plants were originally designed to produce magnesium metal in substantially greater quantities than current calcium metal production.

Although output was unknown, China was believed to be the world's largest producer of calcium metal in 1989. As in the past, China's pricing practices have had an unsettling effect on world calcium markets. They were reported to have sold calcium at 20% to 30% below the yearend published price of $6.71 to $7.60 per kg ($3.05 to $3.45 per lb). Both Pfizer Inc. and Timminco, the Canadian calcium alloy producer, reported poor years due to excessive price cutting by China.

Canada was a major producer of synthetic calcium chloride in 1989. General Chemical Co., which operated the former Allied Signal plant at Amherstburg, Ontario, had a production capacity of 270,000 mt with both liquid and solid capabilities. General Chemical was the last remaining North American producer of synthetic calcium chloride as a byproduct of the Solvay process for synthetic soda ash production. Byproduct calcium chloride was produced in Eastern and Western Europe, where in many cases it was treated as a waste product. The calcium chloride brine from many facilities was dumped into rivers and estuaries. This practice, because of increased pressure from Government agencies and environmental groups, is expected to be severely curtailed.

TABLE 2

U.S. EXPORTS OF CALCIUM CHLORIDE, BY COUNTRY

Country	1988		1989	
	Metric tons	Value[1]	Metric tons	Value[1]
Canada	11,028	$2,046,478	14,461	$2,621,658
Mexico	987	279,933	465	162,180
Netherlands	468	130,960	106	615,823
Sweden	404	272,229	326	337,793
Switzerland	1,400	283,105	482	82,778
United Arab Emirates	422	78,327	511	100,997
Venezuela	69	91,131	19	9,656
Other	2,196	2,350,233	3,946	1,764,265
Total	16,974	5,532,396	20,316	5,695,150

[1] U.S. Customs declared value.

Source: Bureau of the Census.

OUTLOOK

The major end uses of calcium metal were in the lead industry, primarily in maintenance-free and sealed lead-acid batteries; in the steel industry; and as a reducing agent 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 went into the U.S. starter battery market. Based on projections made for the battery industry, it is estimated that calcium metal consumption in this market segment will grow by only 2% to 3% annually over the next 5 years.[3] Industry estimates for consumption by the steel industry call for annual growth of 5% to 10% annually. The steel industry is finding that despite the high raw material cost, using calcium metal lessens the final costs by producing a better product with fewer rejects. Conservative estimates for consumption in the permanent magnet market call for an annual growth of 5% to 10%, while optimistic estimates forecast growth of

TABLE 3

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]
1985	223,278	$1,395,198	68,385	$9,059,352	2,136	$1,907,976
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	279	586,939

[1] U.S. Customs, insurance, freight.

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF CALCIUM CHLORIDE, BY COUNTRY

Country	1988		1989	
	Metric tons	Value[1]	Metric tons	Value[1]
Crude:				
Canada	160,716	$13,158,601	89,682	$14,288,798
Germany, Federal Republic of	11,849	2,023,953	6,854	1,672,643
Mexico	15,509	3,130,215	17,784	3,878,249
Sweden	2,522	365,755	4,822	723,128
Other	10,732	2,537,171	154	292,700
Total	201,328	21,215,695	119,296	20,855,518
Other:				
Canada	626	$492,281	4	39,863
Germany, Federal Republic of	289	496,070	13	117,085
Sweden	5	5,887	261	422,709
Other	2,282	802,476	1	7,282
Total	[2]3,202	1,796,714	279	586,939

[1] U.S. Customs, insurance, freight.

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

Source: Bureau of the Census.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF OTHER CALCIUM COMPOUNDS

	1988		1989	
	Metric tons	Value[1]	Metric tons	Value[1]
Calcium borate (crude)	22,799	$5,828,965	15,002	$4,202,321
Calcium bromide	4,286	1,558,272	7,769	3,230,923
Calcium carbide	16,475	6,843,414	NA	NA
Calcium carbonate, precipitated	12,760	7,634,854	19,745	12,029,684
Calcium carbonate, chalk whiting	5,020	1,376,203	3,298	950,042
Calcium carbonate, (crude) natural chalk	319,666	1,887,045	NA	NA
Calcium cyanamide	3,207	1,592,096	NA	NA
Calcium hypochlorite	4,788	7,834,702	4,065	6,703,152
Calcium nitrate	155,178	19,463,769	NA	NA
Dicalcium phosphate	2,380	2,688,120	1,786	2,088,291
Total	XX	56,707,440	XX	29,204,413

NA Not available. XX Not applicable.

[1] U.S. Customs declared value.

Source: Bureau of the Census.

25% to 30% annually.

The outlook for calcium chloride consumption over the next 5 years is tied to its major use in deicing and dust control. Due to changing environmental and economic policies, annual consumption for deicing is projected to be static or decreasing. Problems with rust and corrosion and the high cost compared to rock salt have caused government agencies to seek alternatives. Consumption for dust control is expected to remain steady.

The outlook for precipitated calcium carbonate consumption is primarily dependent on the pace of conversions to alkaline sizing by the paper industry. Pfizer Inc. announced that in 1990 it will be signing contracts for, building, or starting up 10 to 11 new satellite PCC plants. GK Carbonate announced plans to build two satellite PCC plants in 1990. The North American market has the potential for 35 to 40 satellite plants. One industry estimate sees alkaline papermaking capturing 60% of the total domestic paper market in the next 3 years.[4] Overall, during the next 5 years the outlook for PCC consumption in the paint and plastics industries is good, and exceptional in the paper industry.

BACKGROUND

Technology

Calcium Metal.[5]—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. Over the next 50 years this process was slowly improved. By 1904, Rathenau had obtained calcium by the electrolysis of molten calcium chloride held at a temperature above the melting point of the salt but below the melting point of calcium metal. An iron cathode just touched the surface of the bath and was raised slowly as the relatively chloride-free calcium deposited on its end. This process accounted for virtually all calcium metal production from 1904 to 1940.

Prior to 1939, calcium was manufactured exclusively in France and Germany. However, 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. Tried 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 the desired amount of 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. This 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 mm Hg) while the bottom is heated to 900° to 925° C. The calcium quickly distills to 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.[6]—Domestic calcium chloride is produced from natural brines and by reacting hydrochloric acid with limestone. Most U.S. production is natural and comes from brine wells in Michigan and dry lakebeds 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 to extract the 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 the sodium chloride, which was used to produce chlorine, hydrogen, and sodium hydroxide. The remaining brine was sent to another evaporator where magnesium chloride was precipitated out. The remaining 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.

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[1] Hagemeyer, R. Precipitated Calcium Carbonate—Fillers for Paint, Paper and Elastomers. Soc. Min. Eng. AIME preprint 89-22, 1989, 14 pp.

[2] Metal Bulletin (London). No. 7446, Jan. 4, 1990, p. 29.

[3] McLaughlin, P. Battery Market Update & Five Year Forecast. The Battery Man, v. 32, No. 1, Jan. 1990, pp. 12-22.

[4] Zahodiakin, P. Fillers Benefiting From Alkaline Trend. Chemical Marketing Reporter, v. 236, No. 13, pp. SR25-27.

[5] 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.

[6] Pavlick, J. Chemicals From Michigan Brines. Soc. Min. Eng. AIME preprint 84-385, 1984, 10 pp.

OTHER SOURCES OF INFORMATION

Mannsville Chemical Products Corp. Calcium Chloride. Chemical Products Synopsis (Asbury Park, NJ). Mar. 1989, 2 pp.

Roskill Information Services Ltd. The Economics of Calcium Metal. 3d ed. (London). 1987, 70 pp.

CEMENT

By Wilton Johnson

Mr. Johnson, a minerals industry specialist with 28 years of industry and 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 assistant.

U.S. demand for cement declined slightly for the second year following five consecutive years of growth. Housing starts declined 8%, and the value of new construction put in place also declined slightly. Cement shipments increased to four of the nine Census regions. California continued to lead all States in the amount of cement consumed.

Domestic cement production increased slightly for the first time following two consecutive years of decline. Shipment of domestically produced cement from domestic mills increased slightly, while the amount of imported cement shipped by producers declined 23%. Total imports declined for the second year, making up 17% of apparent consumption compared with 19% experienced in the record year of 1987.

Cement prices increased for the first time in 6 years, reaching their highest level since 1985.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for cement are developed by means of the portland and masonry cement voluntary survey. Of the 127 cement manufacturing plants to which an annual survey collection request was made, 125 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.

ISSUES

The primary issue facing the cement industry is a lack of capital investment 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 127 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

TABLE 1

SALIENT CEMENT STATISTICS

(Thousand short tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:[1]					
Production[2]	77,895	78,786	78,198	76,867	77,189
Shipments from mills[2 3]	83,032	87,592	r89,246	r89,460	86,238
Value[2 3 4] thousands	$4,286,399	$4,407,722	$4,393,684	$4,370,463	$4,242,931
Average value per ton[2 3 4]	$51.61	$50.32	r49.23	r48.85	$49.20
Stocks at mills,[2] Dec. 31	7,232	6,725	6,159	5,997	6,300
Exports	98	59	52	101	512
Imports for consumption	14,120	r16,091	17,536	r17,298	15,548
Consumption, apparent[5 6]	87,456	91,501	93,886	93,256	90,676
World: Production	r1,057,794	r1,106,182	1,153,425	p1,215,498	e1,235,613

e Estimated. p Preliminary. r Revised.

[1] Excludes Puerto Rico and the 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.

eastern boundaries of Broome, Chenango, Lewis, Madison, Oneida, and St. Lawrence Counties.

New York, Eastern.—All counties east of the above dividing line, except Metropolitan New York.

New York Metropolitan.—The five counties of New York City (Bronx, Kings, New York, Queens, and Richmond) plus Nassau, Rockland, Suffolk, and Westchester Counties.

Pennsylvania, Eastern.—All counties east of the eastern boundaries of Centre, Clinton, Potter, 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 above dividing line.

Clinker Production

Clinker production in the United States, excluding Puerto Rico, was essentially the same at 69.3 million tons. California continued to lead all States in clinker production, accounting for approximately 14% of the total. More than two-thirds of the clinker came from eight plants in the southern part of the State. Texas followed with about 10% of total production. Pennsylvania ranked third, with most of the clinker produced at plants in the eastern part of the State, followed by Michigan and Missouri. Together these five States accounted for 46% of total U.S. clinker production.

By yearend, multiplant operations were being run by 25 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 29% of total clinker production; the 10 largest producers provided a combined 50%. The 10 largest companies, in decreasing order of size of clinker production, were Lafarge Corp., Southdown Inc., Lone Star Industries Inc., Lehigh Portland Cement Co., Ideal Basic Industries Inc., Dundee Cement Co., Blue Circle Inc., Ash Grove Cement Co., Gifford-Hill and Co., and CalMat Co.

Portland Cement

Portland cement production increased slightly to 73.9 million tons. This was the first production increase following two consecutive years of decline. The increase was attributed to less reliance on imports of finished cement to satisfy demand primarily in Eastern markets. The closing of plants in Alabama, Texas, Utah, and Washington reduced operating capacity slightly to 98.1 million tons. The capacity utilization rate increased to 75.3%.

The industry operated 122 plants, including 8 grinding facilities to produce various types of finished hydraulic cement, compared with 126 plants in 1988. California continued to lead all States with 15% of production, followed by Texas with 10%, Michigan with 7%, and Pennsylvania East and Missouri with 6% each. Together these five States accounted for 44% of total U.S. cement production.

The size of individual companies, as a percentage of total U.S. finished cement production capacity, ranged from 0.01% to 7.0%. The top 10 producing companies, in declining order of production, were Lafarge Corp., Southdown Inc., Lone Star Industries Inc., Lehigh Portland Cement Co., Ideal Basic Industries Inc., Dundee Cement Co., Ash Grove Cement Co., Gifford-Hill and Co., Blue Circle Inc., and CalMat Co.

Masonry Cement

Production of masonry cement declined 8% to 3.3 million tons. At yearend, 81 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 industry's energy efficiency for production of clinker and finished cement continued to improve. Average energy consumption per ton of clinker produced was 3.8 million British thermal units (Btu), slightly lower than that required in 1988. The consumption of electrical energy remained at the equivalent of 1.1 million Btu per ton. Average fuel consumption for kiln for firing plus electricity for grinding was 4.9 million Btu per ton. Fuel used in wet-process plants was 4.5 million Btu per ton, 36% higher than the dry process of 3.3 million Btu per ton. Approximately 67% of clinker was produced by the dry process method. The industry reported 67 suspension and 10 grate preheaters in use during the year. Kilns without preheaters averaged 4.5 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. Coal accounted for 93% of kiln fuel consumption, natural gas accounted for 4%, and oil and waste fuel accounted for the remainder.

Corporate Changes

Dundee Cement Co., a subsidiary of Holderbank Financiere Glaris SA, purchased the Mason City, IA, cement plant of Northwestern States Portland Cement Co. Ideal Basic Industries, also a subsidiary of Holderbank, acquired Allied Cement Co.'s Birmingham, AL, plant and began using it as a distribution terminal. National Portland Cement Co. of Florida sold its remaining 59% interests to a group of Spanish producers: Cementos Molins, S.A.; Uniland Cementera, S.A.; and Asland S.A. The group initially purchased 41% interest in National in 1988. Lafarge Corp. acquired controlling interest in the Swiss firm Cementia Holdings S.A. Cementia owns two U.S. cement plants—Davenport Cement Co. in Buffalo, IA, and Missouri Portland Cement Co. in Sugar Creek, MO. Riverside Cement Co., a subsidiary of Gifford-Hill and Co., formed a joint venture with the Republic of Korea's Ssangong Cement Industrial Co. to operate a bulk storage facility at the port of Stockton in Northern California. Ash Grove Cement Co. purchased the Leamington, UT, cement plant from Martin Marietta.

TABLE 2

PORTLAND CEMENT PRODUCTION, CAPACITY, AND STOCKS IN THE UNITED STATES, BY DISTRICT[1]

District	1988					1989				
	Plants active during year	Production[2] (thousand short tons)	Capacity[3]		Stocks[4] at mills, Dec. 31 (thousand short tons)	Plants active during year	Production[2] (thousand short tons)	Capacity[3]		Stocks[4] at mills, Dec. 31 (thousand short tons)
			Finish grinding (thousand short tons)	Percent utilized				Finish grinding (thousand short tons)	Percent utilized	
New York and Maine	5	3,459	4,265	81.1	310	5	2,980	4,265	69.8	308
Pennsylvania, eastern	8	4,840	5,821	83.1	308	8	4,492	5,771	77.8	435
Pennsylvania, western	4	1,523	2,417	63.0	169	4	1,513	2,417	62.5	176
Maryland	3	1,824	2,030	89.8	143	3	1,884	2,030	92.8	185
Ohio	4	1,495	2,200	67.9	147	4	1,449	2,200	65.8	153
Michigan	5	5,127	6,090	84.1	348	5	5,266	6,090	86.4	335
Indiana	4	2,629	3,140	83.7	188	4	2,469	3,140	78.6	224
Illinois	4	2,033	2,580	78.7	196	4	2,700	2,750	98.2	283
Georgia and Tennessee	4	2,273	2,595	87.5	180	4	1,987	2,595	76.5	192
South Carolina	3	2,482	3,440	72.1	117	3	2,270	3,306	68.6	140
Kentucky, Virginia, West Virginia	3	2,351	3,052	77.0	143	3	2,277	3,132	72.7	227
Florida	6	3,349	4,761	70.3	229	6	3,804	4,660	81.6	290
Nebraska and Wisconsin	1	W	W	W	W	1	W	W	W	W
Alabama	6	3,806	5,326	71.4	235	5	3,411	5,276	65.9	302
Arkansas, Louisiana, Mississippi	3	1,385	2,040	67.8	133	3	1,191	2,200	54.1	75
Utah	3	778	1,365	56.9	63	2	W	W	W	W
South Dakota	1	577	1,800	32.0	58	1	W	W	W	W
Iowa	4	2,006	2,725	73.6	219	4	2,230	2,725	81.8	323
Missouri	5	4,460	4,780	93.3	332	5	4,418	4,780	92.4	287
Kansas	5	1,607	2,460	65.3	206	5	1,544	2,425	63.6	208
Oklahoma	3	1,579	2,048	77.0	218	3	1,526	2,048	74.5	217
Texas, northern	8	3,202	6,055	52.8	291	7	3,217	5,825	55.2	286
Texas, southern	6	3,561	5,090	69.9	178	6	4,204	5,712	73.6	186
Idaho and Montana	3	836	960	87.0	92	3	768	1,090	70.4	68
Colorado and Wyoming	4	1,282	2,720	47.1	200	4	1,282	2,720	47.1	103
Alaska and Oregon	2	W	W	W	W	2	W	W	W	W
Arizona, Nevada, New Mexico	4	2,114	2,910	72.6	132	4	1,949	3,060	63.7	97
California, northern	3	2,873	3,150	91.2	156	3	3,150	3,175	99.2	99
California, southern	8	7,483	8,833	84.7	318	8	7,796	8,357	93.2	332
Hawaii	1	357	650	54.9	34	1	474	600	79.0	46
Washington	3	753	1,270	59.2	150	2	W	W	W	W
Total or average	126	73,272	98,673	74.3	5,559	122	73,895	98,104	75.3	5,847
Puerto Rico	2	1,385	2,116	65.4	19	2	1,370	2,116	64.7	34

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 (9 in 1988 and 8 in 1989) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), Texas (1) in 1988 and (2) in 1989, Utah (1) in 1988, and Washington (1) in 1988.

[2] Includes cement produced from imported clinker (1988—2,339,720 ton, 1989—1,932,281 tons).

[3] Grinding capacity based on fineness necessary to grind Types I and II cement, making allowance for downtime required for maintenance.

[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, 1989

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	83	3,393	2,780	81.9
Pennsylvania, eastern	2	5	—	7	16	16	56	4,955	4,443	89.6
Pennsylvania, western	3	1	—	4	8	7	69	2,076	1,528	73.6
Maryland	1	2	—	3	7	6	35	1,980	1,834	92.6
Ohio	2	2	—	4	7	7	64	2,112	1,425	67.4
Michigan	2	2	—	4	9	16	57	4,936	4,610	93.3
Indiana	2	2	—	4	8	9	51	2,829	2,525	89.2
Illinois	—	4	—	4	8	8	52	2,509	2,501	99.7
Georgia and Tennessee	1	3	—	4	7	7	30	2,346	1,937	82.5
South Carolina	2	1	—	3	7	8	63	2,417	2,286	94.5
Kentucky, Virginia, West Virginia	1	2	—	3	9	8	68	2,390	2,244	93.9
Florida	2	2	—	4	8	10	16	3,496	2,981	85.2
Nebraska and Wisconsin	—	1	—	1	2	W	54	W	W	W
Alabama	—	5	—	5	6	13	57	4,016	3,456	86.0
Arkansas, Louisiana, Mississippi	3	—	—	3	6	6	54	1,867	1,196	64.0
Utah	1	1	—	2	3	W	59	W	W	W
South Dakota	—	—	1	1	4	W	56	W	W	W
Iowa	—	3	—	3	5	7	50	2,207	2,051	92.9
Missouri	2	3	—	5	7	14	55	4,342	4,306	99.2
Kansas	3	2	—	5	15	7	45	2,246	1,580	70.3
Oklahoma	1	2	—	3	7	6	72	1,758	1,552	88.2
Texas, northern	3	3	—	6	14	13	17	4,536	3,223	71.0
Texas, southern	—	4	1	5	6	14	47	4,458	3,760	84.3
Idaho and Montana	3	—	—	3	4	2	5	835	749	89.7
Colorado and Wyoming	1	3	—	4	6	7	41	2,269	1,152	50.7
Alaska and Oregon	—	1	—	1	1	W	120	W	W	W
Arizona, Nevada, New Mexico	—	4	—	4	11	8	43	2,576	1,770	68.7
California, northern	—	3	—	3	3	10	59	3,067	3,009	98.1
California, southern	1	7	—	8	22	25	33	8,318	7,016	84.3
Hawaii	—	1	—	1	1	1	107	258	240	93.0
Washington	1	1	—	2	2	W	69	W	W	W
Total or average[4]	41	71	2	114	225	263	53	83,151	69,291	83.3
Puerto Rico	2	—	—	2	9	8	101	2,114	1,182	55.9

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.

CONSUMPTION AND USES

Consumer demand for cement in the United States, excluding Puerto Rico, declined 2.8% to 90.7 million tons. This was the second year of decline following 5 consecutive years of growth after the 20-year low experienced at the depth of the recession in 1982. According to U.S. Department of Commerce data, housing starts declined 8% to 1.4 million units. The value of new construction put in place declined 1% to $414 billion. The value of residential construction put in place declined 1% to $138 billion, primarily in single-unit structures. The value of nonresidential construction put in place increased 2% to $97 billion. The increases were primarily in industrial buildings, hotels and motels, hospitals, and religious and educational institutions. Public construction experienced the biggest increase, 10%, caused primarily by increases in spending for highways and streets, military facilities, and sewer systems.[1]

Among the consuming States, California continued to lead all areas in the amount of portland cement consumed, followed by, in order of shipments received, Texas, Florida, Illinois, Pennsylvania, and New York. Together, these States consumed 43% of total U.S. tonnage.

Cement shipments increased to four of the nine Census regions. Because of the sustained level of construction activity in southern California, the Pacific region continued to lead all other regions of the country with an 8% increase in consumption. Only marginal increases in consumption of 2% or less were registered in the East North Central, West South Central, and Mountain regions. Shipments to all other regions declined with New England registering a 21% decrease in shipments. The Middle Atlantic suffered a 7% decline in consumption, while the South Atlantic declined 6% and the South East Central region decreased 7%. The West North Central region was down slightly.

Shipments of domestically produced cement from U.S. mills increased slightly; however, the amount of imported cement shipped by producers decreased by 23%. All imported cement shipped by producers and inde-

TABLE 4

DAILY CLINKER CAPACITY IN THE UNITED STATES,[1] DECEMBER 31, 1989

Short tons per 24-hour period	Number		Total capacity (short tons)	Percent of total capacity
	Plants	Kilns[2]		
1988:				
Less than 1,150	15	25	11,548	4.2
1,151 to 1,700	31	55	45,327	16.5
1,701 to 2,300	23	38	44,802	16.3
2,301 to 2,800	16	34	39,760	14.5
2,801 and over	34	90	132,930	48.5
Total	119	242	274,367	100.0
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 over	33	86	126,139	46.4
Total	116	234	271,684	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	1987	1988	1989
Calcareous:			
Limestone (includes aragonite, marble, chalk)	81,143	79,517	81,792
Cement rock (includes marl)	17,959	23,398	21,920
Coral	935	783	911
Other	—	9	13
Argillaceous:			
Clay	4,766	4,784	4,801
Shale	4,906	4,126	4,289
Other (includes staurolite, bauxite, aluminum dross, alumina, volcanic material, other)	263	310	436
Siliceous:			
Sand and calcium silicate	1,873	2,011	1,991
Sandstone, quartzite, other	758	993	605
Ferrous: Iron ore, pyrites, millscale, other iron-bearing material	1,079	1,036	1,026
Other:			
Gypsum and anhydrite	4,939	4,174	4,254
Blast furnace slag	109	86	181
Fly ash	803	940	905
Other, n.e.c.	386	348	356
Total	[2]119,920	122,515	123,480

[1] Includes Puerto Rico.
[2] Data do not add to total shown because of independent rounding.

TABLE 6

MASONRY CEMENT PRODUCTION AND STOCKS IN THE UNITED STATES, BY DISTRICT

District	1988			1989		
	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	157	16	4	139	15
Pennsylvania, eastern	7	288	36	6	252	40
Pennsylvania, western	4	95	15	4	90	13
Maryland	2	W	W	2	W	W
Ohio	3	133	17	3	129	19
Michigan	4	264	51	4	242	41
Indiana	4	412	57	4	369	67
Illinois	1	W	W	1	W	W
Georgia and Tennessee	4	212	28	4	193	29
South Carolina	2	W	W	2	W	W
Kentucky, Virginia, West Virginia	4	345	23	4	305	19
Florida	4	480	28	4	487	29
Nebraska and Wisconsin	1	W	W	1	W	W
Alabama	7	260	33	5	205	41
Arkansas, Louisiana, Mississippi	2	W	W	2	W	W
Utah	1	W	W	1	W	W
South Dakota	1	3	2	1	W	W
Iowa	2	W	W	2	W	W
Missouri	4	160	9	3	127	8
Kansas	5	48	18	5	45	24
Oklahoma	2	W	W	2	W	W
Texas, northern	6	82	8	5	87	12
Texas, southern	3	51	4	3	55	9
Idaho and Montana	2	W	W	2	W	W
Colorado and Wyoming	2	W	W	2	W	W
Arizona, Nevada, New Mexico	3	70	7	3	56	6
California, northern	—	—	—	—	—	—
California, southern	1	W	W	1	W	W
Hawaii	1	10	1	1	10	1
Washington	1	W	W	—	—	—
Total or average[2]	87	3,595	438	81	3,294	453

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.

pendent distributors declined for the second consecutive year with imports accounting for 17% of apparent consumption compared with 19% in 1988.

The end-use distribution pattern for portland cement was essentially the same as that of recent years. Ready-mix concrete producers were the primary consumers, accounting for about 74% of the total, followed by concrete product manufacturers with 11%. Smaller amounts were consumed by highway and other contractors; building material dealers; Federal, State, and other government agencies; and 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, 95%; by truck, 90%; and made directly from cement manufacturing plants (rather than from distribution terminals), 61%.

With respect to shipments of cement from plants to terminals, the preferred modes of transportation were railroads, 40%, and waterways, 42%; transportation by truck accounted for 16%. Cement used at producing plants accounted for the remaining 2%.

PRICES

The average mill value of portland cement increased slightly for the first time in 5 years. The increase can be attributed to higher production levels and a reduction of imports. Import prices remained at $48.19 per ton, while domestically produced cement increased slightly to $48.41 per ton. The average value of masonry cement improved slightly to $68.93 per ton compared with $68.25 per ton in 1988. The average value of cement as reported by Engineering News-Record (ENR) declined slightly to $62.52 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 $42.00 in Dallas, TX, to a high of $78 in New York.[2]

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 10% lower than in 1988. This was the second 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, primarily in the eastern regions of the United States. Canada, Japan, and Mexico were the principal import

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)
1988:						
Coal	17	9,701	13.8	1,762	—	—
Natural gas	3	1,114	1.6	—	—	150,769
Coal and oil	30	21,166	30.1	3,745	383	—
Coal and natural gas	49	26,150	37.1	3,543	—	8,363,116
Oil and natural gas	2	170	.2	—	159	300,726
Coal, oil, natural gas	18	12,139	17.2	1,578	417	2,718,967
Total	119	70,440	100.0	10,628	959	11,533,578
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

[1] Includes Puerto Rico.
[2] Includes 1% anthracite, 95% bituminous coal, and 4% petroleum coke in 1988, and 1% anthracite, 98% bituminous coal, and 1% petroleum coke in 1989.

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)
1988:						
Wet	46	23,270	33.0	4,326	368	3,899,033
Dry	69	44,940	63.8	5,993	586	7,501,096
Both	4	2,230	3.2	309	5	133,449
Total	119	70,440	100.0	10,628	959	11,533,578
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

[1] Includes Puerto Rico.
[2] Includes 1% anthracite, 95% bituminous coal, and 4% petroleum coke in 1988, and 1% anthracite, 98% bituminous coal, and 1% petroleum coke in 1989.

sources, accounting for more than 65% of the total. The industry continued to find it more economical to import finished cement instead of clinker for grinding. Clinker accounted for 11% of total imports compared with 32% reached in the peak year 1985. This was the fourth consecutive year that clinker imports declined, reaching its lowest level since 1983. The value of foreign cement delivered to American ports averaged $38 per ton, up 9% from that of 1988, primarily because of increased shipping costs.

Florida led all States in the amount of imports received, accounting for 23% of the total. Sixty two percent, or 2.2 million tons, of the Florida imports was shipped through the Tampa Customs District. Imports made up about 49% of Florida's Portland cement consumption, compared with 17% of consumption nationally. Los Angeles was the second largest recipient of imported cement, receiving 2.2 million tons or 14% of the total.

Exports of hydraulic cement and clinker as reported by the Bureau of the Census increased more than 400% to 512,000 tons. Cement was shipped to 42 countries, with Canada receiving 87% of the total.

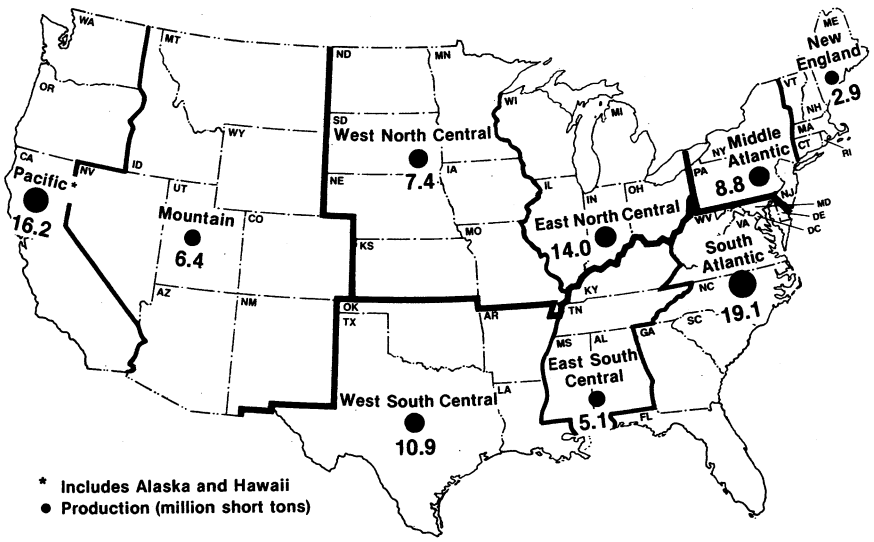
In other trade developments, the International Trade Commission (ITC) was petitioned by cement producers from Arizona, Florida, New Mexico, and Texas alleging that cement from Mexico was being sold in these areas at less than fair value. The ITC conducted a preliminary antidumping investigation and determined that there was a reasonable indication that the industry was materially injured. A final determination was expected to be made by August 1990.

WORLD REVIEW

World cement production was essentially unchanged at 1.2 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. In 1989, 29 countries exported cement to the United States, essentially the same as in 1988. The amount of

FIGURE 1

SHIPMENTS OF CEMENT BY GEOGRAPHIC REGION OF DESTINATION IN 1989



cement imports declined by 10% because of increased demand within exporting countries and because of a reduction in demand in certain coastal markets of the United States.

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.[3]

Capacity

The data in table 23 are estimated and were obtained from a number of different sources, including Government representatives, cement associations, producers, consultants and the Cembureau World Cement Directory. 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 1989, clinker-producing plants

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		
1988:								
Wet	—	—	44	2,993	2,993	30.1	24,345	122.9
Dry[2]	7	733	72	5,873	6,606	66.4	47,989	137.7
Both	—	—	4	345	345	3.5	2,323	148.5
Total or average	7	733	120	9,211	9,944	100.0	74,657	133.2
Percent of total electric energy used	—	7.4	—	92.6	—	—	—	—
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
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	—	—	—	—

[1] Includes Puerto Rico. Includes grinding plants and white cement facilities.
[2] Includes data for grinding plants.

in an estimated 132 countries had a combined annual capacity of about 1.4 billion tons. Of the top 10 producing countries, China led in clinker production capacity, followed by the U.S.S.R., Japan, the United States, India, Brazil, the Federal Republic of Germany, Italy, Spain, and the Republic of Korea. Together these countries control 60% of the world's clinker production capacity.

In the United States, 44% of the clinker production capacity was concentrated in five States: California, Michigan, Missouri, Pennsylvania, and Texas. At yearend, 225 kilns at 114 plants were being operated, excluding Puerto Rico. The average downtime experienced by the industry for maintenance was 53 days, slightly less than in 1988. The average annual kiln capacity increased 2% to 369,560 tons. The average annual plant capacity increased 7% to 729,395 tons as the trend continued toward development of fewer but larger capacity plants.

Australia

Cement demand in Australia continued to flourish with production reaching 7.2 million tons in 1989. Imports from Indonesia, Japan, and The Republic of Korea continued to penetrate the Australian market, prompting the filing of antidumping petitions to curtail imports.

Canada

Canadian cement production declined 2% to 13 million tons. Canada remained the second largest supplier of cement to the United States, supplying markets primarily through ports in 15 custom districts from Anchorage, AK, to St. Albans, VT.

China

China continued to be the world's largest producer of cement. Its production continued to increase at a dramatic rate, reaching an estimated 228 million tons in 1989. Chinese cement is expected to become a bigger player on the international market when several of its plant construction and modernization projects are complete.

Greece

Cement production in Greece as reported to the Bureau of Mines increased slightly following three consecutive years of decline. Greece was the fifth largest supplier of cement to the United States, although the volume of imports declined 38% from that of 1988. The decline was attributed to increased consumption at home, to other European Community countries traditionally served by Greek producers, and to a drop in cement demand in the U.S. eastern seaboard markets.

India

The Indian cement industry continued to aggressively expand its production capacity through new plant construction, modernization, and expansion activities. Cement production in India reached an alltime high of 46 million tons. This was the seventh consecutive year of production growth. India is not a major exporter of cement; however, that situation could change when capacity expansion projects currently in various stages of development are complete.

Japan

Japan continued to maintain its position as the third highest cement producer in the world, producing nearly 90 million tons, or 5% more than in 1988.

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	
1988:							
Railroad	9,496	91	1,479	([3])	3,562	26	5,066
Truck	2,333	335	28,620	731	45,306	3,491	78,148
Barge and boat	9,289	10	2,199	—	334	—	2,533
Unspecified[4]	514	—	419	2	568	18	1,006
Total[2]	21,632	436	32,717	732	49,769	3,535	[5]86,753
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[4]	517	—	495	9	581	18	1,103
Total[2]	22,232	273	32,109	504	48,324	3,291	[6]84,229

[1] Includes Puerto Rico.
[2] Data may not add to totals shown because of independent rounding.
[3] Less than 1/2 unit.
[4] Includes cement used at plant.
[5] Bulk shipments were 95.1% and container (bag) shipments were 4.9%.
[6] Bulk shipments were 95.5% and container (bag) shipments were 4.5%.

TABLE 11

PORTLAND CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1988			1989		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
New York and Maine	3,293	$168,033	$51.02	2,999	$153,319	$51.13
Pennsylvania, eastern	4,800	258,807	53.91	4,259	230,506	54.12
Pennsylvania, western	1,509	70,827	46.93	1,498	71,474	47.70
Maryland	1,808	89,083	49.27	1,871	94,002	50.25
Ohio	1,424	70,816	49.73	1,446	73,230	50.64
Michigan	5,253	231,141	44.00	5,449	253,324	46.49
Indiana	2,315	107,179	46.29	2,364	108,297	45.81
Illinois	2,307	101,760	44.10	2,776	117,224	42.23
Georgia and Tennessee	2,307	114,455	49.61	2,072	100,818	48.66
South Carolina	2,533	118,670	46.84	2,188	99,083	45.28
Kentucky, Virginia, West Virginia	2,463	117,482	47.69	2,288	114,077	49.86
Florida	3,682	168,719	45.82	4,357	207,857	47.71
Nebraska and Wisconsin	W	W	W	W	W	W
Alabama	3,524	157,214	44.61	3,169	130,590	41.21
Arkansas, Louisiana, Mississippi	1,698	68,590	40.39	1,234	48,414	39.24
Utah	771	39,664	51.44	W	W	W
South Dakota	W	W	W	W	W	W
Iowa	2,029	98,930	48.75	2,072	102,387	49.42
Missouri	4,679	184,755	39.48	4,922	182,005	36.98
Kansas	1,569	72,805	46.40	1,505	69,390	46.12
Oklahoma	1,432	42,131	29.42	1,236	39,360	31.85
Texas, northern	3,270	162,816	49.79	3,293	155,937	47.36
Texas, southern	3,730	129,440	34.70	3,907	130,300	33.35
Idaho and Montana	719	39,638	55.12	657	38,366	58.36
Colorado and Wyoming	1,258	60,327	47.95	1,392	56,066	40.26
Alaska and Oregon	W	W	W	W	W	W
Arizona, Nevada, New Mexico	2,325	136,045	58.51	2,234	130,749	58.53
California, northern	3,076	177,733	57.78	3,127	184,543	59.02
California, southern	7,347	423,419	57.63	7,784	457,476	58.77
Hawaii	354	28,880	81.58	493	40,495	82.17
Washington	979	48,233	49.26	W	W	W
Total[2 3] or average	74,074	3,575,906	48.27	74,202	3,592,252	48.41
Foreign imports[4]	r11,712	542,942	r46.36	8,653	416,988	48.19
Puerto Rico	1,397	113,966	81.57	1,374	112,318	81.77
Grand total[3 5] or average	r87,183	4,232,814	r48.55	84,229	4,121,558	48.93

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 (9 in 1988 and 8 in 1989) as follows: Alaska (1), Florida (2), Iowa (1), Michigan (1), Pennsylvania (1), Texas (1) in 1988 and (2) in 1989, Utah (1) in 1988, and Washington (1) in 1988.

[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,[1] BY DISTRICT

District	1988			1989		
	Quantity (thousand short tons)	Value (thousands)	Average per ton	Quantity (thousand short tons)	Value (thousands)	Average per ton
New York and Maine	171	$9,966	$58.28	155	$8,925	$57.74
Pennsylvania, eastern	296	21,065	71.16	254	18,577	73.22
Pennsylvania, western	95	7,648	80.50	95	7,895	82.78
Maryland	W	W	W	W	W	W
Ohio	129	11,140	86.35	128	11,233	88.07
Michigan	265	22,915	86.47	255	22,286	87.50
Indiana	405	27,442	67.75	357	24,054	67.36
Illinois	W	W	W	W	W	W
Georgia and Tennessee	213	14,620	68.63	193	13,307	68.98
South Carolina	W	W	W	W	W	W
Kentucky, Virginia, West Virginia	338	22,093	65.36	289	19,463	67.25
Florida	411	25,892	62.99	477	31,231	65.54
Nebraska and Wisconsin	W	W	W	W	W	W
Alabama	273	16,457	60.28	252	13,852	54.99
Arkansas, Louisiana, Mississippi	W	W	W	W	W	W
Utah	W	W	W	W	W	W
South Dakota	W	W	W	W	W	W
Iowa	W	W	W	W	W	W
Missouri	153	6,310	41.24	123	6,193	50.39
Kansas	50	2,988	59.76	42	2,514	59.44
Oklahoma	W	W	W	W	W	W
Texas, northern	81	7,216	89.08	79	7,010	88.95
Texas, southern	55	3,584	65.16	54	3,725	69.16
Idaho and Montana	W	W	W	W	W	W
Colorado and Wyoming	W	W	W	W	W	W
Alaska and Oregon	W	W	W	W	W	W
Arizona, Nevada, New Mexico	71	5,468	77.01	57	4,545	79.61
California, northern	—	—	—	—	—	—
California, southern	W	W	W	W	W	W
Hawaii	10	1,531	153.10	10	1,566	160.00
Washington	W	W	W	—	—	—
Total[2] or average	3,574	243,941	68.25	3,329	229,441	68.93
Foreign imports[3]	100	7,674	76.74	54	4,250	78.19
Grand total[2] or average	3,674	251,615	68.48	3,383	233,691	69.08

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		
	1987	1988	1989	1987	1988	1989
Destination:						
Alabama	1,405	1,423	1,266	137	122	107
Alaska[3]	94	r95	111	—	W	—
Arizona	2,299	2,131	2,090	W	W	W
Arkansas	766	690	765	43	37	36
California, northern	3,598	3,958	4,190	W	W	W
California, southern	8,121	8,584	8,851	W	W	W
Colorado	1,110	992	1,082	16	13	12
Connecticut[3]	1,029	990	775	24	24	19
Delaware[3]	254	277	268	15	15	12
District of Columbia[3]	146	198	195	1	1	(4)
Florida	6,819	7,002	7,181	531	561	556
Georgia	3,321	3,170	2,666	248	238	197
Hawaii	329	355	493	10	10	10
Idaho	251	324	305	(4)	(4)	(4)
Illinois	1,498	1,278	1,259	30	30	28
Chicago, metropolitan[3]	2,037	2,294	2,421	66	69	69
Indiana	1,704	1,773	1,865	103	108	98
Iowa	1,199	1,225	1,262	12	12	12
Kansas	1,351	1,147	1,094	25	21	18
Kentucky	1,201	1,138	1,100	92	91	83
Louisiana	1,761	1,527	1,621	43	36	34
Maine	361	366	319	12	15	9
Maryland	1,645	1,722	1,518	156	171	136
Massachusetts[3]	1,589	1,439	1,090	51	49	38
Michigan	2,740	2,720	2,717	146	152	141
Minnesota[3]	1,582	1,464	1,588	51	48	42
Mississippi	787	760	705	53	48	43
Missouri	2,091	2,165	1,971	53	48	48
Montana	175	199	172	1	1	1
Nebraska	720	749	829	10	10	10
Nevada	754	1,081	1,256	(4)	(4)	(4)
New Hampshire[3]	345	337	272	15	15	11
New Jersey[3]	1,932	r1,973	1,813	88	83	72
New Mexico	517	507	522	8	6	6
New York, eastern	746	638	637	46	42	36
New York, western	989	1,070	1,036	57	55	55
New York, metropolitan[3]	1,851	r1,622	1,539	55	52	49
North Carolina[3]	2,145	2,179	1,959	283	281	241
North Dakota[3]	278	223	208	4	4	3
Ohio	3,314	3,439	3,451	189	205	184
Oklahoma	1,076	1,061	1,017	34	28	29
Oregon	728	799	844	(4)	(4)	1
Pennsylvania, eastern	2,132	2,446	2,251	87	99	89
Pennsylvania, western	1,350	1,215	1,100	82	79	75
Rhode Island[3]	244	215	189	6	7	6
South Carolina	1,138	1,213	1,109	152	151	126
South Dakota	272	275	289	5	4	5

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		
	1987	1988	1989	1987	1988	1989
Destination—Continued						
Tennessee	1,863	1,698	1,621	203	185	161
Texas, northern	3,799	3,270	3,273	96	87	77
Texas, southern	4,267	3,940	4,017	69	66	75
Utah	804	620	741	1	1	2
Vermont[3]	173	209	172	6	6	7
Virginia	2,557	2,604	2,349	225	241	221
Washington	r1,476	r1,660	1,698	8	r7	8
West Virginia	455	375	361	31	30	29
Wisconsin	1,587	1,635	1,752	46	47	46
Wyoming	317	257	227	1	1	1
U.S. total[5]	r89,092	r88,719	87,472	3,727	3,711	3,374
Foreign countries[6]	185	184	230	114	33	101
Puerto Rico	1,296	1,397	1,379	—	—	—
Total shipments[5]	r90,573	r90,300	89,081	3,841	3,744	3,475
Origin:						
United States[7]	74,868	73,743	74,155	3,715	3,468	3,190
Puerto Rico	1,296	1,397	1,379	—	—	—
Foreign:[8]						
Domestic producers	r10,595	r11,712	8,653	60	r211	264
Others	3,814	3,448	4,894	67	66	22
Total shipments[5]	r90,573	r90,300	89,081	3,841	r3,745	3,475

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—305,000 tons, 1988—318,000 tons, and 1989—183,935 tons) used in the manufacture of prepared masonry 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 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.

Japanese exports to the United States increased 37% to 2.4 million tons in 1989. Of Japanese exports to the United States, 67% was shipped to the Los Angeles area.

Korea, Republic of

The Republic of Korea's cement production increased 49% during the past 5 years to 34 million tons in 1989. Internal cement consumption in Republic of Korea has increased steadily, reducing the amount of production available for export. Korean exports to the United States declined 59% in 1989, and further declines were expected. Exports to the United States were shipped primarily to the Los Angeles area.

Mexico

Cement production in Mexico continued to grow, reaching about 26 million tons in 1989. Mexico was again the biggest supplier of cement to the United States, accounting for 28% of total imports. Eighteen of the 36 customs districts reported receiving Mexican cement. The Tampa, FL, Customs District was the largest recipient of Mexican cement with 1.2 million tons, or 28% of the total.

CURRENT RESEARCH

The Bureau of Mines concluded research on the use of lightweight concrete for ground support in underground mining. The objective of the research was to develop concepts for new, innovative continuous liners and other support systems for metal and nonmetal underground mines having soft, caving, and squeezing ground conditions. Field and laboratory tests demonstrated the feasibility of using lightweight concrete in lining systems. The innovative concepts developed by this research will aid mine operators by decreasing capital and maintenance costs and by improving productivity in soft, caving, squeezing or bursting ground conditions found in deep mines.[4]

The Construction Technology Laboratories (CTL) of the Portland Cement Association reported development of a new concrete using lightweight aggregates. According to CTL, the new concrete is lighter and has better insulating properties than conventional concretes. Unit weights can range from 120

pounds per cubic foot (pcf) to as low as 20 pcf, compared with 140 pcf to 150 pcf for normal weight concretes. CTL also claims that the product offers a broad range of compressive strengths and thermal and fire resistances. The materials are particularly suited for constructing high- and-low-rise buildings, bridges, religious facilities, sports arenas, floor slabs, roof decks, and fire barriers.[5]

OUTLOOK

The demand for cement in 1990 is expected to remain essentially unchanged from 1989, driven primarily by continued weakness in the multifamily residential and nonresidential building construction markets. Gradual increases in demand are anticipated after 1990 as the economy improves. The Portland Cement Association estimates that cement demand will reach 100 million and 101 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. The price of foreign cement will also rise as water freight rates continue to increase and as more complaints are filed by domestic producers alleging that the industry is being injured by dumping.

BACKGROUND

The science of making cement is ages old. During construction of the Great Pyramid about 2600 B.C., the Egyptians made cementing material by calcining impure gypsum containing calcium carbonate. The Greeks were probably the first to calcine limestone for mortar, about 185 B.C. Portland cement was first produced and patented by Joseph Aspdin in 1824. The name "portland" was chosen because the set cement resembles a building stone quarried from the Isle of Portland off the southern coast of England. The first cement plant in the United States was built in Pennsylvania where David O. Saylor obtained a patent for creating a cement equal to the portland cement made in England.

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.[7] The National Institute for

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	
	1988	1989	1988	1989	1988	1989	1988	1989
Northeast:								
New England	3,556	2,818	4	3	115	89	3	3
Middle Atlantic	9,005	8,377	10	10	411	376	11	11
Total[3]	12,561	11,194	14	13	526	465	14	14
South:								
Atlantic	18,740	17,606	21	20	1,645	1,518	44	45
East Central	5,019	4,692	6	6	431	394	12	12
West Central	10,488	10,692	12	12	255	251	7	7
Total[3]	34,247	32,990	39	38	2,331	2,164	63	64
Midwest:								
East	13,139	13,465	15	15	669	565	18	17
West	7,248	7,241	8	8	147	139	4	4
Total[3]	20,387	20,706	23	23	816	704	22	21
West:								
Mountain	6,112	6,396	7	7	22	22	1	1
Pacific	r15,451	16,187	17	19	r17	18	—	—
Total[4]	r21,563	22,583	24	26	38	40	1	1
Grand total[3]	r88,759	87,472	100	100	r3,712	3,374	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 1989, 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	190	6.3	432	14.4	2,151	71.6	123	4.1	88	2.9	(3)	0.1	17	0.6	3,002
Pennsylvania, eastern	358	8.4	913	21.4	2,661	62.5	193	4.5	34	.8	42	1.0	59	1.4	4,259
Pennsylvania, western	171	11.4	248	16.5	934	62.3	110	7.3	36	2.4	—	—	(3)	.1	1,498
Maryland	99	5.3	354	18.9	1,329	71.0	31	1.6	46	2.5	—	—	14	.7	1,872
Ohio	49	3.4	202	14.0	1,152	79.7	41	2.8	1	.1	(3)	—	1	—	1,446
Michigan	191	3.5	684	12.5	4,100	75.4	357	6.5	84	1.5	8	.1	25	.5	5,449
Indiana	124	5.3	301	12.7	1,762	74.5	161	6.8	—	—	—	—	17	.7	2,365
Illinois	12	.4	162	5.8	2,358	84.9	219	7.9	24	.9	—	—	(3)	.1	2,776
Georgia and Tennessee	123	5.9	376	18.1	1,400	67.5	79	3.8	87	4.2	(3)	.1	8	.4	2,073
South Carolina	55	2.5	414	18.9	1,518	69.3	96	4.4	36	1.7	22	1.0	48	2.2	2,189
Kentucky, Virginia, West Virginia	77	3.4	309	13.5	1,657	72.4	127	5.5	119	5.2	—	—	—	—	2,288
Florida	440	10.0	630	14.4	2,918	66.5	143	3.2	127	2.9	3	.1	129	2.9	4,389
Nebraska and Wisconsin	W	W	W	W	W	W	W	W	W	W	—	—	W	W	W
Alabama	212	6.7	452	14.3	2,041	64.3	157	4.9	85	2.7	4	.1	221	7.0	3,172
Arkansas, Louisiana, Mississippi	39	3.2	119	9.7	762	61.7	124	10.1	129	10.4	9	.7	52	4.2	1,234
Utah	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
South Dakota	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Iowa	48	2.3	384	18.5	1,361	65.7	236	11.4	12	.6	5	.2	27	1.3	2,072
Missouri	70	1.4	229	4.7	3,998	81.2	362	7.4	134	2.7	—	—	129	2.6	4,922
Kansas	82	5.4	92	6.1	1,135	75.4	119	7.9	28	1.9	1	—	49	3.3	1,505
Oklahoma	54	4.3	85	6.9	710	57.4	120	9.8	214	17.3	(3)	—	53	4.3	1,236
Texas, northern	182	5.5	281	8.5	1,719	52.2	194	5.9	483	14.7	75	2.3	359	10.9	3,294
Texas, southern	151	3.8	358	9.2	2,808	71.9	196	5.0	164	4.2	11	.3	219	5.6	3,907
Idaho and Montana	14	2.1	71	10.7	421	64.0	42	6.4	76	11.6	(3)	—	34	5.2	658
Colorado and Wyoming	68	4.9	143	10.3	848	60.9	233	16.7	87	6.3	(3)	—	13	.9	1,393
Alaska and Oregon	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Arizona, Nevada, New Mexico	71	3.2	382	17.1	1,387	62.1	21	.9	362	16.2	7	.3	4	.2	2,234
California, northern	176	5.6	391	12.5	2,486	79.5	23	.7	38	1.2	(3)	.1	12	.4	3,127
California, southern	258	3.3	1,109	14.2	5,903	75.8	9	.1	348	4.5	5	.1	159	2.0	7,791
Hawaii	30	6.1	65	13.2	364	73.8	5	1.1	16	3.3	7	1.4	5	1.1	493
Washington	W	W	W	W	W	W	W	W	W	W	—	—	W	W	W
Foreign Imports[4]	—	—	—	—	8,608	99.5	—	—	—	—	—	—	45	.5	8,653
Total[2] or average	3,475	4.2	9,436	11.4	60,914	73.5	3,943	4.8	3,030	3.6	202	.2	1,909	2.3	82,909
Puerto Rico	607	44.2	92	6.7	643	46.8	—	—	27	1.9	5	.4	(3)	—	1,374

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] Less than 1/2 unit.

[4] Cement imported and distributed by domestic producers only. Source of imports withheld to avoid disclosing company proprietary data.

TABLE 16

PORTLAND CEMENT SHIPPED FROM PLANTS IN THE UNITED STATES,[1] BY TYPE

	1988			1989		
	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)	79,943	$3,826,576	$47.87	77,597	$3,718,291	$47.92
High-early-strength (Type III)	3,359	178,149	53.04	3,133	164,291	52.45
Sulfate-resisting (Type V)	697	36,600	52.51	758	43,970	58.03
Oil well	916	48,193	52.61	869	42,316	48.70
White	365	61,155	167.54	456	70,715	155.24
Portland slag and portland pozzolan	625	33,454	53.52	545	29,618	54.33
Expansive	64	5,595	87.42	40	3,999	100.62
Miscellaneous[3]	769	43,092	56.03	832	48,358	58.10
Total[4 5] or average	86,738	4,232,814	48.80	84,229	4,121,558	48.93

[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.

Standards and Technology establishes and the General Services Administration issues Federal specifications for hydraulic cements used in Federal construction projects. Following is a brief discussion of various types of hydraulic cements and the materials from which they are made.

Clinker.—Clinker is produced by heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and iron oxide in a kiln to a temperature of about 2,700° F at which partial fusion occurs. The fused material, which ranges from fine sand grains to walnut size, is ground with small amounts, 3% to 5%, of calcium sulfate, usually gypsum or anhydrite, to make portland cement.

Portland Cement.—ASTM specifications C-150 covers five types of portland cement: (1) Type I, for use when special properties specified for other types are not required, (2) Type II, for general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired, (3) Type III, for use when high early strength is required, (4) Type IV, for use when a low heat of hydration is desired, and (5) Type V, for use when high sulfate resistance is required. ASTM specifications also include Type IA, Type IIA,

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
1985	51.30	66.64	51.87
1986	50.10	65.68	50.73
1987	r48.79	70.55	r49.70
1988	r48.55	68.48	r49.36
1989	48.93	69.08	49.71

r Revised.
[1] Includes Puerto Rico. Mill value is the actual value of sales to customers, f.o.b. plant, less all discounts and allowances, less all freight charges from producing plant to distribution terminal if any, less total cost of operating terminal if any, less cost of paper bags and pallets.
[2] Masonry cement made at cement plants only.

TABLE 18

U.S. EXPORTS OF HYDRAULIC CEMENT AND CEMENT CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value
Bahamas	1	58	2	161	8	747
Canada	45	7,025	91	6,381	447	18,609
Ghana	2	130	2	133	14	1,018
Mexico	3	1,355	4	1,164	27	2,120
Netherlands	(1)	73	(1)	31	1	139
Other[2]	r1	r922	r2	r1,037	15	2,928
Total	52	9,563	101	8,907	512	25,561

r Revised.
[1] Less than 1/2 unit.
[2] Includes 38 countries in 1987; 27 in 1988; and 37 in 1989.

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	1987			1988			1989		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Canada	4,154	146,693	157,606	3,628	139,968	143,889	3,420	132,558	142,733
Colombia	612	14,914	22,090	647	16,798	23,924	849	23,594	34,122
France	772	15,152	24,373	758	27,085	34,473	355	18,909	28,646
Greece	1,641	36,559	49,141	2,271	62,450	78,470	1,403	41,945	55,948
Japan	723	18,351	25,108	1,758	46,719	57,619	2,415	62,239	78,622
Korea, Republic of	616	14,241	18,095	520	11,326	14,521	211	5,808	7,440
Mexico	4,960	125,666	156,585	4,992	124,527	149,885	4,411	118,468	146,452
Spain	3,044	80,745	106,996	1,857	54,463	68,860	1,562	47,218	62,010
Venezuela	766	17,534	24,498	641	16,530	22,484	755	22,205	30,149
Other	438	18,677	22,096	416	15,857	21,982	360	16,579	19,203
Total	17,726	488,532	606,588	17,488	515,723	616,107	15,741	489,523	605,325

[1] Cost, insurance, and freight.

Source: Bureau of the Census.

TABLE 20

U.S. IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1987			1988			1989		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Canada	846	25,056	28,150	417	12,943	14,163	407	13,063	14,459
Colombia	58	1,265	1,515	39	946	1,235	82	2,012	3,037
France	342	7,839	9,818	402	11,801	15,006	185	8,991	10,949
Greece	343	6,330	8,272	53	1,098	1,101	43	1,155	1,569
Japan	37	883	1,222	137	3,030	4,281	235	5,462	7,598
Mexico	1,215	21,114	26,241	437	8,363	10,415	423	10,511	13,647
Spain	734	14,121	17,543	344	8,282	10,889	254	5,469	7,251
Other	93	2,765	2,941	90	2,163	3,007	116	3,351	4,018
Total	3,668	79,373	95,702	1,919	48,626	60,097	1,745	50,014	62,528

[1] Cost, insurance, and freight.

Source: Bureau of the Census.

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.

ASTM designation C-595 covers the following 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

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Anchorage:						
Canada	8	654	953	12	717	976
Japan	37	990	1,218	65	2,378	3,194
Total	45	1,644	2,171	77	3,095	4,170
Baltimore:						
Canada	22	595	644	64	1,710	1,864
Colombia	—	—	—	94	2,763	2,988
Greece	169	4,084	4,470	81	2,251	2,447
Japan	(2)	45	57	(2)	62	80
Mexico	131	2,585	3,129	160	4,066	4,454
Netherlands	(2)	104	113	(2)	59	63
Spain	82	2,138	2,315	23	675	860
Venezuela	6	150	163	—	—	—
Total[3]	411	9,701	10,892	422	11,586	12,757
Boston:						
Canada	6	145	149	42	1,178	1,235
Colombia	6	157	302	10	285	303
Greece	336	12,465	13,351	220	7,147	7,329
Mexico	—	—	—	24	669	682
Netherlands	(2)	11	14	—	—	—
Spain	54	2,960	3,351	30	790	800
United Kingdom	15	736	746	—	—	—
Venezuela	—	—	—	7	286	296
Total[3]	417	16,474	17,912	333	10,355	10,647
Buffalo:						
Canada	1,017	45,139	45,139	925	41,564	43,692
United Kingdom	(2)	4	4	—	—	—
Total[3]	1,017	45,142	45,142	925	41,564	43,692
Charleston:						
France	—	—	—	(2)	19	24
Germany, Federal Republic of	(2)	3	3	—	—	—
Mexico	46	978	1,260	75	2,176	3,205
Netherlands	(2)	6	6	—	—	—
Spain	108	2,363	2,984	43	1,090	1,392
Total[3]	154	3,351	4,254	118	3,285	4,623
Chicago:						
Canada	(2)	3	3	—	—	—
Belgium	—	—	—	(2)	2	6
Japan	(2)	29	33	(2)	26	34
Lebanon	24	781	1,315	—	—	—
Total[3]	24	813	1,349	(2)	28	40
Cleveland: Canada	135	4,735	5,901	138	4,673	6,284
Columbia-Snake: Japan	125	2,911	3,878	116	2,872	3,861

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Detroit:						
Canada	650	25,283	26,570	550	21,572	23,266
Germany, Federal Republic of	(2)	6	7	—	—	—
Netherlands	(2)	23	27	—	—	—
Turkey	—	—	—	20	783	783
Venezuela	—	—	—	19	770	866
Total[3]	650	25,312	26,604	589	23,125	24,915
Duluth: Canada	144	4,449	4,995	80	2,083	2,458
El Paso: Mexico	450	16,961	16,961	496	18,011	20,022
Great Falls:						
Canada	(2)	2	2	(2)	12	12
Yugoslavia	(2)	13	13	—	—	—
Total[3]	(2)	15	15	(2)	12	12
Honolulu:						
Colombia	—	—	—	30	529	1,148
Japan	137	3,030	4,281	195	4,524	6,319
Korea, Republic of	12	461	643	—	—	—
Mexico	—	—	—	33	788	1,436
Total[3]	149	3,491	4,923	258	5,841	8,902
Houston-Galveston:						
Denmark	—	—	—	(2)	6	6
Germany, Federal Republic of	(2)	24	28	(2)	32	41
Italy	(2)	3	5	—	—	—
Mexico	317	6,323	8,882	54	1,079	1,403
Spain	62	1,525	2,131	11	711	711
Total[3]	378	7,875	11,046	66	1,828	2,161
Laredo:						
China	—	—	—	1	136	161
Mexico	229	8,155	8,223	144	5,894	6,531
Panama	1	31	31	—	—	—
Total[3]	229	8,186	8,254	145	6,030	6,692
Los Angeles:						
Denmark	18	571	1,533	4	181	469
France	(2)	973	1,232	(2)	40	44
Japan	1,158	32,044	37,847	1,607	41,629	50,115
Korea, Republic of	508	10,865	13,878	134	3,833	5,052
Spain	23	822	974	214	6,738	8,650
Sri Lanka (Ceylon)	—	—	—	20	585	716
Taiwan	115	2,783	3,720	76	1,848	2,470
Turkey	—	—	—	33	753	1,300
United Kingdom	—	—	—	29	750	1,001
Venezuela	—	—	—	46	1,811	2,148
Yugoslavia	1	91	136	(2)	56	62
Total[3]	1,823	48,149	59,322	2,162	58,224	72,028

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Miami:						
Belgium-Luxembourg	3	188	284	2	184	340
Brazil	(2)	2	2	—	—	—
Colombia	12	355	447	60	1,917	2,344
Denmark	6	372	452	11	656	839
France	—	—	—	(2)	13	14
Germany, Federal Republic of	(2)	5	7	—	—	—
Greece	505	12,499	16,276	180	5,255	9,131
Mexico	449	9,102	12,954	591	13,073	19,652
Spain	296	10,786	13,420	328	13,587	14,724
Sweden	4	148	170	—	—	—
Venezuela	128	3,200	4,210	187	5,047	6,779
Total[3]	1,404	36,657	48,220	1,360	39,732	53,823
Mobile:						
Greece	52	1,098	1,101	—	—	—
Mexico	334	5,232	6,789	—	—	—
Total	386	6,330	7,890	—	—	—
New Orleans:						
Belgium-Luxembourg	—	—	—	(2)	42	46
Canada	26	865	1,040	—	—	—
France	293	8,982	11,354	206	6,146	8,332
Mexico	300	6,034	10,223	124	2,696	4,490
Spain	439	10,484	13,555	75	2,439	3,071
Total[3]	1,059	26,364	36,172	405	11,323	15,940
New York City:						
Belgium	—	—	—	(2)	54	65
Colombia	—	—	—	14	287	443
France	119	3,303	4,605	—	—	—
Greece	743	19,727	26,251	611	18,677	25,138
Mexico	161	3,222	4,865	14	313	391
Saudi Arabia	36	613	1,076	—	—	—
Spain	208	6,952	8,718	344	10,224	13,937
Sweden	35	1,042	1,397	—	—	—
Switzerland	(2)	2	2	—	—	—
United Kingdom	5	145	210	(2)	1	1
Total[3]	1,308	35,004	47,123	985	29,556	39,976
Nogales: Mexico	418	9,915	9,915	416	10,434	11,806
Norfolk:						
Bahamas	6	217	268	3	96	149
Colombia	34	902	1,317	129	3,866	5,501
France	51	7,801	9,206	75	9,925	18,194
Germany, Federal Republic of	(2)	15	19	—	—	—
Greece	141	4,503	5,545	25	731	975
Mexico	38	1,060	1,500	91	1,978	3,289
Netherlands	(2)	1	1	—	—	—
Spain	52	1,509	1,960	—	—	—

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Norfolk—Continued						
United Kingdom	6	242	309	1	442	506
Venezuela	156	4,283	6,526	180	5,330	8,233
Total[3]	486	20,533	26,652	506	22,368	36,846
Ogdensburg:						
Canada	279	9,089	9,089	316	10,531	11,181
Netherlands	—	—	—	(2)	12	14
Total	279	9,089	9,089	316	10,543	11,195
Pembina: Canada	190	8,780	8,780	253	10,962	12,037
Philadelphia:						
France	41	1,124	1,528	—	—	—
Germany, Federal Republic of	(2)	112	123	(2)	8	11
Greece	104	2,271	3,605	156	4,062	6,180
Spain	202	5,825	7,634	224	7,292	9,613
Total[3]	347	9,332	12,890	380	11,362	15,804
Portland, ME:						
Canada	14	697	697	16	723	772
Mexico	2	64	64	—	—	—
Portugal	20	777	942	—	—	—
Total[3]	36	1,538	1,704	16	723	772
Providence:						
Canada	—	—	—	5	135	146
Colombia	131	3,262	5,961	118	2,900	7,219
Greece	119	3,145	4,254	113	3,319	4,093
Spain	62	1,654	2,412	8	237	351
Venezuela	5	186	246	—	—	—
Total[3]	317	8,247	12,872	243	6,591	11,810
St. Albans:						
Canada	567	17,502	17,504	467	15,484	17,415
France	—	—	—	(2)	130	135
Netherlands	(2)	62	72	(2)	12	14
Total[3]	567	17,564	17,576	468	15,626	17,564
San Diego:						
Japan	25	737	909	—	—	—
Mexico	661	22,942	23,595	627	21,049	22,685
Morocco	(2)	4	4	—	—	—
Total	686	23,683	24,508	627	21,049	22,685
San Francisco:						
Japan	39	1,221	1,605	160	4,229	5,732
Korea, Republic of	—	—	—	77	1,975	2,388
Mexico	274	7,066	7,781	290	7,724	8,173
Yugoslavia	(2)	4	7	(2)	7	12
Total[3]	313	8,290	9,393	527	13,935	16,305

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
San Juan, PR:						
Belgium-Luxembourg	7	461	787	7	499	854
Canada	—	—	—	(2)	11	15
Colombia	39	946	1,235	49	1,224	1,602
Denmark	13	1,069	1,424	10	626	1,064
Germany, Federal Republic of	—	—	—	(2)	10	19
Honduras	32	853	1,303	56	1,581	2,051
Ireland	—	—	—	(2)	10	18
Italy	(2)	2	3	—	—	—
Japan	(2)	5	5	(2)	9	9
Mexico	31	832	1,123	1	34	62
Venezuela	—	—	—	(2)	2	4
Total[3]	122	4,168	5,881	122	4,006	5,698
Savannah:						
Colombia	9	258	273	30	903	910
Mexico	30	688	728	18	506	506
Spain	48	1,749	1,844	—	—	—
United Kingdom	—	—	—	(2)	1	2
Venezuela	—	—	—	8	249	249
Total[3]	88	2,695	2,846	56	1,659	1,668
Seattle:						
Canada	569	22,026	22,417	552	21,042	21,405
China	—	—	—	(2)	19	22
Colombia	(2)	3	3	—	—	—
Japan	237	5,708	7,787	271	6,503	9,267
Yugoslavia	(2)	5	9	—	—	—
Total[3]	806	27,742	30,215	823	27,564	30,695
Tampa:						
Bahamas	—	—	—	3	104	124
Belgium	—	—	—	(2)	73	96
Colombia	331	8,693	11,210	283	7,683	10,163
Denmark	59	W	W	66	W	W
France	253	W	W	73	W	W
Greece	101	2,657	3,617	—	—	—
Mexico	1,121	23,367	31,893	1,227	27,628	36,838
Spain	221	5,696	7,561	263	6,096	7,899
Sweden	5	202	237	—	—	—
Venezuela	286	7,657	10,250	282	7,913	10,675
Total[3]	2,376	57,073	76,234	2,197	56,043	72,979
Virgin Islands of the United States:						
Bahamas	1	35	37	—	—	—
Barbados	1	73	94	(2)	11	11
Canada	2	4	5	—	—	—
Colombia	2	171	179	28	978	1,216
Dominican Republic	—	—	—	15	427	433
Japan	—	—	—	1	8	10

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	1988			1989		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Virgin Islands of the United States—Continued						
Leeward and Windward Islands	(2)	8	10	(2)	34	35
Sweden	3	114	116	—	—	—
Trinidad and Tobago	—	—	—	1	38	40
Venezuela	60	1,054	1,089	25	796	899
Total[3]	68	1,459	1,530	71	2,292	2,644
Wilmington, NC:						
Colombia	79	2,051	2,998	—	—	—
Germany, Federal Republic of	—	—	—	(2)	24	24
Greece	—	—	—	17	503	656
Mexico	—	—	—	28	616	1,132
Total	79	2,051	2,998	45	1,143	1,812
Grand Total[3]	17,488	515,723	616,107	15,741	489,523	605,325

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1] Cost, insurance, and freight.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

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)
1985	9,581	306,472	4,633	103,067	274	27,890	14,487	437,429
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

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

Source: Bureau of the Census.

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 constitutes 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.

TABLE 23

WORLD CEMENT ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989[1]

(Million short tons)

Country	Rated clinker capacity[e 1]
North America:	
Canada	16
Mexico	27
United States (including Puerto Rico)	85
Total	128
South America:	
Argentina	12
Brazil	47
Venezuela	7
Other	20
Total	86
Europe:	
Belgium	8
Czechoslovakia	10
France	26
German Democratic Republic	14
Germany, Federal Republic of	44
Greece	17
Italy	44
Poland	21
Portugal	8
Romania	20
Spain	39
Turkey	25
U.S.S.R.	154
United Kingdom	17
Yugoslavia	12
Other	101
Total	560
Africa:	
Algeria	12
Egypt	22
South Africa, Republic of	12
Other	34
Total	80
Asia:	
China	220
India	56
Indonesia	20
Japan	97
Korea, North	11
Korea, Republic of	34
Thailand	12
Taiwan	24

See footnotes at end of table.

TABLE 23—Continued

WORLD CEMENT ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989[1]

(Million short tons)

Country	Rated clinker capacity[e 1]
Asia—Continued	
Other	35
Total	509
Oceania:	
Australia	9
Other	2
Total	11
World total	1,374

[e] Estimated.
[1] Includes capacities of operating plants as well as plants on standby basis.

Aluminous Cement.—Sometimes known as calcium aluminate cement, high alumina cement, or "Ciment Foundu," 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 composes 96% of the total domestic output; the remainder is mostly masonry cement. About 92% of total portland cement production in 1989 comprised Type I and II cement, 4% was Type III, and 1% was oil-well cement. Cements produced in quantities comprising less than 1% each were portland-pozzolan and portland-blast furnace slag, Type IV, Type V, white, expansive, and waterproof cements. A small quantity of regulated set cement was produced. Each product requires either a change in proportion of raw materials mixed for kiln feed or additives to the clinker.

Industry Structure

The industry is composed of 130 cement producing plants in 40 States. Multi-plant 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 finish 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 cement clinker production are, in order of importance, limestone, clay and shale, and iron ore. In instances where essential chemical components are not present in the primary raw material 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 requirement by importing. Many domestic companies have reported reserves of raw materials exceeding 100 years 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

TABLE 24

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Afghanistan[e]	85	95	110	110	110
Albania[e]	940	940	945	880	880
Algeria[e]	6,720	7,120	7,170	7,170	7,170
Angola[e]	390	390	390	[r]1,100	1,100
Argentina	5,104	6,122	6,947	6,667	4,927
Australia	6,489	6,534	6,469	7,055	7,165
Austria	5,027	5,036	4,985	5,250	5,290
Bahamas	—	([3])	—	—	—
Bangladesh[4]	265	322	342	397	413
Barbados	[e]240	219	226	203	237
Belgium	6,103	6,349	6,271	7,111	7,600
Benin[e]	331	331	331	[r]550	550
Bolivia	418	[r]325	437	499	[5]557
Brazil	22,721	27,885	28,076	27,919	27,560
Bulgaria	5,838	6,285	6,056	6,101	6,100
Burma	526	478	429	342	[5]414
Canada	11,235	11,687	13,892	13,268	13,000
Chile	1,570	1,580	1,757	2,021	1,900
China[e]	157,100	178,000	198,000	224,000	228,000
Colombia	[r]5,946	[r]6,626	6,575	7,031	6,900
Congo	64	[e]64	[4]42	[e]64	64
Costa Rica	524	573	613	613	600
Cote D'Ivoire (Ivory Coast)	748	855	719	770	770
Cuba	3,508	3,643	3,897	3,931	4,100
Cyprus	727	952	941	956	950
Czechoslovakia	11,315	11,352	11,430	12,097	[5]12,002
Denmark	1,917	2,237	2,080	1,853	2,200
Dominican Republic	1,110	1,175	[e]1,200	1,647	1,700
Ecuador	2,167	2,221	1,765	2,200	2,200
Egypt	6,337	8,391	9,641	10,789	10,700
El Salvador	496	488	669	687	[5]697
Ethiopia[e]	275	275	275	275	275
Fiji	103	102	—	—	—
Finland	1,773	1,567	1,572	1,658	1,650
France	25,955	[e]25,900	25,970	[e]26,500	26,500
Gabon	270	232	151	145	155
German Democratic Republic	12,795	13,214	13,702	13,790	13,800
Germany, Federal Republic of	28,393	29,299	27,853	28,897	29,200
Ghana	400	241	302	526	[5]623
Greece	15,067	14,706	14,515	14,388	14,400
Guadeloupe	190	199	[e]210	220	220
Guatemala	580	710	1,459	1,660	[5]1,779
Haiti	291	278	278	276	240
Honduras	383	[r]397	497	617	660
Hong Kong	2,023	2,465	2,454	2,413	2,400
Hungary	4,054	4,239	4,578	4,269	4,300

See footnotes at end of table.

TABLE 24—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Iceland	126	125	144	[e]148	130
India	36,409	40,124	40,763	44,900	[5]46,407
Indonesia	11,112	12,060	13,055	13,495	[5]15,541
Iran	13,739	13,529	14,031	13,450	13,800
Iraq[e]	8,800	8,800	11,000	11,600	13,800
Ireland	1,606	1,541	1,596	1,857	1,800
Israel	2,227	2,270	2,454	2,564	2,500
Italy	40,429	[r]39,615	41,069	[e]40,800	40,200
Jamaica	264	266	337	409	400
Japan	80,300	78,555	78,871	85,489	89,600
Jordan	2,230	1,978	[e]2,500	2,015	[5]1,962
Kenya	934	1,446	1,456	1,366	[5]1,341
Korea, North[e]	8,800	8,800	9,900	11,000	11,000
Korea, Republic of	22,514	25,797	28,287	31,961	[5]33,592
Kuwait	1,315	1,118	[e]1,120	979	990
Lebanon[e]	1,100	1,000	1,000	1,000	1,000
Liberia	105	107	116	117	[5]94
Libya	[e]7,200	2,289	2,976	[e]3,000	3,000
Luxembourg	325	429	561	621	610
Madagascar[e]	39	39	39	39	39
Malawi	68	77	80	72	77
Malaysia	3,448	[r]3,934	3,655	4,161	[5]5,284
Mali[e]	[5]21	22	24	28	28
Martinique[e]	220	220	220	220	220
Mauritania	—	—	88	99	[5]99
Mexico	22,796	21,772	24,633	24,816	25,900
Mongolia[e]	[5]166	[r]470	[r]600	[r]660	660
Morocco	4,072	4,125	[e]4,200	[e]4,200	4,200
Mozambique[e]	[r]220	[r]220	[r]280	[r]440	440
Nepal	35	102	167	237	290
Netherlands	3,209	3,417	[e]3,440	3,400	3,900
New Caledonia[e]	66	44	55	66	66
New Zealand	1,069	999	970	[e]990	1,050
Nicaragua[e]	110	110	110	110	110
Niger[e]	42	42	44	[5]29	30
Nigeria	3,680	4,255	4,189	3,748	3,860
Norway	1,764	1,929	1,807	1,574	[5]1,516
Oman	715	[e]770	926	869	[5]1,044
Pakistan[e]	5,765	5,760	7,530	[5]7,761	7,700
Panama	336	370	[e]385	[e]385	385
Paraguay	51	197	288	354	360
Peru	1,937	2,432	2,849	[e]2,800	2,200
Philippines	3,395	3,910	3,660	4,700	4,400
Poland	16,535	17,416	17,747	[re]18,740	16,500
Portugal	5,913	6,001	[e]6,400	6,300	6,600
Qatar	350	340	[e]330	[re]330	330
Romania	13,490	15,670	15,760	[e]15,400	15,400
Saudi Arabia	[r]9,062	[r]10,287	9,474	[e]10,500	10,500

See footnotes at end of table.

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 U.S. Flotation, a method of beneficiation used by some companies to remove undesirable constituents from raw materials to increase the calcium carbonate content of the kiln feed, produces waste such as silica sand, or mica fines which 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 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 paper bags and pallets add to the complexity of cement price patterns. Extreme competition among producers and stiff competition from imports are primary contributors to depressed prices, which severely 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 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.

TABLE 24—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Senegal	449	397	410	431	[5]419
Singapore	2,195	1,989	1,684	1,759	[5]1,881
South Africa, Republic of	7,754	[r]7,399	7,424	9,354	9,600
Spain (including Canary Islands)[e]	[5][6]26,673	26,500	25,800	26,500	27,000
Sri Lanka[e]	660	660	660	440	440
Sudan	213	[r e]165	134	[r e]165	165
Suriname[e]	55	55	55	55	55
Sweden	2,341	2,336	2,467	2,425	2,425
Switzerland	4,689	4,842	5,089	5,473	[5]6,020
Syria	4,736	4,630	4,266	3,671	[5]3,859
Taiwan	15,893	16,321	17,226	19,049	[5]19,889
Tanzania[e]	330	330	330	330	330
Thailand	8,726	8,723	10,931	12,692	[5]16,561
Togo	313	384	407	416	[5]429
Trinidad and Tobago	362	[r]360	357	397	420
Tunisia	3,372	3,289	[e]3,750	[e]5,500	5,500
Turkey	19,380	22,050	24,228	24,995	[5]26,235
Uganda	[e]22	[r e]17	12	10	11
U.S.S.R.	144,096	148,943	151,462	153,771	154,300
United Arab Emirates	[r e]4,635	[r e]3,780	3,644	3,897	3,970
United Kingdom	14,704	14,785	[e]14,770	15,983	15,400
United States (including Puerto Rico)	78,859	79,916	79,501	78,252	[5]78,559
Uruguay	346	375	442	479	[5]513
Venezuela	5,836	6,335	6,735	6,833	[5]4,971
Vietnam[e]	1,430	1,700	1,667	1,650	1,760
Yemen (Sanaa)	1,543	1,279	838	712	770
Yugoslavia	9,952	10,061	9,880	9,744	9,400
Zaire	489	490	542	[r e]500	500
Zambia	349	368	413	446	[5]425
Zimbabwe	[e]770	[e]825	894	855	[5]793
Total	[r]1,057,794	[r]1,106,182	1,153,425	1,215,498	1,235,613

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through June 27, 1990.

[2] In addition to the countries listed, Cameroon produces cement, but available information is inadequate to make reliable estimates of output levels.

[3] Less than 1/2 unit.

[4] Data are for the year ending June 30 of that stated.

[5] Reported figure.

[6] Excludes natural cement.

Tariffs.—For countries with most-favored-nation status, duties are imposed only on white cement in the amount of 22 cent per 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 ton and $1.32 per 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 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.[8]

Employment.—In the U.S. cement industry in 1989, there were 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 275 trillion Btu's during 1989. 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 material, 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.

[1] U.S. Department of Commerce, International Trade Administration. Construction Review. V. 36, No. 2, Mar.-Apr. 1990, pp. 1-10.

[2] Engineering News-Record. ENR Materials Prices. V. 224, No. 1, Jan. 1990, pp. 73-74.

[3] Cement International. Rock Products. V. 93, No. 4, Apr. 1990, pp. 59-87.

[4] Skinner, E. H. Structural Uses and Placement Techniques for Concrete in Underground Mining. BuMines RI 9266, 1989, pp. 1-31.

[5] Construction Technology Laboratories Inc. CTL Review. V. 13, No. 1, Apr. 1990, pp. 1-4.

[6] Portland Cement Association. Market and Economic Research. U.S. Cement Consumption Forecast. May 1990, pp. 1-19.

[7] American Society for Testing and Materials. S. 4, v. 04.01, Cement, Lime, and Gypsum. Apr. 1, 1988, pp. 1-544.

[8] U.S. Department of Commerce, International Trade Administration. A Competitive Assessment of the U.S. Cement Industry. July 1987, pp. 144–146.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Cement. Ch. in Mineral Commodity Summaries, annual.
Cement. Ch. in Minerals Yearbook, annual.
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Cembureau, World Cement Directory.

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 19 years Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by the Branch of Data Collection and Coordination, Division of Statistics and Information Services. Chromite world production data by country were prepared by Audrey D. Wilkes, international data coordinator, Geographic Data Section, Division of International Minerals. Cost of production data were prepared by the Minerals Availability Field Office, Division of Resource Evaluation.

In 1989, reported chromium material consumption was 377,726 metric tons, gross weight. All tonnages are in metric tons unless otherwise specified. The reported consumption of chromite by the chemical and metallurgical industry increased while that of the refractory industry decreased. Metallurgical industry chromite consumption includes material consumed as part of the National Defense Stockpile (NDS) program to convert chromite to ferrochromium. Imports of chromite and chromium ferroalloys decreased compared with those of 1988.

United States supply consisted of recycled and imported chromium materials. The United States recycled about 594,000 tons, gross weight, of stainless steel scrap and imported about 894,000 tons of chromium ore, ferroalloys, chemicals, and pigments valued at about $430 million. The United States exported about 26,000 tons of chromium materials valued at about $31 million.

LEGISLATION AND GOVERNMENT PROGRAMS

In accordance with the President's November 1982 directive and Public Law 99-591, the Defense Logistics Agency (DLA) continued to upgrade NDS chromium ore to high-carbon ferrochromium. DLA reported conversion of chromium ore to ferrochromium on a calendar year contract basis. DLA signed a contract with Macalloy Corp., Charleston, SC, to upgrade NDS chromium ore into high-carbon ferrochromium. The contract period covers the years 1990 through 1994, the last 2 years of which are optional for DLA.

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	r31,944	20,898	17.6
1987	125,739	52,414	40,058	r28.8
1988	111,105	41,511	26,727	26.7
1989[1]	120,651	46,940	30,392	31.5
PROJECTED PERFORMANCE				
1990	114,353	e45,286	NA	29.9
1991	114,615	e46,496	NA	30.6
1992	103,977	e46,707	NA	32.7
1993	112,238	e51,424	NA	34.2

e Estimated. r Revised. NA Not available.
[1] Contract performance was extended owing to production delays resulting from hurricane damage among other reasons.
Source: Defense Logistics Agency.

TABLE 1

SALIENT CHROMIUM STATISTICS

(Thousand metric tons, gross weight)

	1985	1986	1987	1988	1989
CHROMITE					
United States:					
Exports	91	84	1	4	40
Reexports	3	1	5	1	2
Imports for consumption	376	443	490	615	525
Consumption	508	388	r506	r551	561
Stocks, Dec. 31: Consumer	272	285	r332	390	392
World production	r10,935	r11,547	11,355	p12,167	e11,901
CHROMIUM FERROALLOYS[1]					
United States:					
Production[2]	100	95	107	120	147
Exports	9	5	5	8	9
Reexports	1	1	2	2	2
Imports for consumption	304	361	303	431	351
Consumption	335	331	396	413	355
Stocks, Dec. 31: Consumer	29	29	23	30	20
World production[3]	r3,099	r3,076	3,244	p3,035	e3,363

e Estimated. p Preliminary. r Revised.
[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 Ferroalloys chapter.

DLA made a contract with Elkem Metals Co., Marietta, OH, to upgrade NDS nonspecification grade low-carbon ferrochromium into electrolytic (vacuum melting grade) chromium metal. The conversion of NDS nonspecification-grade low-carbon ferrochromium to vacuum melting grade electrolytic chromium metal is a new program. Elkem was awarded the $7.2 million contract to convert 2,129 tons of low-carbon ferrochromium to about 1,043 tons of chromium metal over a 1-year period starting in December 1989.

DLA initiated a 26-month program to evaluate plasma smelting technology. DLA planned to select a smelting method, plan a test program, construct a test furnace, conduct a test program, and employ the program's results to design a commercial-scale smelting furnace. The program was being carried out by South Carolina Research Authority, Macalloy Corp., Massachusetts Institute of Technology, Clemson University, and Arthur D. Little Inc.

The Department of State reviewed the status of chromium with respect to the Comprehensive Anti-Apartheid Act (Public Law 99-440). In January 1987, the Department of State found chromium (including ferrochromium) to be a strategic mineral essential for the economy or defense of the United States, unavailable from reliable and secure suppliers. The Department of State continued this classification of chromium (including ferrochromium) as a result of its review.[1]

The Occupational Safety and Health Administration (OSHA) reviewed health, risk, and feasibility evidence for chromium metal, chromic acid and chromates, and chromyl chloride. As a result of their review, OSHA decided to retain the previous exposure limit for chromium metal (8-hour time-weighted average value of 1 milligram per cubic meter) and chromic acid and chromates (ceiling exposers limit of 0.1 mg/m^3). OSHA decided to make rules for chromyl chloride exposure.[2]

Congress authorized the President to revise the goal for refractory-grade chromite ore in the NDS to 630,000 metric tons as part of the National Defense Authorization Act for Fiscal Years 1990 and 1991. At yearend, the authorized change had not been adopted.[3]

STRATEGIC CONSIDERATIONS

Supply Security

There is no primary production of chromium in the United States, and primary consumption of chromium by U.S. industry is by companies that use chromite to produce refractories, chromium chemicals, and ferrochromium, and chromium metal producers that use ferrochromium or chromic oxide. Long-term chromium supply is abundant. 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 alloy steel production, which are in turn essential to both the domestic economy and to the production of military hardware.

Stockpile

The NDS primarily contains chromium source material in the form of 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 cannot be used for economic or budgetary purposes. In addition to private and Government stocks, there exists a large unreported inventory of chromium contained in products, trader stocks, and scrap. The amount of these stocks varies with demand and price of the material. Under severe price pressures resulting from primary chromium shortages, recycling of consumer materials could add to the supply.

Chromite ore must be converted to ferrochromium before it can be used to make steel. Prompt response during a national defense emergency requires that conversion be carried out by domestic industry. However, domestic ferrochromium production capacity is not adequate to meet anticipated domestic demand under mobilization conditions. To ensure prompt response to a national defense emergency using the NDS, the President chose to convert stockpiled chromite ore to ferrochromium. (See Legislation and Government Programs section of this report.)

ISSUES

Ferrochromium production capacity in 1989 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 (Japan, Western Europe, and the United States) to major chromium ore-producing countries (the Republic of South Africa, Zimbabwe, Turkey, Philippines, and Finland). This has occurred through

TABLE 2

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR CHROMIUM IN 1989

(Thousand metric tons, gross weight)

Material	Stockpile goals	Physical inventory		
		Stockpile-grade	Nonstockpile-grade	Total
Chromite, metallurgical	2,903	1,395	216	1,611
Chromite, chemical	612	220	—	220
Chromite, refractory	771	355	—	355
High-carbon ferrochromium	168	581	1	582
Low-carbon ferrochromium	68	272	17	289
Ferrochromium-silicon	82	52	1	53
Chromium metal	18	3	—	3

Source: Defense Logistics Agency.

the creation of new plants or furnaces in chromium ore-producing locations and the closure of furnaces in geographic areas where ferrochromium production was formerly strong. The expansion of world annual gross weight production capacity by about 530,000 tons in 1989 has continued that trend. This expansion represented in the range of 10% to 15% of world capacity of the previous year and continues the historic trend. The largest addition to national annual capacity was in the Republic of South Africa where 290,000 tons, about 20% to 25% of that country's capacity in the previous year, was added. Three-fourths of the new capacity was located in chromium ore-producing countries. An additional 400,000 tons of annual ferrochromium production capacity had been anticipated to be brought into production in 1990, all of which was to have been in chromium ore-producing countries. An additional 400,000 tons of annual production capacity has been planned for 1991 or later. The supply shortage was estimated to have been about 200,000 tons in 1988 or about 5% of 1988 world production capacity. Stainless steel is the major chromium end use. 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 1989 and 1990 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 1989, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore.

Chrome Corp. of America (previously called Chrome Corp. International), a subsidiary of Boulder Gold (Australia), entered a joint venture with Dynamic Capital Corp. (Canada) to conduct a feasibility study of mining chromite from the Stillwater Complex (Montana) and producing ferrochromium. The study was planned to be completed in 1991. Chrome Corp. estimated that production could start in 1993.

TABLE 3

PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1989, BY INDUSTRY

Industry and company	Plant
Metallurgical:	
Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
Macalloy Corp.	Charleston, SC.
Shieldalloy Metallurgical Corp.	Newfield, NJ.
Moore McCormack Resources Inc., Globe Metallurgical Inc.	Beverly, OH.
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 4

PRODUCTION, SHIPMENTS, AND STOCKS OF CHROMIUM FERROALLOYS AND CHROMIUM METAL IN THE UNITED STATES

(Metric tons)

Material	Net production		Net shipments	Producer stocks, Dec. 31
	Gross weight	Chromium content		
1988:				
Low-carbon ferrochromium, High-carbon ferrochromium, Chromium concentrate	109,504	67,739	107,003	6,040
Ferrochromium-silicon, Chromium metal, Other [1]	10,141	5,543	8,496	2,791
Total	119,645	73,282	115,499	8,831
1989:				
Low-carbon ferrochromium, High-carbon ferrochromium, Chromium concentrate	137,997	84,938	129,181	15,199
Ferrochromium-silicon, Chromium metal, Other [1]	8,847	5,135	6,180	5,276
Total	146,844	90,073	135,361	20,475

[1] Includes exothermic chromium additives and other miscellaneous chromium alloys.

Macalloy Corp. won a contract from the DLA to convert NDS chromium ore into high-carbon ferrochromium. (See Legislation and Government Programs section of this report.) Production at Macalloy's Charleston, SC, plant was interrupted by Hurricane Hugo. The plant did not suffer significant damage; however, electrical energy supply was interrupted for several days.

Elkem Metals Co. won a contract from the DLA to convert NDS nonspecification-grade low-carbon ferrochromium into chromium metal. (See Legislation and Government Programs section of this report.) Elkem started a second furnace with a capacity of 17,000 tons per year. Excess supply of ferrochromium by yearend resulted in Elkem closing down both of its ferrochromium-producing furnaces.

CONSUMPTION AND USES

Domestic consumption of chromite ore and concentrate was 560,711 tons in 1989. Of the total chromite consumed, the chemical and metallurgical industry used 516,931 tons, and the refractory industry, 43,780. Much of the chromite consumed and ferrochromium produced by the metallurgical industry were part of the NDS conversion program. (See Legislation and Government Programs section of this report.)

Chromium has a wide range of uses in the three primary consumer groups. In the metallurgical industry, its principal use in 1989 was in stainless steel. Of the 360,962 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 43,780 tons.

The chemical industry consumed chromite for manufacturing sodium bichromate, chromic acid, and pigments. Sodium bichromate is the material from which a wide range of chromium chemicals are made.

TABLE 5

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 (percent)	Gross weight (metric tons)	Average Cr_2O_3 (percent)	Gross weight (metric tons)	Average Cr_2O_3 (percent)
1985	449,216	41.5	59,189	38.1	508,406	41.2
1986	342,281	40.3	45,303	37.1	387,584	40.2
1987	r458,536	r41.0	47,586	39.9	506,122	40.9
1988	r494,713	r42.8	r55,923	38.9	550,636	42.4
1989	516,931	42.8	43,780	39.5	560,711	42.6

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

TABLE 6

U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL IN 1989, BY END USE

(Metric tons, gross weight)

End use	Ferrochromium		Ferro-chromium -silicon	Other	Total[3]
	Low-carbon[1]	High-carbon[2]			
Steel:					
Carbon	2,990	3,963	207	252	7,412
Stainless and heat-resisting	8,274	265,325	6,837	196	280,633
Full-alloy	4,997	25,589	1,263	37	31,886
High-strength, low-alloy and electric	1,928	2,452	8,036	22	12,438
Tool	845	3,318	W	1	4,165
Cast irons	597	6,477	26	5	7,105
Superalloys	3,534	4,551	—	3,592	11,677
Welding materials[4]	432	583	—	136	1,151
Other alloys[5]	1,108	779	—	2,026	3,913
Miscellaneous and unspecified	313	131	45	93	582
Total[3 6]	25,018	313,169	16,415	[7]6,359	360,962
Chromium content	17,231	186,003	5,901	5,161	214,296
Stocks, Dec. 31, 1989	4,421	14,266	425	[8]833	19,945

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1] Ferrochromium that contains not more than 3% carbon.
[2] Ferrochromium that contains more than 3% carbon.
[3] Data may not add to totals shown due to 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 4,676 tons of chromium metal.
[8] Includes 640 tons of chromium metal.

STOCKS

Reported consumer stocks of chromite in the United States increased from 389,621 tons in 1988 to 392,273 tons in 1989. Chemical and metallurgical industry stocks increased, as did refractory industry stocks. Producer stocks of chromium ferroalloys, metal, and other materials increased from 8,831 tons in 1988 to 20,475 tons in 1989. Consumer stocks decreased from 30,425 tons in 1988 to 19,945 tons in 1989. At the 1989 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 6-week supply.

TABLE 7

U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1985	1986	1987	1988	1989
Chromite:					
Chemical and metallurgical	228,204	249,291	308,870	r366,268	368,482
Refractory	44,121	35,379	r23,144	r23,353	23,791
Total	272,325	284,670	r332,014	r389,621	392,273
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	4,973	4,985	3,169	5,683	4,421
High-carbon ferrochromium	21,877	20,840	18,023	23,135	14,266
Ferrochromium-silicon	1,169	1,324	505	647	425
Other[1]	1,161	1,607	826	960	833
Total[2]	29,181	28,756	22,524	30,425	19,945

r Revised.
[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.

PRICES

The price of chromite increased steadily until December when it declined slightly. The published price of South African Transvaal chromite, 44% Cr_2O_3 (no specific chromium-to-iron ratio), increased from a range of from $50 to $56 per ton, f.o.b. South African ports, to a range of from $60 to $66 in March, to a range of from $68 to $72 in September, where it remained until December when it declined to a range of from $60 to $65. The published price of Turkish ore increased from a range of from $150 to $180 per ton, f.o.b. Turkish ports, to a range of $230 to $255 in April, then decreased to a range of from $185 to $200 in September, followed by a further decrease in December to a range of from $175 to $185.

The published price of domestic high-carbon (50% to 55% and 66% to 75% chromium), low-carbon (0.025% and 0.05% carbon), and simplex low-carbon ferrochromium remained unchanged. The price of chromium metal increased from $3.75 per pound to $3.95 per pound in August, where it remained through December.

The price of imported high-carbon (50% to 55% and 60% to 65% chromium) and low-carbon (0.05% carbon) ferrochromium decreased almost monthly following 2 consecutive years of rising imported ferrochromium prices. The published price of high-carbon ferrochromium (50% to 55% chromium) decreased from a range of from 88 to 93 cents per pound of contained chromium to a range of from 52 to 55.5 cents during the year; high-carbon ferrochromium (60% to 65% chromium), from a range of from 93 to 97 cents to a range of from 51 to 54.5 cents; and low-carbon ferrochromium, from a range of from 120 to 126 cents to a range of from 94 to 105 cents.

TABLE 8

PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 1989

Material	January	December
	Cents per pound of chromium	
High-carbon ferrochromium:		
Domestic:		
50% to 55% chromium	50.25	50.25
66% to 70% chromium	52	52
Imported:		
50% to 55% chromium	88 - 93	52 - 55.5
60% to 65% chromium	93 - 97	51 - 54.5
Low-carbon:		
Domestic:		
0.025% carbon	100	100
0.05% carbon	95	95
Simplex	166	166
Imported: 0.05% carbon	120 -126	94 -105
	Cents per pound of product	
Electrolytic chromium metal	375	395

Source: *Metals Week*.

FOREIGN TRADE

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments.

WORLD REVIEW

Industry Structure

Brazil, Finland, the Republic of South Africa, and the U.S.S.R. are countries that mine chromite, produce ferrochromium, and produce stainless steel.

TABLE 9

U.S. EXPORTS AND REEXPORTS OF CHROMIUM ORES AND CONCENTRATES

Year	Exports		Reexports	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1985	91,453	$4,660	3,335	$670
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

Source: Bureau of the Census.

TABLE 10

U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Year	1987	1988	1989		Principal destinations, 1989
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
Chromite ore and concentrate	1,145	3,931	40,445	$5,014	Sweden (60%); Federal Republic of Germany (28%); Mexico (7%); Canada (5%).
Metal and alloys:					
Chromium metal[1]	376	318	196	4,097	Japan (45%); Mexico (15%); Federal Republic of Germany (12%); Netherlands (10%); Canada (4%); Italy (4%).
Chromium ferroalloys[2]	[3]4,144	[4]8,041	[5]9,464	11,037	Canada (51%); Mexico (38%).
Chemicals:					
Chromium oxides:					
Chromium trioxide[6]	4,086	4,174	3,929	8,120	Canada (22%); Venezuela (8%); Thailand (6%); Mexico (5%).
Other	([7])	([7])	448	2,822	Mexico (33%); Singapore (17%).
Chromium sulfates	([7])	([7])	1	39	Canada (95%); Indonesia (5%).
Salts of oxometallic or peroxometallic acids:					
Zinc and lead chromate	([7])	([7])	152	1,774	Canada (30%); United Kingdom (10%).
Sodium dichromate[8]	15,019	19,977	18,556	10,397	Italy (33%); Colombia (16%); Thailand (14%); China (8%); Taiwan (5%); Republic of Korea (4%).
Potassium dichromate[9]	9	27	46	58	Italy (34%); Canada (33%); Republic of Korea (25%).
Other chromates, dichromates, and peroxochromates	([7])	([7])	171	416	—
Pigments and preparations	3,216	3,239	2,264	7,654	Philippines (23%); Federal Republic of Germany (22%); Canada (9%); Singapore (9%); Australia (6%).

[1] Wrought and unwrought and waste and scrap in 1987–88. Articles thereof and waste and scrap in 1989.
[2] Includes high-, medium-, and low-carbon ferrochromium and ferrochromium-silicon.
[3] Contained 2,488 tons of chromium.
[4] Contained 4,845 tons of chromium.
[5] Contained 5,647 tons of chromium.
[6] Chromic acid in 1987–88.
[7] This category is not applicable before 1989. As a result of conversion to the Harmonized Tariff Schedule in 1989, this category was introduced.
[8] Included sodium chromate in 1987–88.
[9] Included potassium chromate in 1987–88.

Source: Bureau of the Census.

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). Associated Ore and Metals Corp. owns chromite mining operations through Rustenburg Development Corp. and operates a ferrochromium smelter (Feralloys). Anglo American, an investment company, operates a ferrochromium smelter, Consolidated Metallurgical Industries (CMI), through Johannesburg Consolidated Investment Co. Two other companies in the Republic of South Africa, Chromecorp Technology and Purity Minerals, have chromite mining and ferrochromium production operations. Bayer AG (Federal Republic of Germany) owns a chromite mining and chromium chemical production operation. Refractory chromite operations are also vertically integrated from chromite production through refractory material production. In the Republic of South Africa, the chromium-related companies are privately owned. Typically, major shares of a company are owned by other companies, and the remainder, if any, are openly traded. In Brazil, the mining and smelting of chromium is vertically integrated, but stainless steel production is independent of the mining-smelting operations. The major mining companies are subsidiaries of Cia. de Ferro Ligas da Bahia S.A. (FERBASA), Pajuca, Bahia. Stainless steel is produced by Companhia Acos Especiais Itabira, Itabira, Minas Gerais. Other chromite operations in Brazil are also vertically integrated. Bayer AG (Federal Republic of Germany) owns a chromite mining and chromium chemical production operation. Refractory chromite operations are also vertically integrated from chromite production through refractory material production. In the U.S.S.R., chromite mining, ferrochromium production, and stainless steel production are state-owned.

Capacity

The data in table 15 are rated capacities for major countries that mine chromium ore, produce ferrochromium, primary chromium chemical, and chromium metal 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 equip-

TABLE 11

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)
1988:												
Finland	—	—	—	30,904	13,908	$1,792	—	—	—	30,904	13,908	$1,792
New Caledonia	—	—	—	—	—	—	4,200	2,291	$664	4,200	2,291	664
Philippines	17,699	6,601	$1,660	—	—	—	2,000	700	197	19,699	7,301	1,857
South Africa, Republic of	50,361	17,021	2,323	145,968	65,306	7,684	190,254	96,116	9,618	386,583	178,443	19,625
Turkey	94,137	34,560	5,816	44,775	18,406	8,482	17,018	7,846	3,096	155,930	60,812	17,394
U.S.S.R.	13,016	4,946	593	—	—	—	5,000	2,300	392	18,016	7,246	985
Total[1]	175,213	63,128	10,392	221,647	97,620	17,958	218,472	109,253	13,967	615,332	270,001	42,317
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

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

Source: Bureau of the Census.

ment 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. Since not all countries or producers make production capacity information available, historical chromium trade data has been used to estimate production capacity.

Reserves

The United States has no chromium ore reserves. However, the United States has a reserve base and resources that could be exploited. (For further information on reserves, reserve base, and resources internationally, see Geology-Resources section of this report.)

Albania

Albania increased its chromium ore reserves as a result of surveys conducted in 1988. A new chromite deposit was discovered near the Alarup Mine in the Pogradec district, near Pojska about 115 kilometers southeast of Tirana. Albania commissioned the Lucana Mine and two others in the 11 Heronjte mining complex in the Mat district. Albania operated the Prenjas Mine in the Librazhd district and mines in the Kukes district. Construction continued on the chromium ore processing plant at the Bulqiza Mine in the Dibra district.

A new ferrochromium smelter, under construction at Elbasan, was planned to have three electric furnaces and to have an annual production capacity of about 38,000 tons. At full production the plant would consume about 100,000 tons of chromium ore. Ore for the plant was planned to come from the Librazhd and Pogradec districts. Albania continued to operate its ferrochromium smelter at Burrel.

Albania and Gesellschaft für Electrometallurgy (GfE) of Federal Republic of Germany made a long-term marketing agreement. GfE had used Albanian ore along with Turkish ore to produce high- and low-carbon ferro-

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon[1] (not over 3% carbon)			Medium-carbon[2] (over 3% and not over 4%)			High-carbon[3] (over 3% 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)
1988:												
Albania	—	—	—	(4)	(4)	(4)	1,950	1,228	$1,286	1,950	1,228	$1,286
Austria	3	2	$5	(4)	(4)	(4)	—	—	—	3	2	5
Brazil	—	—	—	(4)	(4)	(4)	10,108	5,280	9,269	10,108	5,280	9,269
Canada	—	—	—	(4)	(4)	(4)	10	7	33	10	7	33
Chile	—	—	—	(4)	(4)	(4)	684	478	832	684	478	832
China	1,624	1,116	2,285	(4)	(4)	(4)	13,350	8,686	10,983	14,974	9,802	13,268
France	—	—	—	(4)	(4)	(4)	4,934	3,362	3,641	4,934	3,362	3,641
Germany, Federal Republic of	15,605	11,115	24,908	(4)	(4)	(4)	1,947	1,276	1,738	17,552	12,391	26,646
Greece	—	—	—	(4)	(4)	(4)	10,107	6,145	7,713	10,107	6,145	7,713
Hong Kong	—	—	—	(4)	(4)	(4)	400	264	548	400	264	548
India	40	29	60	(4)	(4)	(4)	1,300	819	1,779	1,340	848	1,839
Italy	1,411	1,031	2,830	(4)	(4)	(4)	2,070	1,318	1,617	3,481	2,349	4,447
Japan	549	368	922	(4)	(4)	(4)	2,875	1,849	3,414	3,424	2,217	4,336
Mexico	—	—	—	(4)	(4)	(4)	2,922	1,962	3,794	2,922	1,962	3,794
Netherlands	—	—	—	(4)	(4)	(4)	36	26	54	36	26	54
Philippines	—	—	—	(4)	(4)	(4)	14,767	9,484	15,521	14,767	9,484	15,521
South Africa, Republic of	13,533	7,928	14,914	(4)	(4)	(4)	155,963	81,061	91,108	169,496	88,989	106,022
Sweden	332	239	875	(4)	(4)	(4)	14,490	8,188	10,821	14,822	8,427	11,696
Switzerland	—	—	—	(4)	(4)	(4)	515	331	452	515	331	452
Taiwan	—	—	—	(4)	(4)	(4)	1,792	919	1,570	1,792	919	1,570
Turkey	7,087	4,941	10,284	(4)	(4)	(4)	26,518	17,011	25,521	33,605	21,952	35,805
United Kingdom	303	201	270	(4)	(4)	(4)	146	91	126	449	292	396
Yugoslavia	96	68	135	(4)	(4)	(4)	42,388	27,156	39,245	42,484	27,224	39,380
Zimbabwe	7,856	5,299	6,811	(4)	(4)	(4)	64,094	42,275	57,689	71,950	47,574	64,500
Total[5]	48,438	32,337	64,300	(4)	(4)	(4)	373,363	219,216	288,753	421,801	251,553	353,053

See footnotes at end of table.

TABLE 12—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon[1] (not over 3% carbon)			Medium-carbon[2] (over 3% and not over 4%)			High-carbon[3] (over 3% 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
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
India	—	—	—	—	—	—	4,770	3,032	5,806	4,770	3,032	5,806
Italy	1,375	897	2,040	—	—	—	2,500	1,540	2,838	3,875	2,437	4,878
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[5]	37,180	25,272	50,769	30,903	20,114	35,858	275,650	160,010	243,800	343,732	205,396	330,427

[1] Ferrochromium containing not more than 4% carbon in 1988; not more than 3% carbon in 1989.
[2] Ferrochromium containing not more than 3% carbon but more than 4% carbon.
[3] Ferrochromium containing more than 4% carbon.
[4] This category is not applicable before 1989. As a result of conversion to the Harmonized Tariff Schedule, this category was introduced.
[5] Data may not add to totals shown because of independent rounding

Source: Bureau of the Census.

chromium at its Electrowerk Weisweiler smelter. In exchange for the right to market a minimum amount of Albanian ferrochromium annually in the Federal Republic of Germany, GfE was expected to provide technical advice to Albania in setting up its new ferrochromium smelting facilities.

Albania made trade agreements with Bulgaria to supply chromium ore concentrates, with China to supply chromium ore and concentrates, and with Yugoslavia to supply chromium ore.

Australia

Dragon Resources Ltd. continued to develop its Range Well chromium in laterite deposit near Cue in Western Australia. The company sought a joint-venture partner to conduct reconnaissance exploration to confirm the deposit and develop it. Dragon Resources reported that smelting tests demonstrated 96% to 98% chromium recovery.

Brazil

Companhia Auxiliar de Empresas de Mineração (Caemi) created a subsidiary holding company, Caemi Mineração e Metalurgia, which will own Cia. Ferroligas de Amapá, its ferrochromium-producing operation. The new structure permits Caemi to obtain foreign investment.

Magnesita S.A., a chromite producer in Goias State, started chromite production in Bahia State. Caemi's Vila Nova mine started producing chromite in Amapá territory. The Vila Nova mine had reserves of 4.49 million tons with 34% average Cr_2O_3 content.

Cia. Ferroligas do Amapá continued construction of its ferrochromium smelter at Porto de Santana. Upon completion in 1990, the smelter was to have a ferrochromium production capacity of 19,000 to 20,000 tons. Ferrochromium production would be interchangeable with ferromanganese production.

FERBASA planned to invest $140 million in Bahia State to construct four hydroelectric plants. Construction of two plants had received Government approval. FERBASA planned to have

TABLE 13

U.S. IMPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1987 Gross weight (metric tons)	1988 Gross weight (metric tons)	1989 Gross weight (metric tons)	1989 Value (thousands)	Principal sources, 1989
METALS AND ALLOYS					
Chromium metal:					
Waste and scrap	([1])	([1])	50	$285	China (68%); United Kingdom (32%).
Other than waste and scrap[2]	3,952	4,101	4,152	27,305	United Kingdom (31%); Japan (26%); China (20%); France (19%).
Ferrochromium-silicon	[3]7,580	[4]9,710	[5]6,803	4,565	Zimbabwe (100%).
CHEMICALS					
Chromium oxides and hydroxides:					
Chromium trioxide[6]	2,558	1,542	661	2,727	Italy (53%); Netherlands (33%); China (6%); Mexico (6%); Canada (2%).
Other[7]	([1])	([1])	3,880	10,624	United Kingdom (48%); Federal Republic of Germany (27%); Japan (9%); Canada (6%).
Sulfates of chromium	([1])	([1])	313	312	United Kingdom (87%); Turkey (12%).
Salts of oxometallic or peroxometallic acids:					
Chromates of lead and zinc	([1])	([1])	607	1,255	Norway (58%); Federal Republic of Germany (23%); Hungary (20%).
Sodium dichromate[8]	4,755	3,756	5,489	3,777	United Kingdom (56%); Turkey (18%); Republic of South Africa (13%).
Potassium dichromate[8]	1,006	1,327	827	1,483	United Kingdom (49%); Federal Republic of Germany (25%); U.S.S.R. (24%).
Other chromates and dichromates; peroxochromates	([1])	([1])	1,010	2,296	United Kingdom (77%); France (12%); Turkey (8%); Netherlands (2%).
Chromium carbide	157	68	108	1,203	Federal Republic of Germany (63%); Japan (32%); United Kingdom (5%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM					
Chrome yellow	3,355	3,999	3,688	7,352	Canada (80%); Hungary (15%).
Molybdenum orange	1,106	1,131	1,046	2,858	Canada (92%); Japan (6%).
Zinc yellow	1,207	1,098	542	1,166	Federal Republic of Germany (45%); Norway (41%); Canada (13%).
Other[9]	([1])	([1])	687	1,979	Canada (55%); United Kingdom (46%).

[1] This category is not applicable before 1989. As a result of conversion to the Harmonized Tariff Schedule, this category was introduced.
[2] Includes wrought and unwrought and waste and scrap before 1989.
[3] Contained 2,827 tons of chromium.
[4] Contained 3,885 tons of chromium.
[5] Contained 2,756 tons of chromium.
[6] Called chromic acid before 1989.
[7] Includes material reported as chromium oxide green or hydrated chromium oxide green before 1989.
[8] Included chromates beform 1989 that are reported under other in 1989.
[9] Includes material reported under chrome green, chromium oxide green, hydrated chromium green, or strontium chromate before 1989.

Source: Bureau of the Census.

these two hydroelectric powerplants operating by mid-1992. Electrical energy costs had been increasing rapidly in Brazil. Projections of electrical energy demand and supply showed a significant shortfall in production by the year 2000. Either private investment or accelerated Government-financed production capacity will be required to meet projected demand. Higher electrical energy prices have been suggested as a means to raise the capital necessary to construct new plants.

Burma

Burma exported chromium ore containing 48% Cr_2O_3, having a chromium to iron ratio of 1:3, and sized between 1 and 6 inches. The development of chromium ore resources was being studied.

Canada

Canada studied the development potential of its chromium resources. Federal and Provincial governments studied the potential of producing ferrochromium or stainless steel from chromite resources in Manitoba, which produces nickel and has relatively low-cost hydroelectric power available. Canada is 100% import dependent for ferrochromium. The Manitoba chromium resource was

TABLE 14

U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1989

Item	Harmonized Tariff Schedule Number	Most favored nation (MFN)	Non-MFN	Special	
				CA[1]	A, E, IL[2]
Chromium ores and concentrates therefrom:					
Not more than 40% Cr_2O_3	2610.00.0020	Free	Free	Free	Free
More than 40% and less than 46% Cr_2O_3	2610.00.0040	do.	do.	do.	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 val.	25% ad val.	2.2% ad val.	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 val.	Do.
Salts of oxometallic or peroxometallic acids:					
Chromates of zinc and lead	2841.20.0000	do.	do.	2.2% ad val.	Do.
Sodium dichromate	2841.30.0000	2.4% ad val.	8.5% ad val.	1.4% ad val.	Do.
Potassium dichromate	2841.40.0000	1.5% ad val.	3.5% ad val.	0.9% ad val.	Do.
Other chromates and dichromates;					
peroxochromates	2841.50.0000	3.1% ad val.	25% ad val.	1.8% ad val.	Do.
Carbides, whether or not chemically defined:					
Other: of chromium	2849.90.2000	4.2% ad val.	do.	2.5% ad val.	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad val.	do.	2.2% ad val.	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 val.	7.5% ad val.	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 val.	30% ad val.	do.	Do.
Ferrosilicon chromium	7202.50.0000	10% ad val.	25% ad val.	do.	Do.
Other base metals; cermets; articles thereof:					
Chromium:					
Waste and scrap	8112.20.3000	Free	Free	Free	Do.
Other	8112.20.6000	3.7% ad val.	30% ad val.	2.2% ad val.	Do.

[1] United States-Canada Free Trade Agreement. These tariff values were to become effective Jan. 1, 1990.
[2] A Generalized System of Preferences. E Caribbean Basin Ecomomic Recovery Act. IL United States-Israel Free Trade Area Implementation Act of 1985.

considered an alternative supply source should current Canadian supply be interrupted. Federal and Provincial governments started to evaluate the feasibility of recovering chromium from a chromium-platinum deposit in Coleraine Township, Quebec. The resource was estimated at 1.36 million tons of ore graded at 4.5% Cr_2O_3.

Sherwood Metallurgical Corp. continued development of its low-carbon ferrochromium smelter in Vancouver, British Columbia. A construction site was selected and a Federal-Provincial environmental review process was begun. The environmental review was expected to be completed in June 1990. Plant construction was expected to be completed in 1992.

China

China reported 6.4 million tons of high-grade chromite resources in Tibet Autonomous Region.

Finland

Outokumpu Oy continued expansion of chromium ore beneficiation and sintering facilities. The expanded concentrator facilities at the Kemi Mine and the new sintering plant at the ferrochromium works started operation by year-end. As a result of the plant expansions, Outokumpu was expected to increase ferrochromium production capacity to about 200,000 tons per year. Outokumpu also planned to reorganize its chromium-related operations. Effective January 1, 1990, the chromium ore mining operations and the ferrochromium production facilities were to come under Outokumpu Chrome Oy, an wholly owned subsidiary of Outokumpu Oy. Outokumpu reported 1989 production of 0.8 million tons of chromium ore excavated (down from 1.1 million tons in 1988), 169,000 tons of ferrochromium (up from 156,000 tons

TABLE 15

WORLD CHROMIUM RESOURCES,[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMIUM ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1989

(Thousand metric tons, contained chromium)

	Resources[2]			Annual production capacity			
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chemicals
Albania	1,900	1,900	6,300	244	28	—	—
Argentina	—	—	—	—	—	—	7
Australia	—	500	500	—	—	—	—
Brazil	2,300	4,900	4,900	98	77	(4)	7
Canada	—	1,100	1,100	—	—	—	—
Chile	—	—	—	—	1	—	—
China	NA	NA	NA	—	118	2	—
Cuba	700	700	2,000	11	—	—	—
Czechoslovakia	—	—	—	—	13	—	—
Finland	8,900	8,900	8,900	211	84	—	—
France	—	—	—	—	24	2	—
German Democratic Republic	—	—	—	—	10	—	—
Germany, Federal Republic of	—	—	—	—	20	1	35
Greece	400	400	800	18	30	—	—
Greenland	—	—	26,000	—	—	—	—
Hungary	—	—	—	—	—	—	2
India	18,100	23,800	23,800	229	126	(4)	5
Indonesia	200	200	200	12	—	—	—
Iran	700	700	17,700	17	—	—	—
Italy	—	—	—	—	72	—	—
Japan	(5)	100	100	3	215	5	23
Korea	—	—	—	—	—	—	4
Madagascar	2,100	2,100	2,100	33	—	—	—
Mexico	—	—	—	—	4	—	5
New Caledonia	—	NA	NA	—	—	—	—
Norway	—	—	—	—	53	—	—
Oman	NA	NA	NA	1	—	—	—
Pakistan	NA	NA	NA	1	—	—	1
Papua New Guinea	—	—	2,900	—	—	—	—
Philippines	2,300	2,300	2,300	60	59	—	—
Poland	—	—	—	—	36	—	5
Romania	—	—	—	—	26	—	4
South Africa, Republic of	295,200	1,704,400	2,973,700	1,505	692	—	5
Spain	—	—	—	—	12	—	6
Sudan	500	500	500	3	—	—	—
Sweden	—	—	—	—	136	—	—
Taiwan	—	—	—	—	9	—	—
Thailand	NA	NA	NA	(3)	—	—	—
Turkey	2,500	6,000	6,800	181	72	—	8
U.S.S.R	39,600	39,600	40,600	993	276	6	52
United Kingdom	—	—	—	—	—	5	24
United States	—	3,100	35,000	—	128	4	58
Vietnam	NA	NA	NA	3	—	—	—
Yugoslavia	NA	NA	NA	1	64	—	5
Zimbabwe	43,500	285,400	285,400	168	151	—	—
World total[6]	418,900	2,086,500	3,441,600	3,792	2,536	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.
[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.
[6] Data may not add to totals shown because of independent rounding.

in 1988), and 192,000 tons of stainless steel slabs (down from 206,000 tons in 1988).

France

Chromeurope S.A. started production from its second furnace. This furnace has a power rating of 16 megavolt amperes and a production capacity of about 25,000 tons per year. Plant capacity was about 36,000 tons per year with the new furnace. Chromeurope is a subsidiary of Ferroaleaciones Españolas S.A. (Spain).

Greece

Hellenic Ferroalloys SA increased its concentrator capacity to accommodate additional chromite from new mining operations in the Rizo area. The concentrator is near Skoumtsa. The new mining operation was expected to produce about 150,000 tons per year of chromium ore compared with 170,000 tons provided in 1988 by current mining operations in the Kozani area. From the 170,000 tons of run-of-mine chromium ore produced in 1988, Hellenic Ferroalloys produced 31,750 tons of concentrate graded at 49% Cr_2O_3 and 44,147 tons of high-carbon ferrochromium. Fimisco, a refractory company, produced 15,000 tons of refractory grade chromite ore from mines at Eretria.

India

Summary.—India was making major developmental changes in its chromium industry. New chromium ore mining capacity, beneficiation plants, ferrochromium smelters, and electrical power generating plants were being planned, constructed, and put into operation. In recent years, India has been the world's fourth or fifth largest chromium ore producer. Should India utilize about 300,000 tons of planned and developed capacity expansion, Indian chromium ore production would be about 1 million tons annually. At this level of production, India would displace Albania as the third largest chromium ore producer, after the Republic of South Africa and the U.S.S.R. New ferrochromium production capacity was coming into production and more was planned. Major ferrochromium producers installed or were installing captive electrical power generation plants to offset supply shortages from the State power company. India brought 65,000 to 71,000 tons of annual production capacity into production through new furnace construction (Indian Charge Chrome Ltd.) and furnace conversion (Nav Bharat Ferro Alloys Ltd.). India had under construction or planned an additional annual ferrochromium production capacity of about 240,000 tons. This ferrochromium would be produced in small producers through new plants, expansion of existing ferrochromium plants, or the expansion of ferroalloy producers into ferrochromium production. Should all of this planned capacity be constructed, India would increase its annual ferrochromium production capacity by about 140% over that of 1988 and would move from being the world's fifth largest production capacity country to second to the Republic of South Africa, passing Zimbabwe, the U.S.S.R., and Japan.

Chromium Ore.—Major chromium ore producers in India included: Tata Iron and Steel Co. (TISCO), Orissa Mining Corp. Ltd. (OMC), and Mysore Minerals Ltd. (MML). TISCO and OMC produced in Orissa and exported through the port of Paradip. MML produced in Karnataka and exported through the port of New Mangalore.

TISCO had reserves of about 9,460,000 tons of over 40% chromic oxide ore down to 60 meters. TISCO practiced mechanized mining and hand sorting. Annual production capacity was about 300,000 tons, with historical production by financial year of 132,000 tons in 1985, 165,000 in 1986, 157,000 in 1987, and 200,000 in 1988. TISCO was constructing a beneficiation plant, to begin operation in 1990, that could add about 100,000 tons to its annual production.

TISCO developed its chromite and ferrochromium production capacity by expanding its mining operations and installing a beneficiation plant to upgrade chromium ore fines containing 20% to 30% Cr_2O_3 to about 50% Cr_2O_3. The beneficiation plant was planned to start operation in March 1990. Mine production was to be expanded from a rate of about 200,000 tons per year of friable and lumpy market chromite ore to about 350,000 tons per year. The beneficiation plant was to process about 300,000 tons of run-of-mine ore to about 105,000 tons of marketable product. When the beneficiation plant is fully operational, marketable chromite output was expected to be about 455,000 tons per year. TISCO planned to convert one of its two 9-megawatt furnaces, used for ferromanganese production at its ferroalloy plant in Keonjhar District, Orissa, to a 15-megawatt furnace capable of producing 15,000 tons of high-carbon ferrochromium annually. It was planned to convert the second 9-megawatt furnace, subject to successful conversion of the first one. Conversion of the first furnace was planned to be completed by the end of 1990.

OMC had ore reserves of about 14,400,000 tons of over 40% chromic oxide ore down to 100 meters. Annual production capacity was about 300,000 tons, with historical production of 212,000 tons in 1985, 213,000 in 1986, and 300,000 in 1987. OMC was building a beneficiation plant, to begin operation in 1991, that could add 90,000 tons to its annual production.

OMC Alloys, a subsidiary of Orissa Mining Corp., operated a ferrochromium plant at Bamnipal, Orissa, producing high-carbon ferrochromium with an annual production capacity of about 50,000 tons. Owing to limited power supply, OMC produced only at about 50% of its rated capacity. OMC continued construction of a beneficiation and briquetting plant for completion in 1990. The beneficiation plant was planned to have an annual production capacity of about 80,000 tons, the briquetting plant, 50,000 tons. OMC planned to build a 16-megawatt electric powerplant composed of two 8-megawatt diesel-powered generators. The power plant was planned for completion in 1990 at a cost of about $12.5 million.

MML, with an annual production capacity of about 54,000 tons, produced from a reserve measuring several hundred thousand tons.

Ferrochromium.—Ferro Alloys Corp. Ltd. (FACOR) operated a domestic-oriented ferrochromium plant at Shreeramnagar, Andhra Pradesh, and an export-oriented plant at Randia, Orissa. FACOR also operated chromite mines in Orissa. FACOR continued construction of three 10-megawatt diesel-powered electric generators at its Shreeramnagar plant. One generator was tested. The

generators were expected to become operational in 1990. FACOR planned the construction of two 10-megawatt diesel-powered electric generators at its Randia plant. The new powerplant was expected to be constructed by MAN B&W (Federal Republic of Germany) with a completion date of late 1990 or 1991.

Indian Metals and Ferro Alloys Ltd. (IMFA) operated a domestic-oriented ferrochromium plant at Therubali, Orissa, and was constructing an export-oriented ferrochromium plant, Indian Charge Chrome Ltd. (ICCL) at Choudhar, Orissa. ICCL completed construction of its electrical power generation plant, briquetting plant, and electric furnace for ferrochromium production. The powerplant used coal to produce steam from four boilers that drove two turbines rated at 54 megawatts each and started operation in February. The powerplant also supplied power to IMFA's ferrochromium plant at Therubali. The electric furnace was rated at 48 megavolt amperes and 60,000 to 65,000 tons per year production capacity.

Industrial Development Corp. Ltd. (IDC) operated a ferrochromium plant at Jaipur Road, Orissa. IDC produced low-carbon ferrochromium with an annual production capacity of about 10,000 tons. IDC planned to install a 12-megawatt furnace for the production of high-carbon ferrochromium and to build a 9.5-megawatt electrical powerplant. IDC's planned annual high-carbon ferrochromium capacity was 15,000 tons. IDC was licensed for an annual ferrochromium production capacity of 15,000 tons.

Srichrome, a ferrochromium producer in Andhra Pradesh with annual production capacity of about 6,000 tons, started exporting its production. Srichrome operated two 3.6-megawatt furnaces.

Nav Bharat Ferro Alloys Ltd., a major ferrosilicon producer in India, set up a ferrochromium plant in Madhya Pradesh. The plant's annual capacity was 5,000 to 6,000 tons.

Ispat Alloys Ltd., an Indian ferroalloy company, planned to enter the ferrochromium production business. Ispat planned to build a chromium ore pelletizing plant and a ferrochromium smelter in Balasore District, Orissa, to produce high-carbon ferrochromium and charge-grade high-carbon ferrochromium. Ispat planned a pelletizing plant using Outokumpu Oy (Finland) technology to produce about 160,000 tons per year of pellets. The planned annual capacity of the ferrochromium smelter was 15,000 tons of high-carbon ferrochromium and 22,500 tons of charge-grade high-carbon ferrochromium. Ispat sought to raise about $80 million to finance these plans. The company was licensed for an annual production capacity of 15,000 tons.

Baroda Ferro Alloys planned to build a ferrochromium plant in Gujarat State with an annual production capacity of about 4,000 tons. Baroda raised $48.5 million[4] in Indian money markets for this purpose.

VBC Ferro Alloys Ltd., a ferrosilicon producer in Medak District, Andhra Pradesh, requested an Indian Government license to produce 15,000 tons per year of high-carbon ferrochromium. VBC ordered a 16.5-megawatt furnace from V/O Thermoexport (U.S.S.R.) and started operation of three 2.27-megawatt diesel-powered electrical generators.

Misrilal Mines Ltd. planned to build a low-carbon ferrochromium plant that would use its own ore production and a captive powerplant. Misrilal was licensed to build an electrical powerplant and a ferrochromium smelter with an annual ferrochromium production capacity of 15,000 tons.

In addition to those listed above, eight other companies were licensed by the Indian Government to produce ferrochromium. Those companies, annual production capacities, and locations are as follows: Kamini Steel, 25,000 tons in Maharashtra State; Jindal Strips, 15,000 tons in Madhya Pradesh; Vinod Kumar Garg, 15,000 tons in Madhya Pradesh; Kamal Kishore Shard, 15,000 tons at Madhya Pradesh; Ridhi Sidhi, 15,000 tons in Andhra Pradesh; B C Ferro Alloys, 15,000 tons at Andhra Pradesh; A D Monteiro, 15,000 tons in West Bengal; and S N Mishra, 15,000 tons at West Bengal.

Indonesia

PT Ispat Alloys, a subsidiary of Ispat Alloys Ltd. (India), planned to build a bulk ferroalloys plant that would include ferrochromium production. Ispat selected a site and identified raw material; electrical power, water, and equipment were completed. Construction was expected to begin in 1990. The plant was expected to cost about $34 million, produce 50,000 tons per year of ferroalloys including ferrochromium, ferrosilicon, and ferromanganese, and to export about 65% of its production.

Iran

Iran operated three major chromite mines: the Faryab and Esfandagheh, Kerman Province, which are export-oriented, and the Sabzevar in Khorasan Province, which supplies the domestic chemical industry. Iranian chromium exports were interrupted by the revolution and the subsequent Iran-Iraq war. The country resumed exporting chromium ore following the cease fire in the Iran-Iraq war.

Italy

Italcromo, a member of the Schlax group of companies, received approval for financing through GEPI, a state-owned financing company. Italcromo planned to borrow $15.9 million[5] to build a high-carbon ferrochromium plant with an annual production capacity of 100,000 tons at Termoli, Molise region. Ore was to be obtained from Albania. Shipping time was 4 to 6 hours across the Adriatic Sea from Albania to Termoli. Italcromo negotiated with the local electrical power supplier over electrical power cost.

Japan

Japan continued to operate its two-level stockpiling program. The Japan Rare Metals Association operated the stockpile under the Metal Mining Agency of Japan, a part of the Ministry of International Trade and Industry. Japan built a second warehouse, adjacent to the first, at Takahagi City, north of Tokyo.

Japan reported stainless steel production of about 2,711,000 tons in 1989. Its ferroalloy industry reported production of about 356,000 tons of ferrochromium. Japan reported imports of 1,043,000 tons of chromium ore, 477,000 tons of ferrochromium, and 818 tons of chromium metal. High-carbon ferrochromium imports had increased their market share from about 40% in the early 1980's to about 60% in 1987–88. Over the same time period (early 1980's to late 1980's), the value of the yen strengthened relative to the U.S. dollar, making Japanese-produced ferrochromium less competitive on the

world (and Japanese) market. Japanese ferrochromium producers benefited from the worldwide short supply of ferrochromium in 1989, increasing their share of the Japanese market from 41% in 1988 to 43% in 1989.

The president of Nippon Denko Co. became chairman of the Japan Ferroalloy Association. He noted that the number of workers employed in the Japanese ferroalloy industry has been reduced from a range of 7,000 to 8,000 in previous years to about 3,400 in 1989. His goals for the ferroalloy association were to stabilize prices and improve the competitiveness of Japanese producers.

Japan Metals and Chemicals Co. Ltd. (JMC) operated two ferrochromium producing plants: one at Kyushu, Fukouka Prefecture, and one at Oguni, Yamagata Prefecture. A third plant, at Sakata, Toyama Prefecture, produced ferrochromium until 1987, when it was idled. JMC shifted from production of ferrochromium-containing chromium in the range of 60% to 65% to ferrochromium-containing chromium in the range of 50% to 55%. The shift was a cost saving measure. The price of high-grade chromium ore increased significantly in 1989 because of high demand for ferrochromium worldwide in 1988 and 1989.

NKK Corp. operated one ferrochromium-producing plant at Toyama, Toyama Prefecture, typically operating with one furnace in production and one idle. NKK started its second furnace. High demand for ferrochromium in 1989 and the ability of the company to transfer skilled workers from its Niigata ferroalloy plant made production from the second furnace possible.

Madagascar

Kraomita Malagasy (Kraoma), the company that mines chromium ore in the Andriamena region, celebrated its twentieth anniversary in 1989. Madagascar exported 95,000 tons in 1987, and 130,000 tons in 1988. Exports in 1989 were expected to be about the same as those of 1988. Kraoma was investing about $8 million to improve mine and beneficiation plant production. The project was expected to be completed in 1990 or 1991. Madagascar sought a contractor to perform a final feasibility study and basic engineering. The study was to have started by yearend 1989.

Mexico

Compañia Minera Autlán S.A. de C.V., the only ferrochromium producer in Mexico, was taken over by its creditor, Mexico's Government development bank—Nacional Financiera. The foreclosure resulted from Autlán's failure to make a scheduled payment on its loan.

New Caledonia

Chromical, the chromium ore mining company that operates the Tiebaghi Mine in New Caledonia, planned to close its mining operation from October 1989 until 1991. During the closure, Chromical planned to prove new reserves. The Tiebaghi Mine had been in operation since 1982, producing about 450 tons per day of run-of-mine ore containing a range of from 20% to 50% Cr_2O_3, which was beneficiated to 52% Cr_2O_3. Annual production of beneficiated ore was about 80,000 tons per year.

Norway

Norsk Ferrokrom AS began production of high-carbon ferrochromium at Mo i Rana. Norsk Ferrokrom is a new company owned 51% by Norsk Jern Holdings (Norway), 33% by Ferralloy Consulting Establishment, a subsidiary of Macalloy Corp. (United States), and 16% by Fesil KS (Norway). Norsk Ferrokrom planned to produce ferrochromium containing 60% to 65% chromium from two furnaces previously used by Norsk Jernwerk to produce pig iron. Each furnace was rated at about 25 megavolt amperes and could produce about 45,000 to 50,000 tons per year of high-carbon ferrochromium. One furnace was started in September but startup of the second furnace, planned for December, was delayed because of declining ferrochromium prices.

Oman

The Ministry of Petroleum and Minerals of Oman initiated a 2-year, $982,000 program for exploration of the Batinah coastal region in the north of Oman. Chromite deposits were to be sought in the Rajmi-Fizh and the Far-Hilti areas. A chromite deposit with reserves of about 180,000 tons was being developed in Ghashabi. Oman hoped to prove reserves of 1.6 million tons in the northern part of the country. Oman considered building a ferrochromium plant with an annual production capacity of 25,000 to 50,000 tons to process its domestic resources, should such an operation be feasible.

Philippines

The Philippines developed chromite resources and ferrochromium production facilities. High demand for ferrochromium in 1988 and 1989 resulted in high ferrochromium production in the Philippines and a short supply of chromium ore.

Under an agreement between the Philippine Government and the United Nations (U.N.), the United Nations Revolving Fund for Natural Resources Exploration conducted a resource identification program consisting of compiling existing data, geological mapping, trenching, gravimetric surveys, and preliminary drilling on Palawan and Dinagat Islands. Dinagat is a major chromite mining area. The U.N. proved 500,000 tons of reserves graded at 50% Cr_2O_3 on Dinagat Island. Major mining deposit operations on Dinagat include Acoje-Masdang, Velore Mining, and Malayan Wood (currently idle). Numerous small mines also operated in the area. Resources were thought to be in the millions of tons. The Philippines planned to find a developer for the deposit quickly. Malayan Wood planned to restart production from its Ledond chromite mine at the annual rate of 20,000 tons of lumpy ore and 5,000 tons of concentrate. The product was to be sold to Ferrochrome Philippines Inc., a local ferrochromium producer. Merlin Mining N.L. (Australia) acquired interests in three operating chromium mines: Filipinas, Matalisbong, and Gloria. All are on Dinagat Island.

Ferro Chemicals Inc., Mindanao Island, started operation of its second furnace in 1988, achieving an annual ferrochromium production capacity of 30,000 tons. Ferro Chemicals converted one of its furnaces to silicomanganese production in 1989, owing to unavailability of chromium ore and declining price of ferrochromium.

Ferro Chrome Philippines Inc., a subsidiary of Voest Alpine Stahl Linz GmbH (Austria), operated its high-carbon ferrochromium plant on Mindanao Island. The plant's annual production capacity was about 55,000 tons.

Integrated Chrome Corp. started production and shipments of charge-grade high-carbon ferrochromium. Integrated converted a 20-megavolt ampere furnace, previously operated by Electro Alloys Corp. for the production of silicon, to the production of ferrochromium at an annual capacity of about 26,000 tons. Integrated is a joint venture between Nippon Denko Co. Ltd., a Japanese ferrochromium producer, and Kaschrome, a Philippine chromium ore producer. Integrated planned to raise money through the sale of stock for the purpose of purchasing mechanical equipment and developing chromium ore resources.

Qatar

Qatar, along with Pennant Holdings (Australia) and Vitkovice (Czechoslovakia) started a study to determine the feasibility of constructing a ferroalloy plant at Umm Said. The planned $300 million, 230,000 ton ferroalloy plant was planned to produce 60,000 tons of ferrochromium. The plant would include a captive 180-megawatt electrical powerplant that would convert natural gas associated from the North Field gas reserve to electrical energy.

South Africa, Republic of

Anglovaal Ltd. purchased the Grootboom Chrome Mine from Lavino SA (Pty.) Ltd. for $31.06 (R77.655) million. The mine is located at Lydenburg, near Steelpoort, Transvaal province. With an annual production capacity of about 400,000 tons, the Lavino Mine is one of the Republic of South Africa's major chromium mines. Lavino was sold by American International Minerals Corp. (AIMCOR) of the United States. AIMCOR was to continue as exclusive sales agent for Lavino's ore for 5 years.

CMI, a subsidiary of Johannesburg Consolidated Investment Co. Ltd., worked on the construction of a third 32.5-megavolt-ampere furnace at its production facilities at Lydenburg, Transvaal province. With construction nearly complete by year end, CMI planned to start the furnace in February 1990. The additional furnace was expected to increase CMI's annual production capacity to 200,000 tons.

ChromeCorp Technology continued operation of their two 30-megavolt-ampere furnaces, reaching an annual capacity production rate of 60,000 tons per furnace. ChromeCorp started construction of a third furnace, due for completion in 1990. With the new furnace, ChromeCorp's annual production capacity was expected to reach 180,000 tons.

Middelburg Steel and Alloys (Pty.) Lt. (MS&A) expanded transformer capacity on its direct current transferred arc plasma furnace at Krugersdorp from 16 megavolt amperes to 40 megavolt amperes. Operating power of the furnace was being steadily increased. Upon reaching full power operation, the plasma furnace annual production capacity was expected to increase from about 20,000 tons to about 50,000 tons. Full power operation was not expected before 1990. The 40-megavolt-ampere transformer capacity was achieved by using two 20-megavolt-ampere transformers with a third 20-megavolt-ampere transformer acting as a spare. MS&A continued construction of a kiln and associated housing and materials handling equipment to produce ferrochromium via a chromium direct reduction (CDR) process. The CDR process was being developed by MS&A and Krupp Stahl AG (Federal Republic of Germany). MS&A anticipated ferrochromium production via the CDR process to start in 1990.

Tubatse Ferrochrome (Pty.) Ltd., a subsidiary of Samancor, started production from its fourth furnace. The new furnace had an annual production capacity of 60,000 tons, bringing Tubatse's production capacity from 180,000 tons to 240,000 tons. Tubatse started construction on a fifth furnace, which was to be completed in 1990. Upon completion of this furnace, Tubatse planned to have an annual production capacity of 300,000 tons.

Samancor and Gencor rationalized their interests in Cromore, the group responsible for mining, and Tubatse. The net effect of the changes was to make Cromore and Tubatse subsidiaries of Samancor. Samancor made improvements to increase productivity of its chromium ore mining operations. In the eastern Transvaal, a new shaft was put in at the Mooihoek Mine, and the Jagdlust Mine was reequipped. In the western Transvaal, the plant at the Waterkloof Mine was modified to increase production and improve quality. Retreatment plants were established at the Mooinooi, Waterkloof, and Tweefontein Mines to recover ore from the slimes dams.

Purity Minerals was developing a chromite mine and a ferrochromium smelter near Rustenburg, Transvaal province. The mine and smelter were to be completed in 1990. Purity's chromite mine was expected to produce about 30,000 tons per month run-of-mine ore that was to be concentrated to 21,000 tons per month of product from a reserve of 7.2 million tons in the lower group chromitite seam number 6 (LG6) and lower group chromitite seam number 6A (LG6A) chromite seams of the Bushveld Complex. The product was to be moved by truck 10 kilometers from the mine site to the smelter. The smelter was to consist of two 33-megavolt-ampere furnaces with annual production capacity of 60,000 tons each.

Spain

Prerreducidos Integrados del Suroeste de España (Presur) requested the Ministry of Industry to import a 2-megavolt-ampere plasma furnace tax free for the purpose of producing ferrochromium. Presur planned to produce 2,000 to 3,000 tons per year of ferrochromium at Fragenal de la Sierra, Badajoz province.

Swaziland

Royal Swaziland Chrome Corp. was a joint venture being planned among Australian Overseas Mining Ltd. (Australia), 35%; German Mines Ltd. (Australia), 20%; International Metals S.A. (Luxembourg), 10%; Swaziland Government, 15%; Boulder Gold N.L. (Australia), Chrome Corp. of America (USA), 10%; and Luxembourg Alloys Co. (Luxembourg), 10%. They proposed to use Krupp's Codir prereduction process to produce ferrochromium in Swaziland using chromite from Lebowa homeland South Africa and local coal. Negotiations started with the Swazi Government in April 1989.

Sweden

SwedeChrome AB operated a ferrochromium plant at Malmö having a production capacity of about 50,000 tons per year. Production capacity had been increased from about 30,000 tons per year in 1988 and was increasing to a target capacity of 80,000 tons per year. SwedeChrome planned to close its

plant in 1990. The plant was to be closed because of the declining price of ferrochromium, an unfavorable cost position owing to the Swedish embargo toward South African chromite, and, to a lesser degree, uncertainty of electrical power rates. With SwedeChrome out of production, Sweden was expected to be left with one ferrochromium producer, Vargön Alloys AB. Vargön produced high-carbon ferrochromium with an annual capacity of about 160,000 tons.

Turkey

Etibank General Management operated several chromium mines and two ferrochromium plants. The Antalya plant produced low-carbon ferrochromium with an annual capacity of about 10,000 tons. The Elâzig plant produced high-carbon ferrochromium. Construction continued at the Elâzig plant where construction of two electric furnaces of 30-megavolt-ampere electrical capacity and annual high-carbon ferrochromium production capacity of 50,000 tons of each were under development. One of these two furnaces was completed and began production, increasing the plant annual production capacity to 100,000 tons. The second furnace was expected to be completed in 1990, increasing the plant's annual production capacity to 150,000 tons. Etibank operated the Kefdag, Guleman, and Soridag chromite mines in Guleman Province to supply the Elâzig ferrochromium smelter. These mines produce about 250,000 tons of chromium ore annually. Upon completion and operation of the new furnaces at Elâzig, Etibank expected to convert all of its ore and ore purchased from local independent producers to ferrochromium. A new chromium ore deposit was identified in the Adana area, about 75 kilometers west of Iskenderun. Turkey planned to develop mining and ferrochromium production based on the deposit.

Kromsan Birlesik Sanayi ve Ticaret S.A., the chromium chemicals producer, was being sold as part of Turkey's industrial privatization program. The plant, located at Mersin (near Elâzig, Guleman province), produced sodium dichromate: 26,800 tons in 1987, and 27,500 tons in 1988.

United Arab Emirates

The Al Fujayrah Emirate evaluated its chromite resources, and found that Al Fujayrah had a chromite reserve of about 100,000 tons of chemical- or metallurgical-grade ore. The Emirate sought chromite resources useful for the production of refractories for use by its cement industry.

U.S.S.R.

The Donskoye Ore Mining and Enrichment Combine, located in the northwestern part of Kazakhastan, is the major chromium ore mining area in the U.S.S.R., accounting for about 95% of the U.S.S.R.'s chromium ore production. The U.S.S.R. is the leading centrally planned economy chromium ore producer and accounts for about 40% of world chromium ore production. The collection of ore bodies mined by the Donskoye Combine are collectively called the Yuzhno-Kempirsayskiye (or Donskiye) deposits. The Donskoye Combine operated four surface mines and one underground mine. The surface mines include Yuzhniy, 40 Years of the Kaz-SSR, Obyedinenniy, and Mirnyy. Molodezhnaya, the underground mine, started operation in 1982 and produced about 1.1 million tons in 1987 with an annual design capacity of 2 million tons. Tsentral'naya was a second underground mine under development to be operated by the Donskoye Combine, starting in 1991. In 1987, about 24% of production came from the underground operations. These operations have been developed to compensate for the depletion of high-grade ore available from the surface operations. It was planned that all production would ultimately come from underground operations. Donskoye Combine operated two crushing and grinding mills to process high-grade ore and two concentrators to process lower grade ores. The first concentrator started operation in 1975, and, in 1989, had an annual output capacity of about 615,000 tons. The second concentrator started operation in 1987 with an annual output capacity of 600,000 tons. The West Kazakhastan Geological Association reported the discovery of additional chromite reserves in the Donskoye Complex.

Venezuela

Central de Ferroaleaciones de Venezuela C.A. (Cefeca) planned to produce ferrochromium at Puerto Ordaz. Export oriented chromium ferroalloy annual production capacity of about 180,000 tons was planned for 1992. Cefeca is owned by PT Investment Alloy, Corporación Venezolana de Guayana (Government owned), GT Administración y Participación S.A., Italmagnesio S.A. (Brazil). The project was planned to take advantage of inexpensive electrical power available from the Guri Dam on Venezuela's Caroni River.

Vietnam

Vietnam sought to develop its chromite resources. Vietnam has been producing small quantities of chromite, but sought to develop its mining by granting mining rights to Covictory Investment Ltd. (Australia) in exchange for investment. The Nui Nua chromite mine is located about 150 kilometers (km) south of Hanoi in Thanh Hoa province. The alluvial chromite deposit was thought to vary in thickness from 6 to 35 meters, to be about 3 km wide by 12 km long, and to contain about 30 million tons of ore containing 1.5% to 5% Cr_2O_3. Up to 80% of the chromite grains were between 70 and 280 microns in size. Feasibility studies were being done on the deposit.

Zimbabwe

Zimbabwe reported that foreign exchange earnings from ferrochromium exceeded those of gold in 1988. Zimbabwe Mining and Smelting Co. started production from its remelting furnace. The 3-megavolt-ampere furnace remelts below commercial size ferrochromium resulting from crushing operations with an annual production capacity of about 15,000 tons. The Government of Zimbabwe, Union Carbide (owner of Zimbabwe Mining and Smelting), and Zimbabwe Alloys were developing technology to mechanize the recovery of chromite from the narrow seams in the Mutorashanga area of the North Dyke. The objective was to make that 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. Owing to a lack of economic recovery methods for narrow seam chromite mining, only the Middle and Southern sections of the Great Dyke chromite are now mined.

TABLE 16

CHROMITE: WORLD PRODUCTION BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Albania[e]	825,000	850,000	830,000	750,000	700,000
Brazil[3]	189,504	222,990	191,033	[re]240,000	225,000
Cuba	37,700	50,000	52,400	[re]55,000	55,000
Finland[4]	506,200	678,091	543,000	[e]700,000	750,000
Greece[5]	58,948	[e]62,000	63,825	[e]63,000	65,000
India	565,479	[r]637,522	623,591	759,000	800,000
Indonesia[e]	—	—	—	7,636	25,000
Iran[e]	[6]56,000	56,000	56,000	56,000	56,000
Japan	11,920	10,642	11,815	9,508	11,500
Madagascar	127,415	82,910	106,600	107,307	107,000
New Caledonia	78,820	72,207	61,832	70,341	66,000
Oman	—	4,820	—	([7])	—
Pakistan	5,188	8,299	9,963	3,327	5,000
Philippines	272,031	174,230	187,900	[e]190,000	190,000
South Africa, Republic of[4 8]	3,698,500	3,907,000	3,847,000	4,245,000	3,800,000
Sudan	8,799	8,500	13,015	8,000	9,000
Thailand	30	361	5	776	800
Turkey	588,576	543,156	[e]600,000	[e]625,000	650,000
U.S.S.R.	3,360,000	3,640,000	3,570,000	[re]3,700,000	3,800,000
Vietnam[e]	[r]4,000	[r]4,000	[r]4,000	[r]4,000	4,000
Yugoslavia	10,015	8,780	13,172	11,538	12,000
Zimbabwe	536,490	533,105	570,298	561,477	570,000
Total	[r]10,944,611	[r]11,554,613	11,355,449	12,166,910	11,901,300

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 3, 1990.

[2] In addition to the countries listed, Bulgaria, China, 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] Figures are sum of (1) crude ore sold directly for use and (2) concentrate output, both as reported in Brazilian sources. Total run-of-mine crude ore (not comparable to data for other countries) was as follows, in thousand metric tons: 1985—727,125; 1986—763,000; 1987—830,000 (revised, estimated); 1988—810,000 (revised, estimated); and 1989—810,000 (estimated).

[4] Direct-shipping lump ore plus concentrates and foundry sand.

[5] Exports of direct-shipping ore plus production of concentrates.

[6] Reported figure.

[7] Revised to zero.

[8] Includes production by Bophuthatswana, which was as follows, in metric tons: 1985—358,000; 1986—454,000; 1987—508,000; 1988—450,000 (estimated); 1989—350,000 (estimated).

CURRENT RESEARCH

Bureau of Mines research provides fundamental scientific and technical information essential for advancing mineral science, processing technology, and conserving and developing domestic mineral resources. This research is conducted in support of the Strategic and Critical Materials Stock Piling Act of 1946 as amended, the Defense Production Act of 1950 as amended, the Mining and Minerals Policy Act of 1970, and the National Materials and Minerals Policy, Research and Development Act of 1980.

Recent research related to chromium includes the study of chromium alloys with the objective of reducing chromium content and the recycling of chromium containing materials.

The Bureau of Mines studied heat-resistant steels containing 8% chromium as a substitute for Type 304 stainless steel, the most popular stainless steel grade, that contains nominally 18% chromium. Tests found that the new alloys were very susceptible to room-temperature, deformation-induced martensitic transformations. At higher temperatures, tensile strengths and workability of several of the alloys were comparable to that of Type 304. Some of the alloys had superior oxidation resistance.[6]

The effect of aluminum additions on sulfidation resistance of some iron-chromium-nickel alloys was studied. Alloys containing 4% aluminum were found to form thin adherent scales in a wet sulfur vapor atmosphere by a mechanism different from that of aluminum-free alloys. It was found that if the sulfur-containing environment could be modified by the injection of water to an oxidizing environment, then aluminum addition dramatically improves corrosion resistance.[7] The Bureau studied the prediction of microstructure in low-chromium substitutes for stainless steel. Relationships were developed to predict the microstructure for iron-base alloys containing 4% to 12% chromium.[8] The Bureau also studied the structural stability and oxidation resistance of these alloys.[9]

The Bureau studied impact spalling of high-chromium white cast-iron balls that are used in the milling of minerals. Spalling and abrasive wear tests were conducted and reported on numerous alloys with varying heat treatments.[10] The Bureau also studied NiHard 4 with the objective of improving its impact resistance. The NiHard 4, a 9% chromium-containing alloy, could then be used as an alternative to an alloy containing 15% to 30% chromium. Alloys were developed that achieved comparable impact and abrasion resistance under moderate conditions at only marginally higher cost.[11] The Bureau studied an iron-nickel-chromium electrodeposition process which, in combination with heat treatment, could produce stainless steel coatings. A ferrous nickelous electroplating bath containing 3-micrometer-diameter chromium particles was used to produce 250-micrometer-thick coatings that were homogenized by heat treating. Coating corrosion rates approximated that of Type 304 stainless steel.[12]

The Bureau of Mines studied the recovery of chromium from zinc-treated superalloy scrap. Mixed and contaminated superalloy scrap was pyrometallurgically and hydrometallurgically treated to separate and recover metal values. More than 98% of chromium could be leached from zinc-treated or atomized scrap.[13] An X-ray fluorescence analysis method to promptly analyze the superal-

loy leach liquors using thin-film techniques was also developed.[14] The Bureau studied the recovery of chromium from hard-face alloy grinding waste. The process involved deoiling the grinding waste followed by chloride-based dissolution of the deoiled material. The final raffinate was chromic chloride solution.[15] The Bureau tested tannery sludge for chromium recovery potential. Thermal treatment residues were tested for leachability and to help conceptualize a chromium recovery process.[16]

The Department of Defense studied the erosion of chromium plated tank gun barrels. Metallurgical examination found that microcracks originally present in the coating resulted in spalling which, in turn, resulted in erosion.[17]

The Council for Mineral Technology (MINTEK) of the Republic of South Africa developed a method to improve prereduction of chromite and evaluated the progress and trends in the substitution for chromium in steels. MINTEK studied the chromite prereduction process. They found that by using coated and fluxed chromite pellets, reduction in the presence of carbon dioxide of 70% of the chromium and 90% of the iron could be achieved. Application of this technique could result in greater productivity and lower electrical energy consumption for existing ferrochromium-producing plants and reduced capital investment cost without sacrificing annual production capacity for new plants.[18] MINTEK found that substitutes for Type 304 stainless steel, the most common grade, in general had inferior corrosion resistance, poorer mechanical properties, and a higher cost than Type 304 stainless.[19] The mechanism of chromite reduction under varying physical conditions was studied.[20]

Private industry conducted research to improve product quality or to develop more economic production and utilization processes. Ferrochromium production by top- and bottom-blowing converter, direct current plasma, and plasma heater furnaces have been studied. In order to replace energy supplied by the use of expensive electricity in traditional smelting technology with less costly coal combustion, ferrochromium was produced in a top- and bottom-blowing converter. The smelting reduction process was demonstrated technically feasible in furnaces of 100 kilogram and 1 ton capacity.[21] One direct current plasma arc has been applied to ferrochromium production since 1983. The furnace was found to process less expensive raw materials, achieve greater chromium recovery, and permit freedom in selecting slag composition. However, the furnace was also found to consume more electrical energy than its alternating current submerged-arc counterpart and to produce a higher carbon-containing product.[22] The chemistry and metallurgy of metal and slag contained in the direct current plasma furnace was studied.[23] Production by the Plasmachrome process was studied. It was found that energy recovery was an important economic factor and that the chromium content of the ferrochromium product could be adjusted by diluting high chromium-to-iron ratio ore with iron ore. Energy recovery was about 4.5 kilowatt hours per ton of ferrochromium product.[24]

OUTLOOK

On the average in the United States, about 75% of chromium is consumed by the metallurgical industry, and about 75% of metallurgical industry chromium consumption is for stainless steel production. 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. The outlook for chromium consumption in the United States 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 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 or develop new stainless steel production capacity.

BACKGROUND

Definition, Grades, and Specifications

United States industry chemically and physically specify chromium materials through the American Society for Testing and Materials (ASTM). Other organizations also specify chromium materials. 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 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, chromium ore and concentrates made therefrom are classified by their chromic oxide content. Ore and concentrates are 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 chromium 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 chromium ore is also called chromite 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. Ferro-

TABLE 17

CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
						WORLD PRODUCTION						
World production	3,622	3,324	3,102	3,003	3,102	3,003	2,943	3,292	3,476	3,419	3,663	3,585
						DISTRIBUTION OF U.S. SUPPLY						
Components of U.S. supply:												
Domestic mines												
Secondary	60	64	58	65	61	75	79	85	84	95	119	99
Imports:												
Chromium ore	258	258	254	228	130	53	83	109	133	133	185	162
Chromium ferroalloy	165	123	160	228	79	148	223	173	206	171	255	208
Chromium metal	NA	3	4	3	2	3	4	4	4	4	4	4
Chromium chemicals	1	(1)	1	1	2	4	3	5	4	3	2	5
Chromium pigments	3	2	3	2	1	2	2	2	2	2	4	NA
Stocks, Jan. 1:												
Government	1,301	1,301	[2]1,051	1,051	1,051	1,051	1,051	1,051	[3]1,080	[3]1,110	[3]1,079	[3]1,057
Industry	428	399	288	219	232	181	164	114	106	102	119	137
Total U.S. supply	2,216	2,152	1,818	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	1,673
Distribution of U.S. supply:												
Exports:												
Chromium ore	6	4	2	18	2	3	15	27	25	(1)	1	12
Chromium ferroalloy	5	8	16	7	3	2	9	6	3	2	5	6
Chromium metal	NA	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Chromium chemicals	7	9	9	6	5	5	7	4	7	6	8	6
Stocks, Dec. 31:												
Government	1,301	1,301	1,051	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097
Industry	399	288	219	232	181	164	114	106	102	119	137	139
Total U.S. distribution	1,719	1,610	1,297	1,314	1,243	1,226	1,197	1,223	1,247	1,207	1,208	1,261
Apparent industry demand	497	542	521	483	315	292	412	349	402	382	537	451

NA Not available.
[1] Less than 1/2 unit.
[2] Nonstockpile grade material that was included before 1980, was deleted from stockpile count.
[3] Variation in stockpile quantity does not contribute to apparent industry demand because variation results from upgrading programs.

chromium 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 72% 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 as a pigment, a plating material, and 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

TABLE 18

COMPOSITION OF TYPICAL CHROMIUM FERROALLOYS AND CHROMIUM METAL

(Composition, percent)

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 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.

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 chromium ore or as ferrochromium. Substantial amounts of chromium chemicals, pigments, and metal are also traded.

Industry Structure

Stainless steel was developed in about 1900. Since then, stainless steel has grown to become the major end use of chromium. Chromium is used in stainless steel production in the form of ferrochromium, a product of smelting chromite ore with a carbonaceous material (chemical reductant) and silicious material (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. 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 chro-

mic 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 are 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.[25]

The data in table 15 are rated reserves and reserve base for major chromium ore producing countries.[26] 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 chromium 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,

TABLE 19

PRINCIPAL WORLD CHROMITE PRODUCERS, 1989

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. Misrilall Mines Pvt. Ltd. Mysore Mineral Ltd. Orissa Mining Corp. Ltd. (Government owned). Tata Iron and Steel Co. Ltd. (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 Turk Maadin Sirketi AS. Haryi Ogelman Madencelik 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 20

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1989

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	Gesellshaft für Elekrtometallurgie (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	Norsk Ferrokrom AS
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 Alloys Division Krugersdorp Samancor Ltd. Batlhako Ferrochrome Ltd. Ferrometals Ltd. Tubatse Ferrochrome (Pty.) Ltd.
Sweden	SwedeChrome AB Vargön Alloy AB.
Turkey	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 Dusika Ruse
Zimbabwe	Zimbabwe Alloys Ltd. (Zimalloys). Zimbabwe Mining and Smelting Co. (Pvt.) Ltd. (ZIMASCO).

[1] Other ferrochromium producing countries included Albania, Chile, Czechoslovakia, German Democratic Republic, Poland, Mexico, Romania, Spain, and Taiwan.

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 chromium ore to produce ferrochromium requires electric arc furnace technology. Early electric furnaces having power ratings in the kilovolt-ampere range have developed in modern furnaces having power ratings of about 50 megavolt amperes. Covered and partly covered electric arc furnaces replaced open ones when pollution control became a factor of production. Industry is developing new production technologies using high-temperature plasmas or using alternatives to electrical energy 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 chromium ore in the electric arc furnace. Both briqueting and pelletizing are practiced. Efficient production technology uses prereduced and preheated pelletized furnace feed. Advanced smelting technologies have been designed to use fine ore.

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 a byproduct 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 dictate the use of those tailings, thereby making chromium a byproduct of some platinum operations.

Economic Factors

Prices.—Inadequate supplies of ferrochromium resulted from strong demand for stainless steel in all three major producing regions: the United States, Japan, and Europe. Inadequate ferrochromium supply resulted in increasing ferrochromium prices until mid-1989, when supply exceeded demand and prices began to decline. The price of chromite rose in 1989 following the steady rise in ferrochromium prices since mid-1987. In 1989, new ferrochromium plants and plant expansions were under construction or being completed. U.S. stainless steel production declined 12% from that of 1988. Although declining, U.S. stainless steel production remained strong. Reduced stainless steel production permitted ferrochromium producers, traders, and consumers to rebuild stocks after about 3 years of generally increasing production. Reduced demand for ferrochromium, resulting from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, have resulted in declining ferrochromium prices. Ferrochromium production capacity increased about 300,000 tons contained chromium (10% to 15% of 1988 world capacity) in 1989. A similar expansion was anticipated in 1990.

The historical value of chromium ore by grade, ferrochromium by grade, and chromium metal imported to the United States is shown in tables 21 and 22. These values show that, as chromium 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 seven times that of chromium ore; the value of chromium metal is about 30 times that of chromium ore. Variations of the value of ore are shown to follow those of ferrochromium, indicating values of chromium ore change in response to demand with ferrochromium value first to reflect demand changes.[27] Ferrochromium values show greater variation that those of chromium ore. The unit value of chromium materials has increased by 10% to 15% per year in actual value since 1963.

Costs.—Operating and transportation are the two major components of chromium ore cost in the market place. Operating cost includes mining (the production of run-of-mine ore) and beneficiation (the production of marketable chromium ore or concentrate from the run-of-mine ore). Mining cost typically runs from 75% to 80% of operating cost, but may exceed 90% in some cases. Labor cost is the major component of production and of beneficiation cost. Labor cost typically runs from 20% to 60% of mining cost and from 25% to 80% of beneficiation cost, but can be higher.

Electrical energy and labor cost are the major components of high-carbon ferrochromium production cost. Electrical energy cost runs from 20% to 55% of production cost, whereas labor

TABLE 21

TIME-VALUE[1] RELATIONSHIPS FOR CHROMIUM 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
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	278	187	227	229	278
1989	292	373	290	306	247	317	271	347

[1] Custom value per ton of chromium contained in imported material.

TABLE 22

TIME-VALUE[1] RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL

(Average annual value)

	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
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	1,909	2,441	1,524	1,949	1,609	2,058	6,567	8,294

NA Not available.
[1] Custom value per ton of chromium contained in imported material.
[2] Carbon not more than 4%.
[3] More than 4% carbon.

cost runs from 10% to 30% of production cost.

Tariffs.—Import tariffs are typically imposed to protect domestic industry. Where there is no domestic industry, such as chromium ore production in the United States, there is no tariff. (See Foreign Trade section of this report for U.S. tariff duties on chromium materials.) In some cases, such as ferrochromium imports to the European Community, import tariffs are used 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 chromium ore exports from India, are export duties applied.

Operating Factors

Environmental Requirements.—Chromium releases into the environment are regulated by the Environmental Protection Agency. Workplace exposure is regulated by the OSHA.

Toxicity.[28]—The toxic effect of an element depends on its chemical form and concentration and on the conditions and 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 15th most common element in sea water. Chromium is ubiquitous. Chromium is generally recognized to be essential to human health. Hexavalent chromium compounds are generally recognized as toxic. The toxic status or trivalent valent 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.

Energy Requirements.—Ferrochromium production is an energy intensive process, requiring about 3800 kilowatt hours per metric ton of product. Currently available technology can reduce the electrical energy requirement to about 2000 kilowatt hours per ton by thermal energy recovery and recycling. Traditional technology uses electricity to supply the energy required to smelt chromium 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 which would permit nonelectrical energy sources to supply a significant fraction of the energy required to smelt chromium 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 local railhead. It is then usually transported by rail to ports or to smelters. Smelters that do not have associated ship loading and unloading facilities 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 ship loading and unloading facilities.

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CLAYS

By Sarkis G. Ampian

Mr. Ampian, a physical scientist with 37 years of experience, has been the commodity specialist for clays since 1972. Domestic survey data were prepared by Sarkis Ampian and Rosa McGee, supervisory mineral data assistant. The international tables were prepared by Peter Roetzel, Harold Willis, and Virginia Woodson, international data assistants.

Total quantity of clays sold or used by domestic producers decreased about 5% in tonnage while increasing over 8% in value to a new record high of $1.52 billion. This decrease in production reverses the upward trend in clay output that had occurred for 6 of the previous 7 years. Clays in one or more of six classification categories, ball clay, bentonite, common clay and shale, fire clay, fuller's earth, or kaolin, were produced in 44 States and Puerto Rico during 1989. Clay production was not reported in Alaska, Delaware, the District of Columbia, Hawaii, Rhode Island, Vermont, or Wisconsin. The leading seven States, in descending order, were Georgia, Ohio, Texas, North Carolina, California, Wyoming, and Alabama. The cost of fuels, such as coal, gas, and oil, were still a major concern to clay producers and manufacturers trying to reduce operating costs in the highly competitive marketplace. Industrywide efforts to economize and modernize were prevalent during the year. Environmental restrictions and associated costs combined with increasing capital cost began to affect production.

Production of common clay and shale was decreased because the downturn in construction, which resulted from rising interest rates, offset an otherwise mixed demand attributed to a slowing domestic economy. Building rates continued to decline because of a soft economy in the oil-producing States of the Southwest. However, firming oil prices for the first three quarters of the year not only increased drilling activity for gas and oil but also slightly improved the overall business atmosphere.

Increases in production for all of the specialty clays—bentonite, fire clay, and kaolin—except for ball clay and fuller's earth, resulted from an improvement in the mixed economy overall and a continued strong export demand. The steel, oil and gas exploration, and foundry industries, all major consumers of specialty clays, had adjusted to lower levels of production and were experiencing increasing demand by foreign and domestic consumers.

Kaolin accounted for 21% of clay production but more than 67% clay value. Kaolin production of 9.0 million tons and exports of 2.34 million tons were record highs. A record high was also posted for fuller's earth.

DOMESTIC DATA COVERAGE

Domestic production data for clays are developed by the Bureau of Mines from one voluntary survey of U.S. operations. Of the 1,080 operations covered by the survey, 1,026 responded, representing 95% of the total clay and shale production sold or used shown in table 1.

ISSUES

Clay mining has an environmental impact because overburden is moved and a hole is excavated. State laws requiring reclamation are being enacted. A minimum requirement usually includes leveling or recontouring 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 zoning boards are zoning clay producers out of business or forcing them to search for new and usually more distant deposits. This in turn increases costs to the community for these products because of increased transportation charges.

Although domestic clay resources are more than adequate and clay is a mature industry, the average price for clays is expected to rise steadily. These prices, somewhat reflecting the higher quality requirements for the specialty clays, are for the most part associated with land acquisition, severance taxes, land rehabilitation, and environmental and energy factors.

TABLE 1

SALIENT U.S. CLAYS AND CLAY PRODUCTS STATISTICS[1]

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
Domestic clays sold or used by producers:					
Quantity	40,800	40,479	43,234	44,515	42,254
Value	$1,011,377	$1,095,179	$1,202,284	r$1,390,908	$1,515,300
Exports:					
Quantity	2,522	2,643	3,023	3,535	3,755
Value	$309,871	$351,161	$512,964	$516,566	$550,343
Imports for consumption:					
Quantity	37	34	34	33	28
Value	$5,981	$7,501	$9,392	$8,835	$10,928
Clay refractories shipments: Value	$629,738	$529,268	$617,493	NA	NA
Clay construction products shipments: Value	$1,427,851	$1,601,640	$1,782,023	NA	NA

rRevised. NA Not available.

[1]Excludes Puerto Rico.

TABLE 2

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, 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	1,703,001	108,241	—	66,828	[2]1,878,070	[2]$23,537,759
Arizona	—	36,853	151,358	—	—	—	188,211	2,506,726
Arkansas	—	—	627,825	—	—	243,488	871,313	17,390,659
California	477	152,663	1,919,694	—	—	122,996	2,195,830	39,243,331
Colorado	—	272	248,308	7,477	—	9,378	265,435	2,064,361
Connecticut	—	—	W	—	—	—	W	W
Florida	—	—	115,981	—	405,069	42,632	563,682	46,940,900
Georgia	—	—	1,606,546	—	667,244	7,494,522	9,768,312	1,004,953,225
Idaho	—	W	W	—	—	8,100	20,618	W
Illinois	—	—	142,207	—	W	—	[3]142,207	[3]24,200,095
Indiana	—	—	871,179	—	—	—	871,179	3,835,574
Iowa	—	—	439,323	—	—	—	439,323	1,772,934
Kansas	—	W	533,099	—	—	—	[2]533,099	[2]2,699,864
Kentucky	W	—	716,990	W	—	—	[4 5]716,998	[4 5]10,863,307
Louisiana	—	—	233,992	—	—	—	233,992	6,114,609
Maine	—	—	W	—	—	—	W	W
Maryland	—	—	351,464	—	—	—	351,464	1,882,283
Massachusetts	—	—	W	—	—	—	W	W
Michigan	—	—	1,249,198	—	—	—	1,249,198	4,598,922
Minnesota	—	—	W	—	—	W	W	W
Mississippi	W	401,748	497,625	—	—	—	[4]899,373	[4]29,161,419
Missouri	—	—	1,048,814	431,084	W	—	[3]1,479,898	[3]32,474,448
Montana	—	65,567	30,176	W	—	—	[5]95,743	[5]1,840,726
Nebraska	—	—	224,624	—	—	—	224,624	879,546
Nevada	—	40,045	—	—	17,219	W	[6]57,264	[6]6,016,172
New Hampshire	—	—	W	—	—	—	W	W
New Jersey	—	—	W	18,492	—	—	W	W
New Mexico	—	—	27,887	3,125	—	—	31,012	94,209
New York	—	—	531,559	—	—	—	531,559	3,428,813
North Carolina	—	—	2,204,617	—	—	65,767	2,270,384	15,528,692
North Dakota	—	—	47,903	—	—	—	47,903	W
Ohio	—	—	3,296,737	222,931	—	—	3,519,668	14,983,071
Oklahoma	—	—	565,956	—	—	—	565,956	1,618,977
Oregon	—	12,004	198,889	—	—	—	210,893	875,772
Pennsylvania	—	—	1,035,514	14,459	—	W	[6]1,049,973	[6]6,140,974
Puerto Rico	—	—	136,873	—	—	—	136,873	310,888
South Carolina	—	—	931,059	—	5,443	659,651	1,596,153	39,075,215
South Dakota	—	—	W	—	—	—	W	W
Tennessee	640,638	—	496,514	—	W	—	W	W
Texas	W	40,059	2,203,895	2,348	30,327	W	2,276,629	0
Utah	—	45,650	276,299	—	—	—	321,949	2,633,139
Virginia	—	—	1,001,394	—	W	—	[3]1,001,394	[3]11,402,335
Washington	—	—	230,480	2,787	—	—	233,267	1,590,871
West Virginia	—	—	251,385	—	—	—	251,385	553,474
Wyoming	—	2,166,497	W	—	—	—	W	W
Undistributed	262,365	151,007	545,823	14,986	756,209	260,306	[7]5,300,311	[7]128,886,672
Total	903,480	3,112,365	26,694,188	825,930	1,881,511	8,973,668	42,391,142	1,515,611,013

W Withheld to avoid disclosing company proprietary data; included with "Total" and/or "Undistributed."

[1]Includes Puerto Rico.

[2]Excludes bentonite.

[3]Excludes fuller's earth.

[4]Excludes ball clay.

[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 1989, BY STATE[1 2]

State	Ball clay	Bentonite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total
Alabama	—	1	22	4	—	19	46
Arizona	—	3	5	—	—	—	8
Arkansas	—	—	16	—	—	4	20
California	1	5	41	—	—	4	51
Colorado	—	1	26	3	—	—	30
Connecticut	—	—	2	—	—	—	2
Florida	—	—	3	—	4	1	8
Georgia	—	—	15	—	8	74	97
Idaho	—	1	1	—	—	2	4
Illinois	—	—	9	—	2	—	11
Indiana	—	—	13	—	—	1	14
Iowa	—	—	11	—	—	—	11
Kansas	—	1	18	—	—	—	19
Kentucky	5	—	14	1	—	—	20
Louisiana	—	—	8	—	—	—	8
Maine	—	—	3	—	—	—	3
Maryland	—	—	7	—	—	—	7
Massachusetts	—	—	2	—	—	—	2
Michigan	—	—	6	—	—	—	6
Minnesota	—	—	1	—	—	2	3
Mississippi	1	5	16	—	1	—	23
Missouri	—	—	9	39	2	—	50
Montana	—	15	5	1	—	—	21
Nebraska	—	—	5	—	—	—	5
Nevada	—	6	—	—	—	2	8
New Hampshire	—	—	1	—	—	—	1
New Jersey	—	—	1	1	—	—	2
New Mexico	—	—	4	2	—	—	6
New York	—	—	9	—	—	—	9
North Carolina	—	—	45	—	—	2	47
North Dakota	—	—	3	—	—	—	3
Ohio	—	—	49	7	—	—	56
Oklahoma	—	—	15	—	—	—	15
Oregon	—	10	7	—	—	—	17
Pennsylvania	—	—	30	4	—	1	35
Puerto Rico	—	—	2	—	—	—	2
South Carolina	—	—	31	—	1	17	49
South Dakota	—	—	1	—	—	—	1
Tennessee	13	—	6	—	3	—	22
Texas	4	5	63	2	1	1	76
Utah	—	3	10	—	—	—	13
Virginia	—	—	14	—	1	—	15
Washington	—	—	8	3	—	—	11
West Virginia	—	—	3	—	—	—	3
Wyoming	—	164	2	—	—	—	166
Total	24	220	562	67	23	130	1,026

[1]Includes both active and idle operations.
[2]Includes Puerto Rico.

These rising prices, if unchecked, will have an adverse affect on the clay industry by making competing materials more socioeconomically attractive.

PRODUCTION, PRICES, AND FOREIGN TRADE

Kaolin

Domestic production of kaolin was relatively unchanged at 9.0 million tons while its reported value increased more than 9% to $1.02 billion. Both the reported output and value, for the fourth consecutive year, reached record highs. Kaolin, in general, and filler grades, in particular, have enjoyed steady growth for most of the past 17 years, with output increasing from 6.0 million tons in 1973 to the record-high tonnage this year of slightly more than the 9.0 million reported last year. The unit value of kaolin rose more than 9% to $113.95 per ton, with filler- and refractory-grade kaolin leading the way in higher reported values. Kaolin was again produced in 13 States, with Georgia (84%) and South Carolina (7%) accounting for 91% of total production. Georgia accounted for more than 92% of the posted values. Georgia produced all grades of kaolins: filler, refractory, chemical and water-washed, air-floated, and unprocessed. South Carolina produced only the latter two. Arkansas, Minnesota, California, Texas, Alabama, and North Carolina were the other six major production States. Arkansas and California produced refractory- and chemical-grade kaolins. Kaolin producers reported major domestic end uses for their clay as follows: paper-coating, 35%; paper-filling, 21%; refractories, 11%; fiberglass and insulation, 6%; face brick and rubber, 4% each; paint and chemicals, 3% each.

Kaolin production was slowed by the slowdown in the overall economy, particularly in the downturn in paper production. Softer demands for paper-, catalyst-, plastic-, and paint-calcined grades, were offset by a strong export demand because of a continued weak U.S. dollar, keeping production unchanged from 1988. The strong inroads of calcium carbonate, both ground and precipitated, as substitutes for kaolin in the paper-filling markets has yet to manifest itself in the statistics. Apparently the growing demand for coated paper has masked the calcium carbonate inroads. Capacity increases in water-washed and calcined grades started in the past few years

were gradually coming on-stream to meet the projected demand of catalyst, paint, paper, and plastic manufacturers. The anticipated excess capacity and slowdown in economy is expected to cause a downward pressure on prices. Kaolin refractory sales were steady for the first three quarters. Increased demand for high-alumina, kaolin-base refractory bricks and specialties by the foundry and steel industries was mostly responsible. Sales to cement manufacturers, a major consumer, were restrained during the year because of continued lower construction rates. The refractory industry, which became acclimated to lower levels of production brought about by changes in steelmaking and refractories technology and imports, was put in an enviable position of meeting the unexpected upsurge in demand. Production of the three paper-grade kaolins increased in 1989 from less than 5.9 to slightly more than 5.9 million tons. Water-washed production increased 2% while low-temperature calcined and delaminated production decreased 11% and 1%, respectively.

All Georgia and South Carolina kaolin filler-extender-pigment producers, both air-floated and water-washed, continued to modernize, to reduce unit operating costs, and to produce higher valued products. Emphasis continued to be placed on energy related costs and expanding the production capabilities for calcined pigment lines used chiefly by the growing paper, plastics, paint, rubber, and catalyst industries. The major enlargements of calcined clay capacity in Georgia by Engelhard Corp.'s Pigments and Additives Div., Anglo-American Clays Corp. (a subsidiary of English China Clays (ECC) America Inc.), Georgia Kaolin Co. (a subsidiary of Combustion-Engineering Inc. (C-E), J.M. Huber Corp., and Nord Kaolin Co. (a subsidiary of Nord Resources Corp.) were all completed by yearend. All the major water-washed kaolin producers now have a calcining capability. In noncalcining kaolin development, J.M. Huber Corp. was more than half way through its plans to add another 250,000 tons of nameplate spray-drying capacity at Huber, GA, by early 1990. Huber also successfully completed installation of reportedly the world's largest superconducting high-gradient magnetic separator (HGMS) system. The HGMS system, a 120-inch diameter and 500-ton unit, operates continuously with power consumption at the magnet reduced to zero. Two major expansions in air-float capacity and operations were also completed during the year. Wilkinson Minerals Inc., Gordon, GA, the marketing affiliate of Wilkinson Kaolin Associates Ltd., added sufficient capacity to triple its production to an estimated 250,000 to 300,000 tons per year (tpy). Evans Clay Co., Summit, NJ, doubled its storage and loading capacity at McIntyre to accommodate both bulk and large ton bags on a 24-hour basis.

In development work, the Minnesota State Legislature authorized $75,000 per year for 2 years to research bringing about a local kaolin industry based on the clays found in the southwest sections of the State. The work will stress test drilling on public lands to determine the kaolin reserves in the promising areas that proponents claim are insufficient on which to base a viable industry because of company confidentiality.

In acquisitions and divestitures, C-E of Stamford, CT, and ABB Asea Brown Boveri Ltd. of Switzerland agreed to a definitive merger in which ABB will purchase all the outstanding shares of C-E. C-E is the parent company of Georgia Kaolin Co., a world class producer of a full line of water-washed and air-floated kaolins in Georgia. Another subsidiary, C-E Minerals Co., in Georgia at Andersonville is the world's largest refractory calcine and/or grog producer. Hecla Mining Co., Coeur d'Alene, ID, in another kaolin move, finalized an agreement to purchase the kaolin operations and assets of Cyprus Minerals Co.'s clay division. The acquisition included kaolin mines and air-float plants at Deepstep and Sandersville, GA, and Aiken, SC. The purchase allows Hecla to offer ceramic grades of kaolin to complement its ball clay lines supplied by its subsidiary, Kentucky-Tennessee Clay Co., (K-T) Mayfield, KY. The Georgia and South Carolina operations will be operated by K-T. In another air-float acquisition, Evans Clay Co. purchased the air-float business of J.M. Huber Corp's Clay Div. in Huber, GA. The deal allows Evans Clay to acquire only Georgia crude clay reserves and the rights to tradenames on four air-float products. No employees or plant equipment were involved. These products will be formulated by Evans at its McIntyre, GA, plant. Clayburn Industries Ltd., Abbotsford, British Columbia, Canada, a producer of refractory-grade kaolin calcines at Bovill, near Moscow, ID, was acquired by IXL Industries Ltd., Medicine Hat, Alberta, Canada. The dead-burned clay is fired at Bovill and shipped to Abbotsford for refractory-brick and monolith specialty manufacturing.

Despite strong foreign competition and a fluctuating U.S. dollar, exports of kaolin, reported as clays by the U.S. Department of Commerce, increased more than 9% to 2.34 million tons valued at $371 million. The unit value of the exported clay increased to $158.70 per ton or about 2% more than that of 1988, indicating that a higher percentage of premium-quality grades was shipped. Kaolin, including calcined material, was exported to 67 countries, 2 more than in 1988. The two new countries were mostly small importers. The major recipients, in descending order, were Japan, Canada, Italy, the Netherlands, Finland, and Mexico. Exports to Finland decreased about 15% to 159,056 tons. Since 1985, Finnish imports of U.S. kaolin rose from only 21,000 tons to the high watermark of 187,000 tons in 1988. Finnish imports in the past, destined for their large domestic papermaking industry, have been largely from the United Kingdom. Kaolin producers reported end uses for their exports as follows: paper-coating, 68%; paper-filling, 18%; rubber, 5%; paint, 2%; and other, including ceramics and refractories, 7%.

Kaolin imports for consumption decreased about 60% to 3,106 tons valued at $1.3 million. The unit value rose about 60% to $412.05 per ton, reflecting the continuing strong worldwide demand for premium-quality kaolin. No Chinese imports were noted for the year.

Kaolin prices quoted in the trade journals generally advanced during the year. Chemical Marketing Reporter, December 29, 1989, quoted prices in short tons as follows:

Water-washed, fully calcined bags, carload lots, f.o.b. Georgia per ton	[1]$323.00
Calcined, paper-grade, same basis, per ton	470.00
Paper-grade, uncalcined, bulk, carload lots, f.o.b. Georgia, per ton:	
No. 1 coating	110.00
No. 2 coating	87.00
No. 3 coating	85.00
No. 4 coating	82.00
Filler, general purpose, same basis per ton	64.00
Delaminated, water-washed, uncalcined, paint-grade, 1-micrometer average, same basis, per ton	284.00
Dry-ground, air-floated, soft, same basis, per ton	52.00
National Formultary, powder, colloidal, bacteria controlled, 50-pound bags, 5,000-pound lots, per ton	273.00

[1]Average of quoted prices.

FIGURE 1

KAOLIN SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES

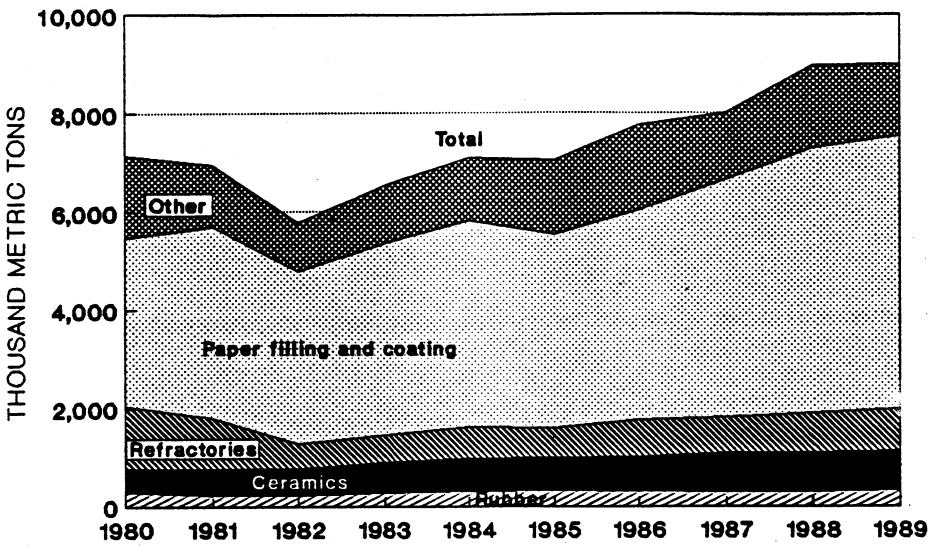


TABLE 4

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988		1989	
	Metric tons	Value	Metric tons	Value
Alabama	44,371	$1,718,220	66,828	$4,097,222
Arkansas	253,254	13,864,977	243,488	15,716,778
California	129,900	5,015,151	122,996	5,089,029
Colorado	2,897	r35,112	9,378	131,603
Florida	40,149	3,654,680	42,632	3,911,500
Georgia	7,427,640	861,334,508	7,494,522	944,862,508
North Carolina	47,896	1,581,316	65,767	1,929,558
South Carolina	720,152	34,230,599	659,651	36,471,151
Other[1]	306,831	13,250,013	268,406	10,377,057
Total	[2]8,973,089	r934,684,576	8,973,668	1,022,586,406

rRevised.
[1]Includes Idaho, Minnesota, Nevada, Pennsylvania, and Texas.
[2]Data do not add to total shown because of independent rounding.

Ball Clay

Production of domestic ball clay decreased almost 9% to about 1.0 million tons valued at about $41 million. Tennessee supplied 71% of the Nation's output, followed by, in descending order of production, Kentucky, Mississippi, Texas, and California. Production increased in all the major producing States. The continuing growth in demand for water-slurried Tennessee ball clays, combined with the number of producers, allowed the publication of additional production statistics. The principal ball clay market was ceramics, mostly dinnerware, pottery, sanitaryware, and wall tile. Domestic producers continued to enjoy a strong export market, usually about 15% of total production. The domestic industry was slowed during the year because of a sluggish overall economy and rising mortgage interest rates that depressed construction rates and housing starts. The slowdown in the overall economy continued from the last quarter of 1988.

Increased production capacities, modernization, and/or new plant construction proceeded slowly during the year while acquisitions, divestitures, and/or mergers were prevalent. Ball clay producers were either concentrating on increasing their capabilities to produce, store, and ship (mostly by slurry-tank rail car) water-slurried ball clay for ceramic markets, chiefly sanitaryware, or developing this capability. The divestiture of Cyprus' clay division was again of considerable interest during the year (see Kaolin section of this chapter). Hecla's attempt last year to also acquire Cyprus' ball clay assets was thwarted by the Federal Government's regulatory agencies. Watts, Blake, Bearne & Co. PLC (WBB), Devon, United Kingdom, on March 31 acquired the same assets through its American operating subsidiary, United Clays Inc., for $7.3 million. This purchase is strategically important to WBB because it establishes the group with a base in its core activity, largely clays, in North America. United Clays, based in Gleeson, TN, produces ball clays comparable with WBB's Devon clays that it mines in the United Kingdom. The assets include extensive reserves in Mississippi and Tennessee, as well as permanent and mobile extraction and processing facilities.

The average unit value for ball clay reported by domestic producers increased 6% to $45.21 per ton. Chemical Marketing Reporter, December 29, 1989, listed ball clay prices, per short ton, unchanged from those of 1988, as follows:

Domestic, air-floated, bags, carload lots, Tennessee, per ton	$49.00
Domestic, crushed, moisture-repellent, bulk carload lots, Tennessee, per ton	24.00

Ball clay exports decreased approximately 16% to 157,000 tons valued at $6.8 million. Unit value declined slightly to $43.62 from $44.54, reflecting a smaller percentage of higher valued clays. Shipments were made to 25 countries, 1 more than in 1988. The major recipients, in descending order, were Mexico (51%), Canada (38%), and the remaining countries (11%). The expanding Mexican ceramic markets continued to be supplied largely with domestic clays because of international financial difficulties. Mexican ceramic exports, mostly

TABLE 5

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND

Kind	1988		1989	
	Metric tons	Value	Metric tons	Value
Airfloat	1,529,397	$80,231,491	1,571,082	$86,081,048
Calcined[1]	1,462,825	300,114,258	1,437,639	307,291,330
Delaminated	1,196,369	130,911,947	1,179,899	142,158,224
Unprocessed	740,608	16,081,244	650,101	15,559,669
Waterwashed	4,043,891	[r]407,345,636	4,134,947	471,496,135
Total	[2]8,973,089	[r]934,684,576	8,973,668	1,022,586,406

[r]Revised.
[1]Includes both low-temperature filler and high-temperature refractory grades.
[2]Data do not add to total shown because of independent rounding.

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
1988				
Alabama and Georgia	452,152	$50,361,214	[1]620,522	[1]$224,324,778
Other	[2]299,695	[2]16,086,192	[3]90,456	[3]9,342,074
Total	751,847	66,447,406	710,978	233,666,852
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

[1]Excludes Alabama.
[2]Includes Arkansas, California, Colorado, Idaho, and South Carolina.
[3]Includes Pennsylvania and Texas.

TABLE 7

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

Kind	1988		1989	
	Metric tons	Value	Metric tons	Value
Airfloat	1,000,005	$43,064,962	1,023,746	$45,949,035
Calcined[1]	1,037,827	273,084,778	1,043,964	278,297,221
Delaminated	1,196,369	130,911,947	1,179,899	142,158,224
Unprocessed	199,318	8,505,018	180,052	8,465,799
Waterwashed	3,994,121	405,767,803	4,066,860	469,992,229
Total	7,427,640	861,334,508	[2]7,494,522	944,862,508

[1]Includes both low-temperature filler and high-temperature refractory grades.
[2]Data do not add to total shown because of independent rounding.

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 8% to 1,483 tons valued at $373,911. The unit value of these clays increased more than 40% to $252.13 per ton, indicating an increasing percentage of the higher valued beneficiated varieties than in previous years.

Fire Clay

Fire clay sold or used by domestic producers increased about 4% in production and 12% in value over that of 1988. This increase in production coupled with the reported increase in 1988 marks only the third major upturn in production in more than 10 years. The increase was attributed chiefly to expanding exports and the recovering smokestack industries, which consumes the bulk of manufactured fireclay refractories and clays. Fireclay production declined from the record highs of the early 1970's, approximately 4 million tons, to about 2 million tons in the early 1980's, and eventually to the low of 592,000 tons in 1986.

Industrywide expansions and modernizations, previously canceled or deferred until economic conditions improved, were cautiously being started again. Manufacturing plants and production lines that were operational were working at full capacity and/or throughput. The increased demand for higher quality fireclay-base product lines was further exacerbating a difficult situation by their slower kiln throughput compared with the lower quality lines.

The clay refractory industry had been in a period of low production because of decreased demand brought about by technological changes and lower consumption levels by its major users—steel, nonferrous metals, ceramics, glass, and minerals processing industries. The technological changes in steelmaking, away from integrated pig iron systems and toward electric furnaces and/or minimills, further compounded the problem by employing shapes and specialty refractories requiring less fire clay.

A world leader in refractory materials production, Didier Refractories Ltd., signed a letter of intent offering to acquire all the remaining outstanding shares of North American Refractories Co. (NARCO), Cleveland, OH, not already owned by Didier. Last year Didier obtained a 35% minority interest in NARCO. The offer is contingent on the approval of greater than 80% of non-Didier shareholders, Didier's board, and regulatory agencies. NARCO is expected to retain its name, management, and operating automony. In another move, East Rock Partners Ltd. Partnership, a New York investment partnership, announced a 7.3% stake in A.P. Green Industries Inc., Mexico, MO, common shares outstanding, and East Rock intends to make a bid for

TABLE 8

GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY USE

(Metric tons)

Use	1988				1989			
	Air-float	Unprocessed[1]	Water washed[2]	Total[3]	Air-float	Unprocessed[1]	Water washed[2]	Total[3]
Domestic:								
Adhesives	13,552	—	26,346	39,898	9,220	—	17,139	26,359
Aluminum sulfate and other chemicals	4,536	136,078	—	140,614	6,560	167,104	—	173,664
Asphalt tile and linoleum	28,503	—	58	28,561	3,425	—	—	3,425
Catalysts (oil-refining)	17,121	—	49,670	66,791	11,858	—	40,670	52,528
Face brick	—	12,710	—	12,710	—	—	—	—
Fiberglass and mineral wool	227,219	—	56,408	283,627	249,899	—	43,124	293,023
Fine china and dinnerware; crockery and earthenware	42,300	—	143	42,444	22,462	—	—	22,462
Firebrick, blocks and shapes	27,216	4,754	85	32,054	27,267	4,536	—	31,803
Grogs and calcines, refractory	36,518	387,368	479	424,365	36,495	390,027	424	426,946
Medical, pharmaceutical, cosmetic	—	—	1,181	1,181	369	—	420	789
Paint	20,559	—	236,457	257,015	18,757	—	199,649	218,406
Paper coating	—	—	2,483,325	2,483,325	—	—	2,568,846	2,568,846
Paper filling	202,895	—	1,253,892	1,456,787	229,758	—	1,312,644	1,542,402
Plastics	370	—	47,133	47,503	370	—	40,177	40,547
Pottery	25,217	—	1,190	26,407	26,324	—	—	26,324
Refractories[4]	12,697	6,350	5,254	24,302	12,707	6,350	5,741	24,798
Roofing granules	9,706	—	—	9,706	10,143	—	—	10,143
Rubber	31,943	—	16,464	48,406	77,630	—	19,556	97,186
Sanitary ware	22,348	—	—	22,348	33,018	—	—	33,018
Miscellaneous, airfloat:								
Common brick, fertilizers, gypsum products, pesticides and related products, roofing and structural tile, other uses not specified	194,572	—	—	194,572	172,726	—	—	172,726
Miscellaneous, unprocessed:								
Fertilizers, pesticides and related products, other uses not specified	—	39,426	—	39,426	—	37,624	—	37,624
Miscellaneous, waterwashed:								
Gypsum products, ink, pesticides and related products, waterproofing and sealing, fertilizers, other uses not specified	—	—	189,779	189,779	—	—	147,516	147,516
Total[3]	917,270	586,686	4,367,865	5,871,821	948,988	605,641	4,395,906	5,950,535
Exports:								
Paint	—	—	31,293	31,293	—	—	27,115	27,115
Paper coating	22,696	—	1,073,315	1,096,011	20,650	—	1,074,973	1,095,623
Paper filling	28,268	—	267,065	295,333	32,479	—	262,155	294,634
Refractories	—	29,937	—	29,937	—	32,540	—	32,540
Rubber	9,072	—	22,221	31,293	—	—	17,451	17,451
Undistributed	22,700	—	49,251	71,951	21,629	—	54,995	76,624
Total[3]	82,735	29,937	1,443,146	1,555,819	74,758	32,540	1,436,689	1,543,987
Grand total[3]	1,000,005	616,623	5,811,012	7,427,640	1,023,746	638,181	5,832,595	7,494,522

[1]Includes high-temperature calcined.

[2]Includes low-temperature calcined and delaminated.

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

[4]Includes electrical porcelain; floor and wall tile, ceramic; flue linings; glazes, glass, and enamels; high-alumina brick and specialties; kiln furniture; refractory mortar and cement.

TABLE 9

SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

Kind	1988		1989	
	Metric tons	Value	Metric tons	Value
Airfloat	477,285	$32,504,576	494,563	$35,383,831
Unprocessed	242,867	1,726,023	165,088	1,087,320
Total	720,152	34,230,599	659,651	36,471,151

TABLE 10

SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND AND USE

(Metric tons)

Kind and use	1988	1989
Airfloat:		
Adhesives	13,307	13,084
Animal feed and pet waste absorbent	3,480	3,480
Ceramics[1]	4,687	5,354
Fertilizers, pesticides and related products	19,053	19,053
Fiberglass	135,164	137,754
Paint	470	542
Paper coating and filling	18,953	17,658
Plastics	7,207	8,275
Rubber	154,878	160,524
Refractories[2]	8,533	8,667
Other uses[3]	53,380	59,161
Exports[4]	58,172	61,009
Total[5]	477,285	494,563
Unprocessed: Face brick and other uses	242,867	165,088
Grand total	720,152	659,651

[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.

the company. A.P. Green, a former unit of USG Corp., was spun-off to USG shareholders in February 1988. A.P. Green, an acquisition of its own, acquired Detrick Refractory Fibers Inc. from M.H. Detrick Co. Ltd. The new addition makes vacuum-foamed refractory fiber's for the glass, ceramic, metal, and petrochemical industries at a facility in Ellisville, MS. This acquisition gives A.P. Green a new product line in one of the fastest segments of the refractories industry.

Fireclay production was again from mines in 11 States. Missouri, Ohio, and Alabama, in descending order of volume, accounted for more than 92% of the total domestic production. Output increased in every producing State, except Ohio, and continued in Colorado.

Exports of fire clay increased about 12% to 284,000 tons. The unit value of exported clay increased about 14% to $84.54 per ton, indicating that the trend of shipping a larger percentage of premium-quality material continued. Fire clay was exported to 34 countries, 2 more than in 1988. The major recipients, in descending order, were Mexico, Belgium-Luxembourg, Japan, the Netherlands, and Australia. Fireclay imported from three countries amounted to 149 tons valued at $77,000.

The unit value for fire clay, reported by producers, ranged from about $60 to $40 per ton, indicating a valued fire clay was being recovered and processed.

Bentonite

Bentonite production increased more than 8% to about 3.1 million tons while the value rose 17% to $125.1 million. This increase marked the second major upturn in production since the record-high year of 1981 when output was 4.4 million tons. The 1987 production figure of 2.5 million tons was the lowest reported figure in the past 17 years. Wyoming, the largest producing State, increased production slightly. Production also continued in Montana. Wyoming and Montana are traditionally the first and second largest swelling bentonite producing States, respectively. Domestic consumption for three major end uses, drilling mud, foundry sand, and iron ore pelletizing, excluding foundry sand, increased modestly in response to improvements in the overall smokestack industries.

Bentonite was produced in 13 States. The high-swelling or sodium bentonite continue to be produced chiefly in Wyoming. The low-swelling or calcium bentonite continued to be produced in the other States, mostly east of the Mississippi River. Calcium bentonite production in Alabama and Mississippi, the major producing States, is suitable for the production of absorbent, acid-activated, and foundry products.

The major and captive producers of bentonite continued to expand their product lines in new marketing areas and restructured to minimize problems associated with industry overcapacity. In addition, no acquisitions, mergers, or divestitures were noted during the year. In a major announcement, Laporte Industries Ltd. of the United Kingdom established a North American marketing and technical service organization to promote its "Laponite" line of synthetic hectorite-type clays suitable for rheological control in paints, cosmetics, and various industrial and pharmaceutical suspensions. In a related Government action, the Food and Drug Administration amended food additive regulations to provide for the safe use of chemically modified bentonites and hectorites in foodstuffs.[1]

On December 29, 1989, Chemical Marketing Reporter quoted domestic sodium bentonite, 200-mesh bags, carload lots, f.o.b. mines, at $30.50 per ton. The average unit value reported by domestic

TABLE 11

KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1988				1989			
	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]	Air-float	Unprocessed[1]	Water-washed[2]	Total[3]
Domestic:								
Adhesives	26,859	—	26,346	53,205	22,304	—	17,198	39,502
Aluminum sulfate and other chemicals	4,536	207,405	—	211,941	4,536	208,290	—	212,826
Animal feed	43	166	4,264	4,472	3,480	—	4,091	7,571
Brick, extruded and other	54,431	306,271	11,539	372,242	49,431	193,910	59,875	303,216
Catalysts (oil and gas refining)	53,358	3,253	51,888	108,499	50,420	—	42,888	93,308
Cement, portland	—	201,012	—	201,012	—	188,286	—	188,286
China and dinnerware	48,357	—	—	48,357	15,172	—	—	15,172
Crockery and other earthenware	3,025	1,455	143	4,624	16,815	1,139	—	17,954
Electrical porcelain	12,733	—	2,218	14,951	13,066	—	2,218	15,284
Fertilizers[4]	3,480	1,167	286	4,932	40	—	2,250	2,290
Fiberglass, mineral wool and other insulation	362,383	10,398	88,292	461,073	387,653	13,517	71,499	472,669
Firebrick, blocks and shapes	51,279	100,738	4,712	156,729	50,681	59,788	4,823	115,292
Floor and wall tile, ceramic; glazes, glass, enamels	16,975	65	3,742	20,783	17,660	1,605	4,497	23,762
Flue linings, highalumina brick and specialities	724	66,225	—	66,948	762	69,639	—	70,401
Foundry sand	501	84	—	585	524	145	—	669
Grogs and calcines, refractory	38,934	510,537	479	549,949	39,726	588,800	424	628,950
Gypsum products and wallboard	4,303	3,953	4,627	12,882	7,700	2,380	122	10,202
Ink	—	—	2,262	2,262	—	—	2,025	2,025
Kiln furniture; refractory mortar and cement	4,544	—	1,512	6,056	4,689	1,344	1,244	7,277
Linoleum and asphalt tile	28,503	—	58	28,561	4,085	—	—	4,085
Medical, pharmaceutical, cosmetic	—	—	3,288	3,288	369	—	2,972	3,341
Paint	21,029	3,426	269,895	294,350	19,299	5,429	201,667	226,395
Paper coating	—	—	2,483,325	2,483,325	—	—	2,568,846	2,568,846
Paper filling	221,848	—	1,257,974	1,479,822	247,417	—	1,313,577	1,560,994
Pesticides and related products	19,186	35,939	476	55,601	19,309	—	383	19,692
Plastics	7,577	930	47,133	55,639	8,645	—	40,177	48,822
Pottery	28,397	—	1,190	29,587	30,147	—	—	30,147
Roofing granules	10,239	—	—	10,239	10,677	—	—	10,677
Rubber	186,821	103	16,464	203,388	238,153	1,155	19,556	258,864
Sanitary ware	24,355	—	—	24,355	35,131	—	—	35,131
Waterproofing and sealing	36,287	—	689	36,976	4,536	—	527	5,063
Miscellaneous	113,125	3,991	224,052	341,168	127,956	120,006	113,823	361,785
Total[3]	1,383,831	1,457,119	4,506,853	7,347,803	1,430,383	1,455,433	4,474,682	7,360,498
Exports:								
Ceramics	16,767	—	—	16,767	17,014	—	—	17,014
Foundry sand, grogs and calcines; other refractories	—	29,937	—	29,937	—	32,540	—	32,540
Paint	—	—	31,293	31,293	—	—	27,115	27,115
Paper coating	22,696	—	1,073,315	1,096,011	22,696	—	1,074,973	1,097,669
Paper filling	28,316	—	267,065	295,381	32,917	—	262,155	295,072
Rubber	66,767	—	22,221	89,988	60,068	—	17,451	77,519
Miscellaneous	11,020	5,399	50,489	66,909	8,004	960	57,277	66,241
Total[3]	145,566	35,336	1,444,385	1,625,286	140,699	33,500	1,438,971	1,613,170
Grand total[3]	1,529,397	1,492,454	5,951,238	8,973,089	1,571,082	1,488,933	5,913,653	8,973,668

[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.

TABLE 12

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
1988								
Tennessee	351,140	$16,405,963	100,988	$4,097,147	201,999	$5,708,846	654,127	$26,211,956
Other[1]	206,180	11,276,089	W	W	W	W	[2]335,766	[2]15,976,087
Total	557,320	27,682,052	100,988	4,097,147	201,999	5,708,846	[2]989,893	[2]42,188,043
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	[2]262,842	[2]14,551,372
Total	525,660	26,631,199	104,752	4,422,232	189,636	5,446,538	[2]903,480	[2]40,843,155

W Withheld to avoid disclosing company proprietary data.
[1]Includes California, Kentucky, Mississippi, and Texas.
[2]Includes data indicated by symbol W.

TABLE 13

BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1988				1989			
	Air-float	Water-slurried	Unprocessed	Total	Air-float	Water-slurried	Unprocessed	Total
Ceramics[1]	W	—	W	72,661	W	W	W	62,600
Dinnerware[2]	126,636	—	121,569	248,205	102,960	1,297	82,640	186,897
Fillers, extenders, and binders[3]	W	—	W	109,460	W	W	W	92,043
Floor and wall tile	63,165	10,327	58,294	131,786	34,124	19,140	108,460	161,724
Refractories[4]	38,413	—	25,835	64,248	33,739	1,829	25,364	60,932
Sanitaryware	14,785	88,129	67,945	170,859	122,636	66,422	5,019	194,077
Miscellaneous	47,294	—	7,257	54,551	32,701	—	5,125	37,826
Exports	129,349	1,960	6,815	138,123	83,218	—	24,163	107,381
Total	576,034	100,416	313,442	989,893	545,609	104,702	253,169	903,480

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.

producers increased 8% to $40.19 per ton. Per ton values reported in the various producing States ranged from $8 to $75, but the average values reported by the larger producers were near the Wyoming average of about $34.48.

Bentonite exports increased more than 18% to 671,000 tons valued at $52.9 million. The unit value of exported bentonite decreased about 7% to $78.86 per ton. This decrease was attributed to the shipment of lower percentages of the costlier drilling mud and foundry grades shipped rather than the lower cost iron ore pelletizing grades exported mainly to Canada. Domestic bentonite producers, although benefiting from an erratically declining U.S. dollar and rising foreign oil and gas exploration activities, continued to face increased competition in foreign markets from lower quality Greek material, particularly in the Canadian iron ore markets. In overseas drilling areas, Mediterranean bentonites continued to make inroads into areas also traditionally served by domestic producers.

Bentonite was exported to 76 countries, 11 more than in 1988. The five major recipients, in descending order, were Canada, Japan, Singapore, Taiwan, and Australia. Domestic bentonite producers reported their exports were foundry sand and others, 34% each, and drilling mud, 32%.

Bentonite imports for consumption consisted mostly of untreated bentonite clay (15%) and chemically or artificially activated materials (85%). Total bentonite imports increased more than 8% to nearly 16,000 tons. The chemically activated category, that slowly increased in quantity for most of the past several years, except for 1988, increased more than 17% to 13,000 tons valued at $6.3 million. Imports from Mexico, the largest source, increased from 14% to more than 90% of the total. Mexican imports usually made up more than 75% of the total activated clay imports. The Federal Republic of Germany, a former major supplier, furnished only 237 tons, and China recorded its second import of this clay to the United States with another exploratory 6-ton batch. The chemically activated bentonite was imported from 12 countries (3 more than last

TABLE 14

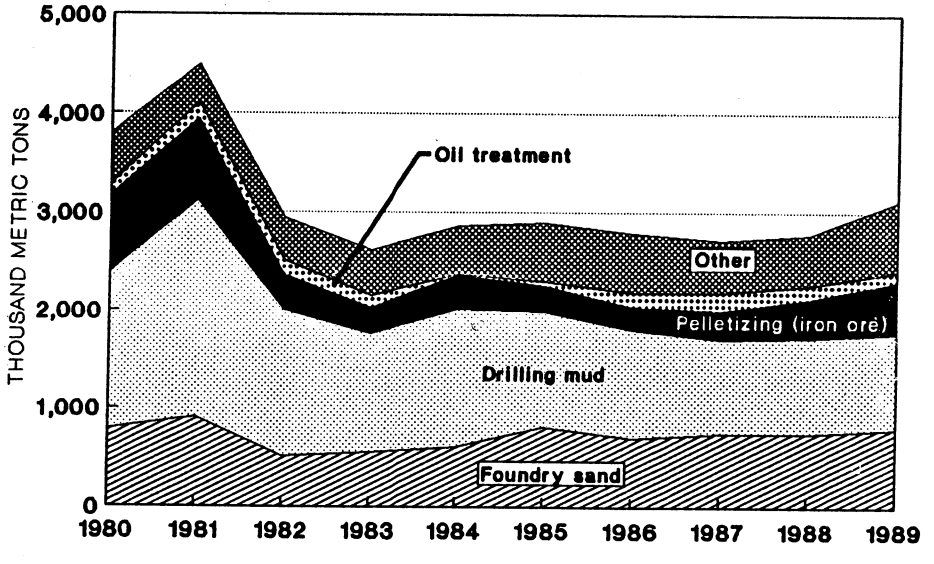
FIRE CLAY[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988		1989	
	Metric tons	Value	Metric tons	Value
Alabama	102,975	$3,352,200	108,241	$4,052,254
Colorado	7,433	48,788	7,477	63,054
Missouri	325,899	8,244,338	431,084	10,785,153
New Jersey	14,954	368,482	18,492	399,700
New Mexico	1,529	10,175	3,125	24,090
Ohio	270,416	5,033,560	222,931	4,695,895
Pennsylvania	33,651	989,039	14,459	488,506
Texas	5,096	78,020	2,348	35,947
Washington	4,582	67,351	2,787	68,159
Other[2]	26,976	464,370	14,986	264,361
Total	[3]793,509	18,656,323	825,930	20,877,119

[1]Refractory uses only.
[2]Includes Kentucky and Montana.
[3]Data do not add to total shown because of independent rounding.

FIGURE 2

BENTONITE SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES



year), with Mexico supplying 92%; Canada, 33%; the Federal Republic of Germany and the Philippines, 2% each; and the remaining countries, 1%.

Fuller's Earth

Production of fuller's earth increased 5% to almost 1.90 million tons valued at $166 million, a record high. The previous high was 1.79 million tons in 1988. This increase in production, except for declines in 1984 and again in 1986, continued the upward trend in production that the industry has enjoyed for more than a decade. A general increase in absorbent-grade clay output in Florida and Georgia was largely responsible. The average unit value increased 10% to $88.06 per ton, indicating that an increasing percentage of higher valued gelling grades, produced mostly in Florida, are included in the total. Production was reported in nine States. The two top producing States, Florida and Georgia, accounted for over one-half of domestic production. All States, except Nevada and South Carolina, showed gains in production. Increases in consumption occurred in every major absorbent product line, with pet waste and oil and grease adsorbents leading the way.

Production from the region that includes Attapulgus, Decatur County, GA, and Quincy, Gadsden County, FL, is composed predominantly of the lathshaped amphibole-like 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.

Industrywide, enlargements, modernizations, acquisitions and/or mergers, and new product development were slowed during the year. In a major expansion, Englelhard Minerals and Chemical Corp., a major attapulgite producer, announced plans to invest an initial $2.5 million to upgrade its Attapulgus works in Georgia. The first phase includes new mining and ancillary equipment to start a statistical process quality control program, new packaging, and a more centralized warehouse operation. A major feature of the packaging improvements will involve new air jet milling schemes that will positively influence the particle sizes of the specialty gelling grades. Generally, the absorbent-producing companies enjoyed a good year while the gel-grade producers experienced a mixed year.

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.

Exports of fuller's earth went to 26 countries, 2 less than last year, and the quantity decreased almost 14% to 96,000 tons. The unit value of exported fuller's earth rose about 5% above that of 1988 to $88.03. The increase was attributed to a larger percentage of high-cost gelling and drilling-mud grades shipped. The major recipients were again Canada (62%) and the Netherlands (23%). A minor amount of

TABLE 15

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
1988						
Alabama and Mississippi	402,376	$17,774,098	—	—	402,376	$17,774,098
Arizona	26,045	907,808	21	$805	26,066	908,613
California	106,944	8,549,976	17,608	1,527,292	124,552	10,077,268
Colorado	3,461	30,291	136	1,600	3,597	* 31,891
Nevada	—	—	8,497	542,461	8,497	542,461
Oregon	2,722	120,000	15,003	604,860	17,725	724,860
Texas	37,117	1,441,149	1,035	29,598	38,152	1,470,747
Utah	652	31,000	29,097	798,612	29,749	829,612
Wyoming	—	—	2,138,794	72,174,070	2,138,794	72,174,070
Other[1]	—	—	81,463	2,259,677	81,463	2,259,677
Total	579,317	28,854,322	2,291,654	77,938,975	2,870,971	106,793,297
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

[1]Includes Idaho, Kansas, Montana, and Tennessee (1988).

decolorizing fuller's earth was imported from Canada.

Common Clay and Shale

Domestic sales or use of common clay and shale decreased 8% in tonnage and 3% in value to 26.7 million tons and $141 million, respectively. Output of the 10 major producing States rose in California, Michigan, and Ohio and declined in Alabama, Georgia, Missouri, North Carolina, Pennsylvania, Texas, and Virginia. Common clay and shale represented about 63% of the quantity but only 9% of the value of total domestic clay production.

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 5% to $5.26 ton. The reported unit value ranged from $5 per ton to $40 per ton.

Increased production capacities, new plants, and modernizations were either deferred or proceeding cautiously during the year. Mergers and/or acquisitions of domestic heavy clay producers were quite active. The construction industry, the largest consumer of heavy clay products such as brick, lightweight aggregate, portland cement, sewer pipe, and tiles generally experienced soft sales the entire year. The large inventories traditionally accumulated during the slack winter months were worked off during the first quarter, and by the end of the second quarter, inventories were beginning to climb again. The slack demand was brought on by the continuing combination of rising interest rates, slowdown in the overall economy, and wet weather in the south and eastern part of the country. The slack demand was also largely attributed to the continuing construction downturn, which lowered the demand for heavy clay products. In an attempt to boost sales, many brick manufacturers were again actively seeking sales outside of their traditional marketing areas by offering highly competitive pricing. Building rates in the oil-producing States of Colorado, Louisiana, Oklahoma, and Texas continued to be depressed. Generally, brick sales in the east were depressed while sales in the Midwest and on the west coast were strong.

In building brick acquisitions, Ibstock Johnson PLC of the United Kingdom, through its subsidiary Glen-Gery Corp., Reading, PA, purchased Midland Corp's three brick manufacturing sites, two in Iowa and one in Missouri. The $18 million transaction involves mines and plants capable of producing upward of 100 million bricks per year. Current production was about 80 million bricks per year. The largest facility in Missouri is capable of manufacturing 50 million bricks per year while the Iowa plants have respective capacities of 20 million and 30 million units yearly. All operations produce a full line of residential and commercial bricks for the midwestern markets. With Midland's

TABLE 16

BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1988			1989		
	Non-swelling	Swelling	Total[1]	Non-swelling	Swelling	Total[1]
Domestic:						
Absorbents	168,974	869	169,843	287,747	1,110	288,857
Adhesives	—	4,452	4,452	—	8,074	8,074
Animal feed	19,661	89,419	109,079	20,527	73,410	93,937
Catalysts (oil-refining)	12,053	—	12,053	12,220	—	12,220
Drilling mud	6,759	833,350	840,109	6,750	839,833	846,583
Filtering, clarifying, decolorizing:						
Animal oils, mineral oils and greases, and vegetable oils	67,823	1,701	69,524	76,699	1,776	78,475
Desiccants	14,415	—	14,415	24,141	—	24,141
Foundry sand	225,246	473,452	698,698	209,970	400,003	609,973
Medical, pharmaceutical, cosmetic	—	10,570	10,570	W	9,169	9,169
Paint	—	4,796	4,796	—	9,984	9,984
Pelletizing (iron ore)	W	405,256	405,256	—	477,275	477,275
Pesticides and related products	4,968	1,697	6,665	9,617	1,814	11,431
Water treatment and filtering	4,207	953	5,159	3,853	930	4,783
Waterproofing and sealing	1,681	97,590	99,271	1,639	87,050	88,689
Miscellaneous[2]	34,674	71,188	105,861	31,815	81,863	113,678
Total[1]	560,459	1,995,291	2,555,750	684,978	1,992,293	2,677,271
Exports:						
Drilling mud	—	136,999	136,999	1,649	133,439	135,088
Foundry sand	3,750	144,064	147,814	2,012	147,899	149,911
Other[3]	9,106	21,303	30,409	53,538	96,556	150,095
Total[1]	12,857	302,365	315,221	57,200	377,894	435,094
Grand total	573,316	2,297,656	2,870,971	742,178	2,370,187	3,112,365

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.

Operations, Glen-Gery will be the fourth largest U.S. brickmaker with a capability of about 700 million bricks per year. Before acquiring Midland, Glen-Gery had already expanded into the firming mideast area's by starting a greenfield brick operation at Caledonia, about 50 miles north of Columbus, OH. The 50-million-brick-per-year Ohio unit should be in full production early in 1990. In another English acquisition, Steetley PLC added Harmer Brick Inc., Pittsburgh, PA, to its group of domestic brick producers, which include Victor Cushwa and Sons Inc., in Maryland, and K-F Brick Inc. in Connecticut and Massachusetts. This purchase will bring Steetley's American brick producing capacity to 200 million bricks per year.

A notice of final results of a countervailing duty review by the International Trade Administration on bricks from Mexico on December 27, 1989, revoked the duty order effective August 24, 1986.[2]

CONSUMPTION AND USES

The manufacture of heavy clay products, including: (1) building brick; sewer pipe; and drain, roofing, structural, terra cotta, and other tile; (2) portland cement clinker; and (3) lightweight aggregate accounted for 32%, 18%, and 8%, respectively, of total domestic consumption. In summary, 58% produced was consumed in the manufacture of these clay- and shale-base construction materials.

Kaolin has many industrial applications, and many grades are specifically designed for use as a filler in paper, paint, rubber, plastics,[3] and ceramics.[4] 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, has good covering or hiding power when used as a pigment or extender in coated films and filling applications. It is also 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.[5]

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

TABLE 17

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
1988						
Florida	380,522	$39,461,646	—	—	380,522	$39,461,646
Georgia	392,505	26,930,915	190,850	$12,472,328	583,355	39,403,243
Southern[1]	—	—	[r]386,094	[r]25,433,770	[r]386,094	[r]25,433,770
Western[2]	17,689	1,600,607	424,571	38,004,712	442,260	39,605,319
Total[3]	790,717	67,993,168	[r]1,001,515	[r]75,910,810	[r]1,792,232	[r]143,903,978
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	893,999	85,051,765	987,512	80,643,145	1,881,511	165,694,910

[r]Revised.
[1]Includes South Carolina, Tennessee, and Virginia.
[2]Includes Illinois, Missouri, Nevada, and Texas.
[3]Data may not add to totals shown because of independent rounding.

TABLE 18

FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

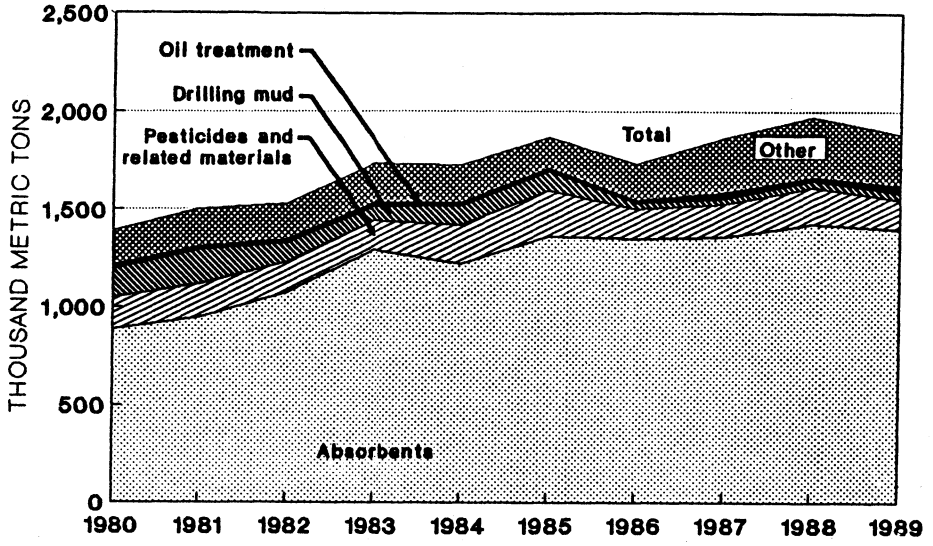
(Metric tons)

Use	1988			1989		
	Attapulgite	Montmorillonite	Total[1]	Attpulgite	Montmorillonite	Total[1]
Domestic:						
Adhesives	210	—	210	118	907	1,025
Drilling mud	32,947	—	32,947	35,181	—	35,181
Fertilizers	45,018	4,391	49,409	45,723	2,361	48,084
Filtering, clarifying, decolorizing mineral oils and greases	7,822	—	7,822	3,834	—	3,834
Medical, pharmaceutical, cosmetic	975	—	975	1,395	—	1,395
Oil and grease absorbents	162,818	[r]130,634	[r]293,452	170,003	128,007	298,009
Paint	18,102	—	18,102	19,341	907	20,248
Pesticides and related products	75,461	[r]56,346	[r]131,807	97,452	43,711	141,163
Pet waste absorbents	295,075	709,947	1,005,021	297,026	718,166	1,015,192
Portland and other cement	—	29,942	29,942	—	43,551	43,551
Other[2]	5,441	—	5,441	4,536	—	4,536
Miscellaneous[3]	82,597	[r]53,172	[r]135,769	109,423	20,291	129,714
Total[1]	726,467	[r]984,431	[r]1,710,898	784,031	957,901	1,741,933
Exports:						
Drilling mud	113	—	113	234	—	234
Oil and grease absorbents	4,703	5,548	10,251	22,945	1,486	24,431
Pesticides and related products	5,081	2,010	7,091	12,553	—	12,553
Pet waste absorbents	39,583	9,525	49,109	52,794	28,125	80,918
Miscellaneous[4]	14,769	—	14,769	21,442	21,442	
Total[1]	64,250	17,084	81,334	109,968	29,611	139,579
Grand total[1]	790,717	[r]1,001,515	[r]1,792,232	893,999	987,512	1,881,511

[r]Revised.
[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.
[4]Includes paint and uses not specified.

FIGURE 3

FULLER'S EARTH SOLD OR USED BY DOMESTIC PRODUCERS FOR SPECIFIED USES



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. The fuller's earth or calcium bentonites also find application in decolorizing and purifying mineral, vegetable, and animal oils. By and large, however, the fuller's earths, both the attapulgite and montmorillonite types, are used for their absorbent properties, especially as a pet waste and oil and grease absorbent. In processing animal or vegetable oils, the clays are usually activated by acid treatment, which leaves a highly absorbent sieve-like structure. The attapulgites are also used in drilling muds in lieu of sodium bentonites for drilling saltwater formations. The sodium bentonite "breaks the emulsion" or flocculates in brine, thereby destroying the gel-like colloidal suspension required for drilling.

Construction

Common clays and shales are used to manufacture a wide variety of construction materials such as structural clay products, cement, and expanded aggregates.

Structural Clay Products

Structural clay products such as building brick, drain tile, and vitrified sewer pipe are used in building construction, for sewer systems, to drain farmer's 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 using this material allow reduction in overall weight, which in turn allows savings in design of the supporting framework. Also, these products 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.[6]

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, generally including, in addition to bentonite or attapulgite, ground barite for its high specific gravity.[7] 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.

Many foreign countries are dependent for specialty clays on sources outside their own borders. Consequently, foreign exploration for deposits is active and so is research directed toward developing substitutes and upgrading available clay deposits.

The United Kingdom, second to the United States in the world's kaolin production, is the biggest exporter of kaolin (china clay) and is also one of the world's largest producers and exporters of ball clay. The United States has been and still is a good

TABLE 19

COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY STATE

State	1988		1989	
	Metric tons	Value	Metric tons	Value
Alabama	1,735,253	$10,969,165	1,703,001	$10,388,283
Arizona	142,326	681,323	151,358	763,412
Arkansas	591,211	1,511,049	627,825	1,673,881
California	1,760,427	16,519,568	1,919,694	21,212,742
Colorado	233,545	1,641,963	248,308	1,866,343
Connecticut and New Jersey	222,334	2,662,599	195,539	2,455,353
Florida	116,250	1,306,436	115,981	W
Georgia	2,263,354	8,032,673	1,606,546	6,841,777
Illinois	163,571	703,945	142,207	641,237
Indiana	1,035,836	4,629,731	871,179	3,835,574
Iowa	403,922	1,587,679	439,323	1,772,934
Kansas	555,666	2,632,114	533,099	2,699,864
Kentucky	762,396	3,217,197	716,990	3,357,200
Louisiana	340,900	9,535,143	233,992	6,114,609
Maine and Massachusetts	118,145	675,231	96,064	474,755
Maryland	357,833	2,016,225	351,464	1,882,283
Michigan	1,248,120	4,431,929	1,249,198	4,598,922
Mississippi	541,501	2,893,727	497,625	2,591,061
Missouri	1,109,144	3,927,188	1,048,814	3,880,428
Montana	33,335	83,723	30,176	79,887
Nebraska	215,419	785,615	224,624	879,546
New Mexico	27,026	72,528	27,887	70,119
New York	551,374	3,653,827	531,559	3,428,813
North Carolina	2,832,204	14,768,129	2,204,617	13,599,134
Ohio	3,094,746	9,389,347	3,296,737	10,287,176
Oklahoma	684,066	1,802,787	565,956	1,618,977
Oregon	207,276	324,096	198,889	327,479
Pennsylvania	1,214,487	4,853,905	1,035,514	4,447,350
Puerto Rico	148,218	364,985	136,873	310,888
South Carolina	1,011,598	2,176,050	931,059	2,214,064
South Dakota and Wyoming	144,690	648,096	196,466	865,197
Tennessee	511,608	1,483,566	496,514	W
Texas	2,642,220	13,669,960	2,203,895	11,965,200
Utah	278,835	1,638,608	276,299	1,799,103
Virginia	1,010,113	6,614,323	1,001,394	6,302,335
Washington	372,341	2,167,920	230,480	1,522,712
West Virginia	239,472	586,266	251,385	553,474
Other[2]	141,857	388,046	105,657	3,206,571
Total	29,062,619	145,046,662	26,694,188	140,528,683

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes Puerto Rico.
[2]Includes Idaho, Minnesota, New Hampshire, and North Dakota.

customer for these high-unit-value clays. However, the United States had changed from a net importer of these two high-quality clays in 1949 to a substantial net exporter by 1969. During the 10-year period 1979-89, U.S. exports increased almost 110% from 1.1 million tons to 2.3 million tons.

The world's fuller's earth needs are supplied from relatively few areas. The United States is both the world's largest producer and user.

Heavy Clay Products

The value reported for shipments by the Bureau of the Census for heavy clay products decreased 7% to about $1.8 billion. The million standard brick count for building or common face brick decreased 14%. Shipments of clay floor and wall tile increased 12% while vitrified clay and sewer pipe fittings decreased 19%. Decreases in common clay and shale used in building brick manufacturing occurred in most States, with total domestic production decreasing 16%. Decreases were largely under 15% with an average State downturn of about 7%.

Lightweight Aggregates

Consumption of clay and shale in the manufacture of lightweight aggregate decreased about 11% to more than 3.4 million tons. The downturn in overall construction of commercial buildings and highway resurfacing was largely responsible for the decrease in demand. Concrete block, the largest category, (61% of total production), declined 11% while the second biggest consuming area, structural concrete (23% of total production), increased markedly. The third largest segment, highway surfacing (10% of production), also declined significantly. The other category, the smallest segment consisting essentially of new market areas such as recreational and horticultural uses, rose 30%.

Refractories

All types of clay, except for fuller's earth, were used in manufacturing refractories. Kaolin, bentonite, and fire clay accounted for 30%, 23%, and 27%, 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 7% and constituted 6% of 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.

TABLE 20

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1989, BY USE

(Metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractory only)	Fuller's earth	Kaolin	Total
Absorbents:							
Oil and grease	—	W	W	—	298,009	—	298,009
Pet waste absorbents	—	W	W	—	1,015,192	—	1,015,192
Other[2]	—	287,747	204,869	—	23,478	31,026	547,120
Ceramics and glass:							
Catalysts (oil-refining)	—	12,220	—	—	16,786	93,308	122,314
Crockery and other earthenware	—	—	—	181	—	17,954	18,135
Electrical porcelain	21,521	—	—	—	—	15,284	36,805
Fine china and dinnerware	3,360	—	—	—	—	15,175	18,535
Glazes, glass and enamels	—	W	—	W	—	2,507	2,507
Mineral wool and insulation, fiberglass	W	W	—	—	—	472,669	472,669
Pottery	125,537	24,416	18,791	20,939	—	30,147	219,830
Roofing granules	—	—	92,418	—	—	10,677	103,095
Sanitaryware	194,077	—	—	—	—	35,131	229,208
Other[2]	73,869	W	W	1,596	—	75,989	151,454
Chemical manufacturing	—	W	—	—	W	217,452	217,452
Civil engineering and sealing	13,183	108,907	1,415,906	3,352	W	7,477	1,548,825
Drilling mud	—	846,583	—	—	35,181	485	882,249
Fillers, extenders and binders:							
Adhesives	—	8,074	907	—	1,025	39,502	49,508
Animal feed	W	93,937	W	—	W	7,571	101,508
Fertilizers	—	W	—	—	48,084	2,295	50,379
Gypsum products and wallboard	W	—	—	—	30,209	10,202	40,411
Ink	—	W	—	—	—	2,025	2,025
Medical, pharmaceutical, cosmetic	—	9,169	—	—	1,395	3,341	13,905
Paint	—	W	W	—	20,248	226,395	246,643
Paper coating	—	—	—	—	—	2,568,846	2,568,846
Paper filling	—	W	—	—	—	1,560,994	1,560,994
Pesticides and related products	W	9,617	14,110	—	141,163	19,692	184,582
Plastics	—	W	—	—	W	48,822	48,822
Rubber	W	W	—	—	—	258,864	258,864
Other[2]	118,155	20,258	75,281	—	24,099	193,710	431,503
Filtering, clarifying, decolorizing:							
Animal oils, mineral oils and greases, and vegetable oils	—	78,475	—	—	15,085	646	94,206
Desiccants	—	W	—	—	—	—	W
Floor and wall tile:							
Ceramic	161,724	—	225,825	4,169	4,536	21,254	417,508
Quarry tile	W	—	14,338	—	—	—	14,338
Other[2]	15,018	—	—	—	—	24,756	39,774
Heavy clay products:							
Brick, extruded	W	W	10,188,861	19,818	—	174,214	10,382,893
Brick, other	—	—	2,244,505	—	—	129,002	2,373,507
Drain tile	—	—	10,251	—	—	—	10,251
Flower pots	—	—	45,049	—	—	—	45,049
Flue linings	—	—	10,096	7,303	—	6,350	23,749
Portland and other cements	—	1,583	7,440,067	W	43,551	188,286	7,673,487
Roofing tile	—	W	3,915	—	100	—	4,015
Sewer pipe, vitrified	—	—	366,927	102	—	8,615	375,644
Structural tile	—	—	49,041	—	—	—	49,041

See footnotes at end of table.

TABLE 20—Continued

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1989, BY USE

(Metric tons)

Use	Ball clay	Bentonite	Common clay and shale	Fire clay (refractory only)	Fuller's earth	Kaolin	Total
Terra cotta	—	—	18,748	W	—	—	18,748
Other[2]	W	3,033	242,997	3,648	—	19,136	268,814
Lightweight aggregate:							
Concrete block	—	—	2,066,480	—	—	—	2,066,480
Highway surfacing	—	—	326,881	—	—	—	326,881
Structural concrete	—	W	773,052	—	—	—	773,052
Other[2]	—	3,615	215,249	—	—	—	218,864
Pelletizing iron ore	—	477,275	76,748	—	—	—	554,023
Refractories:							
Firebrick, blocks and shapes	W	W	100,186	546,769	—	115,292	762,247
Foundry sand	—	609,973	—	64,166	—	669	674,808
Grogs and calcines	—	—	—	58,766	—	628,950	687,716
Highalumina brick and specialties	21,410	—	—	35,613	—	6,622	63,645
Kiln furniture	1,531	W	2,803	—	—	5,933	10,267
Mortar and cement, refractory	—	—	414,294	—	—	1,344	415,638
Other[2]	W	35,637	6,146	40,468	—	52,565	134,816
Other[3]	46,714	46,752	16,556	—	23,791	9,324	143,137
Exports	107,381	435,094	12,891	19,040	139,579	1,613,170	2,327,155
Total	903,480	3,112,365	26,694,188	825,930	1,881,511	8,973,668	42,391,142

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.

TABLE 21

SHIPMENTS OF PRINCIPAL STRUCTURAL CLAY PRODUCTS IN THE UNITED STATES

Product		1985	1986	1987	1988	1989
Unglazed common and face brick:						
Quantity	million standard brick	6,605	7,204	7,313	7,811	6,698
Value	million	$887	$972	$1,060	$1,188	$1,000
Unglazed structural tile:[1]						
Quantity	thousand metric tons	50	65	84	53	W
Value	million	$12	$28	$50	$6	W
Vitrified clay and sewer pipe fittings:						
Quantity	thousand metric tons	334	270	295	286	232
Value	million	$78	$66	$74	$74	$64
Unglazed, saltglazed, ceramicglazed structural facing tile including glazed brick:						
Quantity	million standard brick	W	W	32	26	35
Value	million	W	W	$11	$18	$15
Clay floor and wall tile including quarry tile:						
Quantity	million square feet	370	444	462	488	545
Value	million	$450	$536	$587	$641	$707
Total value	do.	[2]$1,428	$1,602	$1,782	$1,927	$1,786

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(89), Current Industrial Reports—Clay Construction Products.

TABLE 22

COMMON CLAY AND SHALE USED IN BUILDING BRICK PRODUCTION IN THE UNITED STATES, BY STATE[1]

State	1988		1989	
	Metric tons	Value	Metric tons	Value
Alabama	877,154	$4,702,268	794,960	$4,514,209
Arizona[2] and New Mexico[2]	66,030	227,741	59,309	220,616
Arkansas	288,726	708,421	277,670	712,893
California	382,962	2,536,412	369,030	2,574,965
Colorado	233,545	1,539,154	229,158	1,766,510
Connecticut, New Jersey,[2] and New York[2]	363,900	2,818,649	294,593	2,570,000
Georgia	1,788,344	5,580,507	1,178,307	4,474,571
Idaho, Washington, and Wyoming[2]	307,594	1,557,470	187,561	1,111,775
Illinois	122,905	559,670	113,755	542,500
Indiana and Iowa	424,352	1,803,579	322,891	1,421,015
Kansas	156,896	526,831	156,012	555,925
Kentucky[2]	327,809	1,849,836	323,284	2,343,967
Louisiana	89,851	286,693	75,235	266,109
Maine, Massachusetts,[2] and New Hampshire[2]	135,382	781,821	113,073	585,192
Maryland and West Virginia[3]	407,872	2,111,818	390,113	1,943,866
Michigan[2] and Minnesota[2]	191,981	655,429	166,047	550,328
Mississippi	431,778	2,464,209	402,111	2,207,152
Missouri	97,652	501,835	86,610	444,578
Nebraska and North Dakota[2]	211,823	578,179	183,058	557,667
North Carolina	2,501,718	10,429,302	1,872,337	9,537,777
Ohio	958,299	3,716,068	968,224	4,036,590
Oklahoma	224,845	796,140	220,372	861,955
Oregon	20,286	64,383	20,286	67,601
Pennsylvania	1,042,264	3,678,341	886,255	3,719,253
South Carolina	749,273	1,761,672	664,823	1,795,906
Tennessee[2]	400,069	1,076,601	384,976	1,088,435
Texas	1,041,631	5,755,747	788,464	4,520,965
Utah[2]	138,060	1,069,263	150,853	1,248,268
Virginia	736,555	2,790,901	753,998	2,933,106
Total[4] [5]	14,719,558	62,928,940	12,433,366	59,173,694

[1]Includes 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.

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 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 89%; fuller's earth, 5%; bentonite, 2%; and ball clay, common clay and shale, and fire clay, the remaining 4%. Kaolin consumed as fillers increased 2% to 4.9 million tons. An approximate 3% and 5% increase in paper-coater and-paper-filler, respectively, which together constitute 84% of the total filler and extender category, was largely responsible. The rubber-grade kaolin increased 27% while the other filler and extender components that constitute the remaining 16% of this group's demand were mixed in ups and downs. The total quantity of fuller's earth used in pesticides and related products such as fungicides decreased more than 20% from that of 1988.

Absorbent Uses

Absorbent uses for clays accounted for almost 1.9 million tons or 4% of total clay consumption. Demand for absorbents increased 10%. Fuller's earth was the principal clay used for absorbent purposes, and this application accounted for 71% of its entire output. Demand for clays in pet waste absorbents, representing 55% of absorbent uses, increased slightly. Use in floor or oil and grease absorbents, chiefly to absorb hazardous oily substances, accounted for another 16% of the absorbent demand, which decreased from that of 1988. Increases in the use of pet waste absorbents were largely responsible for the upturn.

Drilling Mud

Demand for clays in rotary-drilling muds increased slightly to about 882,000 tons and accounted for 2% of total clay production. This slight increase reverses the downward trend, except for the increase noted in 1984, begun in 1982 when a combination of excess oil production and economic uncertainties resulted in lower oil- and gas-well-drilling activities, which depressed bentonite demand. Oil- and gas-well drilling activity was mixed during the year but generally trended upward by 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 nonswelling sodium-activated bentonites were also used to a limited extent. Bentonite and fuller's earth accounted for almost 100% of the total amount of clay used in this category. Small amounts of kaolin were used in specialized formulations.

Floor and Wall Tile

Common clay and shale, ball clay, kaolin, fuller's earth and fireclay, in order of volume, were used in manufacturing floor, wall, and quarry tile. This end-use category accounted for 1% of the total clay production. The rising interest rates for most of the year, while lessening the demand for more attractively appointed tiled homes, spurred the remodeling markets.

TABLE 23

COMMON CLAY AND SHALE USED IN LIGHTWEIGHT AGGREGATE PRODUCTION IN THE UNITED STATES, BY STATE

Year and State	Metric tons					Total value
	Concrete block	Structural concrete	Highway surfacing	Other	Total	
1988						
Alabama and Arkansas	507,034	92,005	11,085	7,865	617,989	$5,293,951
California	73,119	48,988	—	—	122,107	734,916
Florida and Indiana	219,515	26,082	—	—	245,597	1,693,991
Kansas, Kentucky, Louisiana	292,180	103,380	18,782	47,804	462,146	10,342,400
Mississippi	59,168	12,346	30,052	107,579	209,145	1,593,374
New York	224,413	153,907	—	—	378,320	3,277,666
North Carolina	244,940	81,647	—	—	326,587	3,390,700
Ohio, Oklahoma, Pennsylvania	243,841	13,875	—	—	257,716	733,770
Texas	174,053	244,282	393,368	—	811,703	3,679,947
Utah and Virginia	281,499	74,492	21,734	45	377,770	4,322,029
Total	2,319,762	851,004	475,021	163,293	3,809,080	35,062,744
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, Louisiana	218,632	92,533	10,886	53,506	375,557	7,222,558
Mississippi and Missouri	49,137	5,830	8,330	111,018	174,315	1,483,883
New York and Montana	215,239	140,527	—	—	355,766	2,489,218
North Carolina	230,000	80,000	—	—	310,000	3,200,000
Ohio, Oklahoma, 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

Pelletizing Iron Ore

Bentonite continued to be used as a binder in forming indurated iron ore pellets. Demand increased 14% to about 554,000 tons. Inroads of inexpensive foreign bentonites into the Great Lakes markets traditionally served exclusively by U.S. bentonite producers, lower production levels, metal imports, and changing technology all combined to reduce the long-term demand for domestic bentonite in this category.

Ceramics and Glass

Total demand for clay in the manufacture of pottery, sanitaryware, china and dinnerware, and related products (excluding clay flower pots) accounted for 3% of the total clay output. This demand, principally ball and kaolin clays, decreased 4% to 1.37 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.

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Capacity

The data in tables 27, 28, 29, and 30 are rated capacity for mines as of December 31, 1989. 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.

Australia

The South Australian Department of Mines and Energy supervised an exploration and sampling program on a weathered pegmatite deposit containing high-grade kaolin southeast of Penneshaw on Kangaroo Island.[8] The irregular weathering and limited size of the deposit may restrict its potential as a large world-class kaolin source.

The diversified Australian group, CSR Ltd., and British-based building products group, Redland PLC, announced their intentions to acquire as a joint venture the business and assets of PGH Bricks and

TABLE 24

SHIPMENTS OF REFRACTORIES IN THE UNITED STATES, BY PRODUCT

Product	Unit of quantity	1986		1987	
		Quantity	Value (thousands)	Quantity	Value (thousands)
CLAY REFRACTORIES					
Superduty fire clay brick and shapes	1,000 9-inch equivalent.	21,968	$26,697	27,070	$27,914
Other fire clay including semisilica brick and shapes, glasshouse pots, tank blocks, feeder parts, upper structure parts used only for glass tanks	do.	56,685	40,603	62,006	46,126
High-alumina (50% to 60% Al_2O_3) brick and shapes made of calcined diaspore or bauxite[1]	do.	65,716	118,042	76,004	128,404
Insulating firebrick and shapes	do.	—	—	21,158	20,344
Ladle brick	do.	30,330	9,985	10,302	3,272
Sleeves, nozzles, runner brick, tuyeres	do.	25,279	29,327	9,679	28,315
Hot-top refractories	Short tons	W	W	W	W
Kiln furniture, radiant heater elements, potter's supplies, other miscellaneous-shaped refractory items	do.	27,185	21,965	42,432	33,246
Refractory bonding mortars	do.	79,042	37,156	56,619	29,296
Plastic refractories and ramming mixes, containing up to 87.5% Al_2O_3	do.	75,893	36,669	64,051	32,816
Castable refractories	do.	207,150	78,075	251,808	110,578
Gunning mixes	do.	144,882	37,497	144,940	50,475
Other clay refractory materials sold in lump or ground form[3 4]	do.	502,625	93,252	885,558	106,707
Total clay refractories		XX	529,268	XX	617,493
NONCLAY REFRACTORIES					
Silica brick and shapes	1,000 9-inch equivalent.	4,582	11,825	6,861	19,028
Magnesite and magnesite-chrome brick and shapes	do.	19,467	94,933	21,745	107,987
Chrome and chrome-magnesite brick and shapes	do.	22,914	82,347	27,640	101,124
Shaped refractories containing natural graphite	Short tons	11,548	32,728	17,251	40,117
Zircon and zirconia brick and shapes; other carbon refractories: Forsterite, pyrophyllite, dolomite, dolomite-magnesite molten-cast,[5] other brick and shapes	1,000 9-inch equivalent.	1,557	31,669	1,716	21,924
Other mullite, kyanite, sillimanite, or and alusite brick and shapes	do.	2,825	15,980	2,702	19,108
Other extra-high (over 60) alumina brick and fused bauxite, fused alumina, dense-sintered alumina shapes[6]	do.	4,141	63,508	3,287	58,119
Silicon carbide brick, shapes, kiln furniture	do.	979	28,880	1,105	33,936
Refractory bonding mortar	Short tons	21,094	11,539	29,843	16,944
Hydraulic-setting nonclay refractory castables	do.	19,023	18,227	28,837	21,999
Plastic refractories and ramming mixes	do.	120,306	75,922	136,738	89,385
Gunning mixes	do.	364,806	150,950	323,330	111,939
Dead-burned magnesia or magnesite[3 7]	do.	250,990	64,347	141,967	34,374
Dead-burned dolomite	do.	324,691	46,393	331,982	19,682
Other nonclay refractory material sold in lump or ground form [3]	do.	280,886	74,655	202,486	42,137
Total nonclay refractories		XX	803,903	XX	737,803
Grand total refractories		XX	1,333,171	XX	1,355,296

W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[1]Heat short of fusion; volatile materials are thus driven off in the presence of chemical changes, giving more stable material for refractory use.

[2]More or less plastic brick and materials that, after the addition of any water needed, are rammed into place.

[3]Materials for domestic use as finished refractories and all exported material.

[4]Includes calcined clay, ground brick, and siliceous and other gunning mixes.

[5]Molten cast refractories are made by fusing refractory oxides and pouring the molten material into molds to form finished shapes.

[6]Completely melted and cooled, then crushed and graded for use in a refractory.

[7]Includes shipments to refractory producers for reprocessing in the manufacture of other refractories.

Source: Bureau of Census Report Form MQ 32C(87), Current Industrial Reports—Refractory. Table will be resumed in 1990 Clay chapter.

TABLE 25

U.S. EXPORTS OF CLAYS IN 1989, 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	—	—	1	72	(3)	6	—	—	6	1,533	1	856	8	2,467
Australia	(3)	3	26	2,049	26	2,228	(3)	20	21	3,419	12	3,637	85	11,356
Belgium-Luxembourg	—	—	2	167	47	4,013	(3)	76	83	14,780	3	4,789	135	23,825
Brazil	(3)	13	6	981	—	—	—	—	4	4,376	8	10,755	18	16,125
Canada	60	2,589	257	11,223	12	944	60	4,543	442	56,589	34	16,623	865	92,511
Chile	(3)	16	9	439	—	—	(3)	15	6	1,914	6	3,897	21	6,281
Colombia	—	—	1	124	(3)	68	(3)	—	10	1,853	3	2,755	14	4,800
Ecuador	(3)	58	(3)	58	(3)	48	(3)	5	3	558	1	808	4	1,535
Finland	—	—	—	—	—	—	1	73	159	24,580	5	336	165	24,989
France	—	—	1	381	1	263	(3)	56	13	2,556	3	1,143	18	4,399
Germany, Federal Republic of	1	25	21	854	1	439	1	74	24	5,534	9	3,960	57	10,886
Hong Kong	—	—	1	304	—	—	(3)	18	2	303	(3)	168	3	793
Italy	(3)	2	2	1,118	4	400	(3)	110	213	24,559	3	821	222	27,010
Japan	3	354	166	15,714	47	4,006	1	167	667	112,157	35	9,098	919	141,496
Korea, Republic of	(3)	31	6	1,963	(3)	8	1	61	81	17,152	4	2,158	92	21,373
Mexico	80	2,785	3	484	78	6,037	(3)	23	124	14,070	16	2,429	301	25,828
Netherlands	1	44	24	1,276	27	2,346	22	1,530	199	27,180	7	3,012	280	35,388
Peru	(3)	2	1	83	(3)	21	—	—	2	260	1	254	4	620
Philippines	3	293	7	1,033	—	—	(3)	8	4	1,216	2	609	16	3,159
Saudi Arabia	—	—	3	246	—	—	(3)	14	(3)	66	1	222	4	548
Singapore	—	—	31	3,407	—	—	—	—	1	283	4	999	36	4,689
South Africa, Republic of	1	25	1	96	(3)	10	3	478	19	4,177	3	1,076	27	5,862
Spain	—	—	1	151	—	—	3	249	14	2,086	(3)	240	18	2,726
Sweden	—	—	—	—	7	513	—	—	70	13,618	9	1,785	86	15,916
Switzerland	—	—	(3)	94	14	972	—	—	(3)	46	(3)	147	14	1,259
Taiwan	(3)	6	30	3,240	13	908	—	—	66	12,895	2	1,604	111	18,653
Thailand	—	—	10	966	—	—	—	—	14	3,169	1	187	25	4,322
United Kingdom	1	34	17	2,275	5	440	1	71	18	4,150	16	7,062	58	14,032
Venezuela	1	93	8	458	(3)	30	—	—	11	2,002	1	673	21	3,256
Other	6	476	36	3,690	2	310	3	860	61	13,838	18	5,065	126	24,239
Total[2]	157	6,849	671	52,946	284	24,010	96	8,451	2,337	370,919	210	87,168	3,755	550,343

[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 ½ unit.

Source: U.S. Department of Commerce.

Pipes Ltd. and Zacuba Ltd. from BTR Nylex Ltd.[9] The joint venture will be owned 51% by CSR and 49% by Redland, which will also include all of the local businesses of Redland Monier Ltd.

PGH is one of the leading brickmakers in Australia with 12 plants in New South Wales, Queensland, and South Australia. On completion of the acquisition, the benefits of PGH's large clay reserves and Monier Redland's expanding roofing tile businesses should lead to considerable cost savings. Redland's roof tile operations in Japan, Thailand, and Indonesia are not part of the joint venture. Redland and CSR are already linked in nonclay joint ventures in the United Kingdom and the United States.

The country's leading refractory producer, Heat Containment Industries Pty. Ltd. (HCI), Unanderra, New South Wales, announced a new a $1 million expansion for a new fully automated plant to produce a full line of clay and alumina monolithic refractories.[10] The plant's production capacity is to be in excess of 20,000 tpy and is expected to be commissioned at yearend. HCI, in addition to domestic markets, expects to serve the cement, glass, heavy clay, and alumina markets in Southeast Asia and the other Pacific Rim nations. In kaolin

TABLE 26

U.S. IMPORTS FOR CONSUMPTION OF CLAYS IN 1989, BY KIND

Kind	Quantity (metric) tons)	Value (thousands)
China clay or kaolin:		
Belgium	3	$1
Brazil	2	2
Canada	140	26
Finland	1	4
Germany, Federal Republic of	41	17
Ireland	36	35
Japan	25	17
Korea, Republic of	2	2
Netherlands	7	3
New Zealand	36	19
Taiwan	1	3
United Kingdom	2,812	1,151
Total	3,106	1,280
Fire Clay:		
Canada	146	70
Mexico	2	4
Taiwan	1	3
Total	149	77
Decolorizing Earth's and Fuller's earth: Canada	16	4
Bentonite:		
Australia	61	14
Canada	1,159	442
Denmark	20	60
Germany, Federal Republic of	151	450
Italy	2	5
Japan	23	34
Mexico	732	34
United Kingdom	204	98
Venezuela	75	22
Total	2,427	1,159
Common blue clay and other ball clay:		
Germany, Federal Republic of	17	7
United Kingdom	1,460	356
Taiwan	6	11
Total	1,483	374
Other clay:		
Canada	1,431	275
China	216	22
El Salvador	1	2
France	27	27
Germany, Federal Republic of	76	68

TABLE 26—Continued

U.S. IMPORTS FOR CONSUMPTION OF CLAYS IN 1989, BY KIND

Kind	Quantity (metric) tons)	Value (thousands)
Germany, Federal Republic of	76	68
Italy	2	4
Japan	15	38
Mexico	84	4
Netherlands	2	5
United Kingdom	5,412	1,270
Venezuela	11	3
Total	7,277	1,718
Chamotte or dina's earth: France	60	16
Artificially activated clay and activated earth:		
Brazil	38	510
Canada	416	160
China	6	9
Denmark	16	7
France	32	12
Germany, Federal Republic of	237	1,055
Japan	4	31
Philippines	217	320
Mexico	12,232	4,090
Netherlands	40	29
Thailand	31	53
United Kingdom	7	26
Total[1]	13,276	6,301
Grand total[1]	27,794	10,928

[1]Data may not add to totals shown because of independent rounding.
Source: U.S. Department of Commerce.

TABLE 27

CLAYS: U.S. ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, 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
Water-washed	4,100
Total	8,955
Grand total	54,610

[1]Includes capacity at operating plants as well as at plants on standby basis.
[2]Low-temperature, filler.
[3]High-temperature, refractory.

news, English China Clays PLC (ECC) purchased the kaolin reserves and processing plant of Kaomin NL Ltd. based in Victoria for $3 million.[11]

Belgium

The EC planned to establish another clay-based research facility in Lixhe to be completed by the end of 1991.[12]

Botswana

The Botswana Development Corp. (BDC) has signed a joint-venture agreement with Interkiln Corp. of America, headquartered in Houston, TX, to develop a $12 million facing brick and roofing tiles manufacturing facility capable of producing upward of 25 million bricks per year.[13] The production is targeted largely for domestic consumption except for some export to the Republic of South Africa. The new plant, if on schedule, is anticipated to be on-stream during 1992 using about 75,000 tpy of an indigenous red burning clay described as a semishale. The Overseas Private Investment Corp. (OPIC) has agreed to make a minimal investment to cover about 20% of the total cost. OPIC's interest in the Botswana project peaked during a spring visit by American companies eager to encourage the use of private capital and know-how in friendly and developing countries. OPIC has a $30 million working budget to enhance businesses in Africa and is considering

TABLE 28

KAOLIN: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY[1]

(Thousand metric tons)

Country	Capacity
Algeria	16
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
German Democratic Republic	180
Germany, Federal Republic of	650
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
Taiwan	90
Tanzania	e2

TABLE 28—Continued

KAOLIN: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY[1]

(Thousand metric tons)

Country	Capacity
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 29

FULLER'S EARTH: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, 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
Senegal (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.

TABLE 30

BENTONITE: WORLD ANNUAL PRODUCTION CAPACITY, DECEMBER 31,1989, 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.

equity investment in 15 projects in as many as 13 countries.

Brazil

The State-owned company and world's largest iron ore producer, Companhia Vale de Rio Doce (CVRD), was planning to develop massive kaolin reserves north of the Amazon River between Paru and Jari Rivers in the Almeirim Region within the rain forest.[14] The reserves of the kaolin deposits are in the order of 400 million tons and compare favorably with American clay and that produced by a nearby competitor, Caulim da Amazonia. Further geological work and feasibility tests are planned by CVRD to move the project along. A 50,000 tpy pilot plant was assigned a high priority for further evaluation and testing.

Canada

Western Canada's leading facebrick manufacturer IXL Industries Ltd., Medicine Hat, Alberta, expanded into the refractory brick business by acquiring Clayburn Industries Ltd.'s assets.[15] Clayburn, based in Abbotsford, British Columbia, operates open pits in the United States and Canada and an underground mine in Canada. The clay mined in America is exported to Abbotsford for further processing.

Chile

Sociedad Legal Minera Macarena (SLMM), the country's only calcium bentonite producer, planned to double its plant capacity to about 6,000 tpy.[16] Currently, SLMM's entire production is sold to the fishmeal industry where it is used as a pellet binder. The new production is intended for use by the power generation industry.

China

A directive by the Ministry of Geology called for greater efforts to locate exportable economic mineral reserves in the Coastal Regions.[17] Industrial minerals specifically targeted include kaolin. Apparently, 100 small- and medium-sized mines under consideration, largely in rural areas, were being evaluated. Watts, Blake, Bearne & Co. PLC joint venture, Clay Orient, concentrating on sanitaryware, ceramic tile, and dinnerware markets has been making slow but steady progress in meeting its near-term production and marketing goals.

France

The Devon-based WBB, Europe's leading producer of ball clays, purchased the assets of Pornon et Cie SRL, including extensive reserves and an open pit mine north of the Central Massive in Diou Department Allier.[18] The company plans to let its West German subsidiary, Fuchs'sche Tongruben GmbH & Co. KG, operate the quarry and expand its production to upward of 15,000 tpy, mostly for the Western European markets. These clays are said to complement Fuchs'sche's famous Westerwald clays and are ideally situated to serve the growing demand for early vitrifying and fast-firing systems in southern France, Spain, and Italy by the excellent West German transportation network.

New Zealand

The Australian building products group, Monier PGH, a joint venture between CSR Ltd. (51%) and Redland RLC (49%), acquired the New Zealand Brickmakers (NZB) operations for an undisclosed amount of cash from its parent company, Ceramco Corp. Ltd.[19] Ceramco has been on a divestment policy for a number of years. NZB recently completed a NZ $8 million upgrading of its Auckland plant, which solidified its position as one of New Zealand's largest brick manufacturers.

Nigeria

The Government cited the need for investments and technical expertise in exploiting the nation's largely underdeveloped mineral wealth.[20] Large reserves of industrial minerals, including bentonite, were touted as most promising by its geological survey.

Pakistan

The Government has allocated two large grants to the Saindek Integrated Mineral Development Project, in Chaghai District, Baluchistan, and the other to the geological survey.[21] Future growths in production were noted for many industrial minerals, including china clay, as the principal justification for the project.

South Africa, Republic of

A new 6,000 tpy sulfuric acid-activation plant was commissioned by G & W's Base and Industrial Minerals (Pty.) Ltd. to be located at Koppies in the Transvaal.[22] The new plant is using bentonite from its nearby Ocean deposit as a plant feed to supply local markets with a wide array of vegetable and mineral oil refinery clays. Exports, because of a weakened Rand, are also contemplated. G & W's new plant will compete directly with a joint venture, West Germany's Sud-Chemie AG and the local Cullinan Minerals Ltd. (CML). It is unclear whether the local demand is sufficient to accommodate both plants. CML, in another bentonite action, was spending more than R$500,000 on modernizing its mine and mill complex at Heidelberg in the Cape Province.[23] The project was to include a new rotary kiln for improved quality control. In refractory clay, the flint clay and Chamotte operations of Chamotte Holdings (Pty.) Ltd. were acquired by ECCA Minerals (Pty.) Ltd., which now makes ECCA the largest domestic chamotte producer.[24] Chamotte Holding's mines and calcining plant are also at Bronkhorstspruit in the Transvaal. The acquisition will bring ECCA's existing total raw and calcined flint clay production capacities to 85,000 tpy and 56,000 tpy, respectively.

Spain

The Zaragosa-based sepiolite producer, Sociedad Anominia de Minería y Tecnologia de Arcillas (MYTA), announced it bought SEPCO SA, an attapulgite producer near Segovia in central Spain.[25] The SEPCO plant, northwest of Madrid, has a production capacity of 50,000 tpy and is presently producing about 15,000 tpy. MYTA's plant in the same area, operational since 1987, has a production capacity of about 150,000 tpy. Current sales are about 65,000 tons of pet waste absorbents and 10,000 tons of other products, mostly for exports within Europe. MYTA and SEPCO products are also sold into the industrial absorbents, animal feed, agricultural chemicals, and insecticide carrier markets. MYTA and SEPCO are part of the Luengo group of Aragon, with diversified interests in mining, predominantly in subbituminous coal. The group apparently has identified further clay deposits for exploration, including an excellent kaolin property.

U.S.S.R.

A brickworks with an annual capacity of 60 million standard bricks started production in Tokmak in Kirghizia.[26] The plant was built with Bulgarian assistance and imported production line equipment. Another ceramic production line was augmented at the Angren ceramics complex in Tashkent to supply the construction needs of the earthquake devastated areas in Armenia and Tajikistan.[27] The new production capacity of the Tashkent facility was stated to be its full design capacity of more than 200,000 square meters of facing tiles.

United Kingdom

In environmental affairs involving fuller's earth (calcium bentonite), the application of Laporte Earth Ltd. for permission to mine clay from deposits at Waterhouse Farm, Bletchingley, and Jackass Lane near Tandridge in Surrey was denied by the Secretary of State for the Environment.[28] Laporte, although disappointed, does not intend to press the issue even though industry reserves for Laporte and Steetley

PLC, the other domestic producer, at current production rates, would last about 5 years. The Secretary of State also suggested that cat waste absorbents and exports to foreign facilities were not a valuable use of scarce natural resources. In a related event, Steetley agreed to purchase via its subsidiary, Steetley Minerals Ltd., the Absorbent Products (AP) Div. of Lawrence Industries PLC based in Metcham, Surrey.[29] AP is a major supplier of imported material, including Danish molar earths, attapulgite, fuller's earth, sepiolite, and other materials for cat litter and other industrial absorbent markets. This buy-out expands Steetley's similar Flixborough, South Humberside, bulk storage and packaging facility that also serves export markets. This acquisition not only makes Steetley more formidable in the growing domestic absorbent marketplace but also positions itself for the future in the event of continuing reluctance on the part of Government officials to approve domestic mining permits. A joint venture, Abbey Chemicals, between NL Chemicals-Europe and Steetley Minerals Ltd., planned to raise the production capacity of its bentone organoclay rheological additives plant in Livingston, Scotland, United Kingdom, by 50%.[30] The plant manufactures the additives from NL's American hectorite and bentonite clays for use not only in the paint and surface coatings industries but also for plastisols, ink, grease, and cosmetics and in thickening, antisettling, antisagging, and flow-control markets. In fireclay news, Hepworth Ceramic Holdings PLC purchased British Steel's 22% minority holding in the Hepworth subsidiary, GR-Stein Refractories Ltd., a major international refractories manufacturer.[31]

The EC announced two kaolin actions during the year. The first was another new research facility in St. Austell, Cornwall, to be completed by yearend 1991 and the divestiture of its 21% stake in a competing kaolin and ball clay producer, WBB, for £13 million to a syndicate consisting of Sablieres et Carrieres et Compagne Belge des Silicas Reunies SA (Sibelco) of Antwerp, Belgium, and Quarzwerke GmbH of Frenchen, West Germany.[32] The EC apparently felt uncomfortable with its minority ownership in a major competitor. In brick expansion news, Ibstock Johnsen PLC implemented a new tunnel kiln and automated brick marshaling equipment at its Leicester manufacturing facility.[33] A new £1 million brickworks at St. Ives, Cambridgeshire, capable of producing up to 20 million bricks per year, was opened by ARC Powell Duffryn Brick Ltd. (APDB) to serve the Cambridge and East Anglia markets.[34] The new works will extend APDB's brick range into a full line of specialties indigenous to the area. Baggeridge Brick PLC fired its first kiln at the recent completed Waresley factory near Kiddenminister.[35] The new Lingl kiln, Europe's largest, has the capacity to produce upward of 2.5 million bricks weekly with initial production of 1 million bricks per year of its special line. Base material for the bricks is the West European Upper Triassic clay and Keuper marl mined adjacent to the plant. Baggeridge also manufactures bricks at Kingsbury and Hartlepool, which recently have undergone expansions. London Brick Co., The United Kingdom's largest brick producer, announced production cutbacks amounting to 15% to accommodate the slump in house building activity.[36] London Brick, owned by the giant conglomerate Hanson PLC, closed five kilns at two of its plants in the southern region. The kilns were to be refurbished for an anticipated upturn in the construction industry. Increased sales to commercial and industrial construction partly offset the slump in the housing demand. Cutbacks and postponements in ongoing enlargements were also announced by Butterby Brick Ltd., Britain's second largest brick producer at its Desford, Leicestershire plant.

TECHNOLOGY

Indepth reviews were published on the industrial minerals of Belgium,[37] Brazil,[38] Guyana,[39] South Africa,[40] and Namibia,[41] which include sections on clay, local geology, reserves, mineralogy, mining and milling flowsheets, indigenous mining methods, company profiles, and markets. The Belgian paper covered the lightweight expanded clay aggregates and kaolinitic sand producers while the Brazilian report also highlighted the Brazilian mining laws and clay production statistics by region and State. A noteworthy section on the individual Brazilian kaolin mining companies and their longterm production and marketing goals was of particular interest. A similar but lesser treatment was afforded the Brazilian bentonite and acid-activated manufacturers. The Guyanese study stressed the large kaolin deposits that underlie the presently producing extensive bauxite horizons. An excellent section underscored the technology of characterizing these indigenous deposits to form a basis of a major ceramics development in the Caribbean. The comprehensive South African manuscript, a first of two articles, highlighted its attapulgite, bentonite, kaolin, acid-activated, and refractory clay producers, including flints. A map showing the clay-producing areas and chemical analyses of white calcined and standard chamotte products was a high point of the clays section. The Namibian paper stressed the industrial minerals potential of the country, with an eye toward future independence. The geological presentation included technical descriptions of areas considered to be promising for future specialty clay production. The specialty clays were targeted largely for export while the common clays were designated for local consumption. A similar exhaustive study on the Australian kaolin clays was also published.[42] This excellent work not only summarized the country's major kaolin producers and districts, but also presented the clay's complete chemical analyses along with appropriate physical and chemical properties required by the filler and extender, and ceramic industries in the Pacific Rim. A noteworthy inclusion was a detailed map locating the major producing areas.

A scientific article on drilling for oil and gas in the U.S. Gulf of Mexico was published.[43] This article stressed the importance of the Gulf of Mexico to U.S. oil and gas production, the geology of deep water versus shallow water exploration, and the structure of the drilling fluids industry not only in the Gulf, but also nationally. A high watermark of the work was tables listing the minerals, including attapulgite, bentonite, and organoclays, in drilling fluids. These included consumption rates, technical rationale for use, and the general classification methods for water-, salt-, and oil-base systems employed in drilling. A discussion on the quality requirements for bentonites used in drilling fluids was the topic of another drilling related work. The paper showed the suitability of non-Wyoming and South Dakota area clays as well as Oregon clays to meet American Petroleum Institute (API) specifications for nontreated bentonites. The API specifications and its bentonites tests were most informative.[44]

A timely review article dealt with the current technical and financially driven decisions by U.S. papermakers in assessing the various quantities and qualities of minerals to be used in their formulations

TABLE 31

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria	13,000	14,200	[e]14,000	[e]14,000	14,000
Argentina	73,802	117,378	128,455	94,105	[3]40,000
Australia[4]	[5]165,827	185,617	176,958	[e]180,000	185,000
Austria (marketable)	100,151	[r]46,291	92,186	89,491	85,000
Bangladesh[6]	4,178	2,695	12,272	10,097	[3]7,092
Belgium[e]	[3]37,000	40,000	45,000	[r]40,000	35,000
Brazil (beneficiated)	524,182	623,822	680,000	770,000	[3]846,200
Bulgaria	257,000	265,000	281,000	[e]285,000	280,000
Burundi	4,360	5,113	5,290	4,021	[3]4,305
Chile	48,537	42,170	44,533	54,464	[3]58,320
Colombia	1,041,151	1,155,267	1,221,000	1,306,470	[3]1,800,000
Czechoslovakia	548,000	546,101	697,000	685,958	680,000
Denmark	[e]13,000	10,404	9,304	39,324	15,900
Ecuador	2,981	[e]2,000	1,600	5,000	4,500
Egypt	108,378	127,784	125,256	124,122	[3]121,515
Ethiopia (including Eritrea)[e 7]	[r]75	[r]90	[r]2,500	750	400
France[8]	1,510,000	1,350,000	[e]1,400,000	[e]1,400,000	1,400,000
German Democratic Republic (marketable)[e]	175,000	165,000	150,000	165,000	150,000
Germany, Federal Republic of (marketable)	410,000	512,000	588,000	673,000	675,000
Greece	87,623	141,210	144,634	[e]147,000	145,000
Guatemala	1,042	2,017	1,880	1,186	[3]2,573
Hong Kong	9,602	850	—	—	—
Hungary	29,038	29,837	33,289	29,572	30,000
India:					
Salable crude	585,000	733,000	695,000	579,000	[3]605,000
Processed[e]	[3]110,000	100,000	150,000	150,000	150,000
Indonesia	106,877	[r]132,240	122,046	147,109	[3]157,122
Iran[e]	[r]70,000	[r]70,000	[r]70,000	[r]70,000	80,000
Israel[e]	27,000	27,000	27,000	27,000	27,000
Italy:					
Crude	59,856	35,132	57,054	70,585	65,000
Kaolinitic earth	25,970	[r]21,110	22,194	18,626	20,000
Japan	221,996	203,983	172,781	157,771	[3]165,696
Kenya	320	2,000	40	42	[3]42
Korea, Republic of	658,282	849,742	630,945	832,110	[3]1,219,174
Madagascar	6,367	[e]6,000	1,427	365	[3]1,315
Malaysia	82,576	85,052	96,882	116,869	[3]108,347
Mexico	282,337	276,400	151,104	159,041	197,500
Mozambique[e]	[3]152	200	200	200	[3]
New Zealand	24,471	28,464	25,548	29,649	25,000
Nigeria[e]	300	250	250	250	[3]550
Pakistan	6,644	37,056	32,208	41,968	[3]39,907
Paraguay	60,000	60,000	72,000	70,000	[3]74,000
Peru	210	6,328	626	[e]200	200
Poland	48,500	49,200	[e]49,000	[e]50,000	50,000
Portugal	80,097	54,841	66,763	71,200	58,300
Romania[e]	410,000	410,000	400,000	400,000	400,000
South Africa, Republic of	128,899	126,124	151,730	175,033	[3]139,711
Spain (marketable)[9]	413,719	375,082	433,077	438,160	440,000
Sri Lanka	5,405	6,260	6,869	7,100	[3]7,761
Sweden	106	60	100	[e]100	100

See footnotes at end of table.

TABLE 31—Continued

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

Country[2]	1985	1986	1987	1988[p]	1989[e]
Taiwan	76,605	63,228	67,525	81,879	[3]98,115
Tanzania	1,636	2,270	1,446	528	1,000
Thailand	106,704	[8]132,155	206,568	269,688	[3]328,824
Turkey	69,390	78,430	134,114	209,223	[3]249,931
U.S.S.R.[e]	[r]2,000,000	[r]2,000,000	[r]2,000,000	[r]2,000,000	2,000,000
United Kingdom	[r]2,870,034	2,912,607	3,058,821	3,276,795	[3]3,140,000
United States[10]	7,069,991	7,755,970	8,007,919	8,973,097	[3]8,973,668
Venezuela	[e]23,500	[e]22,000	25,598	24,800	15,000
Vietnam[e]	1,000	1,000	1,000	1,000	1,000
Yugoslavia[e]	205,000	210,000	215,000	250,000	250,000
Zimbabwe	1,104	901	780	95	[3]15
Total	[r]21,003,975	[r]22,258,931	23,007,772	24,818,043	25,669,083

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through July 25, 1990.

[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]Reported figure.

[4]May include ball clay and other clays grouped for statistical purposes as kaolin.

[5]Excludes Western Australia.

[6]Data for year ending June 30 of that stated.

[7]Data for year ending July 6 of that stated.

[8]Includes kaolinitic clay.

[9]Includes crude and washed kaolin and refractory clays not further described.

[10]Kaolin sold or used by producers.

TABLE 32

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria[3]	33,000	30,000	[e]30,000	[e]30,000	30,000
Argentina	147,065	146,191	108,595	169,552	150,000
Australia[3]	29,070	[r]39,933	30,392	35,671	35,000
Brazil	236,021	206,021	194,586	214,767	210,000
Burma	710	851	406	508	420
Chile	—	—	—	529	[4]2,005
Cyprus	52,000	55,000	79,600	90,300	[4]60,000
Egypt	[e]3,000	5,126	3,827	[e]4000	4,000
France[e]	[4]14,900	10,000	8,000	8,000	8,000
Germany, Federal Republic of	169,000	179,000	167,000	197,000	200,000
Greece	886,972	1,317,825	1,300,525	[e]1,200,000	1,200,000
Guatemala	2,727	3,836	26,500	976	[4]8,236
Hungary	59,843	79,888	98,331	118,573	110,000
Indonesia	6,658	5,730	7,962	8,266	[4]3,863
Iran[e]	27,000	27,000	27,000	27,000	37,000
Israel (metabentonite)[e]	6,000	6,000	6,000	6,000	6,000
Italy	[r]304,172	[r]299,638	313,094	301,434	220,000
Japan	461,530	478,254	468,705	455,137	[4]526,131
Kenya[e]	200	200	200	200	
Mexico	267,695	136,500	129,596	168,146	188,500
Morocco	2,877	3,834	2,948	3,445	[4]3,970
Mozambique	361	1,112	936	986	[4]126
New Zealand (processed)	7,400	3,140	—	1,255	2,000

See footnotes at end of table.

TABLE 32—Continued

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Pakistan	1,611	1,362	2,537	4,880	5,466
Peru	2,017	33,080	16,194	[e]20,000	20,000
Philippines	24,971	1,800	759	2,030	[4]2,782
Poland[e]	75,000	75,000	75,000	[r]80,000	80,000
Romania[e]	180,000	185,000	180,000	180,000	180,000
South Africa, Republic of	43,472	48,265	48,953	66,750	[4]62,987
Spain	90,239	114,972	103,420	103,753	100,000
Tanzania[e]	75	75	75	75	75
Turkey	46,855	55,367	85,848	77,527	[4]90,336
U.S.S.R.[e]	2,890,000	2,900,000	2,900,000	2,900,000	2,900,000
United States	2,898,710	2,551,950	2,545,775	2,870,971	[4]3,112,365
Yugoslavia	148,752	148,447	154,288	125,069	130,000
Zimbabwe[5]	68,533	71,987	116,802	113,157	[4]104,865
Total	9,188,436	[r]9,222,384	9,233,854	9,585,957	9,794,127

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through July 25, 1990.

[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]May include other clays.

TABLE 33

FULLER'S EARTH: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	3,500	3,500	3,500	3,500	3,500
Argentina[e]	[3]1,743	2,000	2,000	2,000	2,000
Australia (attapulgite)	[e]15,000	47,376	10,960	[e]15,000	15,000
Germany, Federal Republic of (unprocessed)	701,000	680,000	677,000	670,000	665,000
Italy	30,400	30,960	40,150	38,955	[3]43,550
Mexico	58,000	52,200	49,112	40,727	44,400
Morocco (smectite)	24,425	35,100	46,271	52,694	[3]48,420
Pakistan	10,647	15,228	18,045	12,395	[3]15,436
Senegal (attapulgite)	95,957	81,857	111,048	108,425	[3]98,882
South Africa, Republic of (attapulgite)	5,885	10,125	6,026	7,161	[3]6,609
Spain (attapulgite)	59,697	67,820	40,818	43,585	45,000
United Kingdom[4] [e]	216,000	202,000	213,000	[r]210,000	210,000
United States[5]	1,868,149	1,732,703	1,865,890	1,973,137	[3]1,881,511
Total	[r]3,090,403	[r]2,960,869	3,083,820	3,177,579	3,079,308

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available.

[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 25, 1990.

[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]Estimates made by British Geological Survey of marketable production based on reported crude production, in metric tons, of: 1985—292,000; 1986—248,000; 1987—NA; 1988—NA; and 1989—NA.

[5]Sold or used by producers.

to achieve optimum grades. This work emphasized technical paper terminology, minerals (in particular kaolin and its substitutes), quality and specifications, other mineral possibilities, and the outlook for North American papermakers. The rationale for calcined kaolin and/or lightweight papers and the kaolin, calcium carbonate, both ground and precipitated, along with talc were featured.[45] The detailed report addressed the mining and marketing of primary and secondary Minnesota kaolins found in four southwestern countries near the Iowa border.[46] An excellent section compares these northern clays and their mining and refining methods with the more conventional sources and flowsheets practiced in the Georgia and South Carolina kaolin areas.

An article critically reviewed the technology developed by European research projects that are continually being undertaken in the tile, tableware, and sanitaryware industries on the Continent.[47] The many advances made during the past decade, such as in automation, energy efficiency, quality optimization, and cost effective production, were condensed to only seven fundamental steps: body preparation, including raw materials selection of ball clay, kaolin, and calcined clays; shaping; drying; decorating; firing; and final treatment and inspection. The sections on high-pressure dry pressing, shaping, fast-firing, along with body preparation systems and their flowsheets, commonplace in Europe, were highlights of the report. The trend in the clay and whiteware industries to use shortened expensive firing cycles for wall tiles was the subject of another investigation.[48] The research revealed that kaolin-bearing lead and lead-free fast-fired wollastonite wall tiles showed acceptable properties when compared with conventionally fired tiles.

A new generation of technically sophisticated refractories, including high-alumina clay-base bricks and monoliths developed for the steelmaking industries, was covered in an article.[49] Although the work stressed the role of fluxes in steelmaking, its influence on refractory consumption by the different steelmaking processes was exemplary. Another article provided an overview of major pyroprocessing techniques used for selected minerals, including clays.[50] The technology of rotary and tunnel kilns in manufacturing refractory aggregates from aluminosilicates such as kaolins was examined indepth. The major thrust of another article was to familiarize the reader with an overview of popular pyroprocessing techniques.[51] The technology, market position, future availability of high-alumina kaolin clay specialty calcines and refractory minerals were explored. The paper compared the different mullite-based refractories made from sillimanite group minerals—andalusite, kyanite, and sillimanite—with its clay-derived counterparts.

An overview on fine-grinding techniques, including wet, dry, and classifications schemes, currently used to meet the demand for finer and finer particle sizes was published.[52] The technology of attrition grinding mills, used largely by the kaolin industry, including sections on media for attritors and agitators, and media used for milling were covered in detail. Similar treatment was given to fluid energy and roller milling schemes. Diagrams of the equipment, specifications, and a graph of typical working ranges for the different mill types were high points of the report.

Research indicated that bentonite and/or montmorillinite clays specifically treated with a one- or two-step modification process soak up and immobilize carcinogens such as dioxin, polychlorinated biphenyls (PCB), and other toxic organic compounds.[53] The clays treated with a cationic inorganic polymer hydroxy aluminum proved to be far less expensive than conventionally activated carbon absorption systems. If further research proves out this new approach, it should go a long way in inexpensively removing selected toxins from industrial wastewaters, municipal sewage treatment plants, and chemical and/or municipal waste dumps.

OUTLOOK

U.S. clay demand during the past decade, 1979-89, has rebounded slowly from the recessionary years of 1981-82 to about 42 millon tons or 5 million below the prerecessionary period high in 1979. The decade before witnessed a decrease in construction activity in the public, private, and commercial sectors. Large declines in the manufacture of bricks, lightweight aggregates, portland cement, and other heavy products were responsible, and this demand has never fully recovered. Higher mortgage rates in the late 1980's, as in the late 1970's, coupled with the limited availability of affordable housing and funds for public and business ventures is again reasserting itself in slowing down the overall economy. This pattern, if not offset by lower interest rates and increased availability of capital, will again not only depress construction activities, but also spread into the overall economy. The specialty clays used in more diversified applications and industries held up better than their common clay and shale counterparts. Demand for these clays, which include kaolin, ball clay, fuller's earth, fire clay, and bentonite, generally fared better during the preceding decade and are expected to repeat this behavior. In addition, the weakening U.S. dollar in the latter part of the decade has encouraged specialty clays, led by kaolin, to expand its share of export markets. This performance in exports is expected to continue well into the next decade and possibly the next century.

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. 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.

BACKGROUND

Definitions, Grades, and Specifications

Clays are classified in six groups in Bureau of Mines publications. These 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 Bureau of Mines Information Circular 8335.[54]

Kaolin, or china clay, is defined as a white, claylike material approximating the mineral kaolinite. It has a specific gravity of 2.6 and a fusion point of 1,785° C. The other kaolin-group minerals, such as halloysite and dickite, are encompassed. Specifications are based on 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 principally for bonding in ceramicware.

These clays are of sedimentary origin and consist mainly of the clay mineral kaolinite, sericite micas, and organic matter. Ball clays are usually much finer grained than kaolins and, in general, set the standards of plasticity. Specifications for ball clays are based on methods of preparation (crude, shredded, air-floated, water-washed, or slurry) and pertinent physical and chemical tests, which are much the same as those for kaolin.

Fire clay is defined as detrital material, either plastic or rocklike, containing low percentages of iron oxide, lime, magnesia, and alkalies to enable the material to withstand temperatures of 1,500° C or higher. Fire clay is basically kaolinite but usually contains other clays such as diaspore, burley, burley-flint, ball clay, and bauxitic clay and shale. Fire clays commonly occur as underclay below coal seams and are generally used either for refractories or to raise vitrification temperatures in heavy clay products. The fired colors of fire clays range from buffs to grays. Specifications are based on pertinent physical and chemical tests to determine the properties of the clays and of products made from them.

Bentonite consists essentially of smectite minerals (montmorillonite group according to some usages). The swelling-type has a high-sodium ion concentration and will increase materially in volume when wetted with water, whereas the nonswelling types are usually high in calcium. Standard grades of swelling bentonite increase from 15 to 20 times their dry volume. The specifications are also based on pertinent physical and chemical tests, particularly those relating to 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. The term has neither a compositional nor a mineralogical connotation, and the substance is defined as a nonplastic clay or claylike material, usually high in magnesia, that has adequate decolorizing and purifying properties. Fuller's earths are composed predominantly of the distinct needle- and/or lath-shaped amphibole-like clay mineral attapulgite or varieties of montmorillonite. Fuller's earths containing opal or other forms of colloidal silica are also produced. Specifications are based on physical and chemical tests to determine the properties of the products. Sepiolite-type clays are also included for statistical convenience.

Common clay is defined as a clay or claylike material that is sufficiently plastic to permit ready molding. Its vitrification point is usually below 1,100° C. Shale is a consolidated sedimentary rock composed chiefly of clay minerals that has been both laminated and indurated while buried under other sediments. The common clays and shales are chiefly illitic or chloritic. The materials may also contain some kaolins and montmorillonites and are usually higher in alkalies, alkaline earths, and ferruginous minerals, but much lower in aluminum than the high-quality kaolins, fire clays, and ball clays. The presence of iron usually imparts a reddish hue after firing. There are no specific recognized grades based on preparation and very little terminology based on its usage, although such 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.

Although many specifications have been established by the American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemists' Society, American Petroleum Institute, Technical Association of the Pulp and Paper Industry, and other national organizations, many producers and consumers rely on their own tests and specifications applicable to their specific needs. The tolerance limits of mineralogical composition, particle size, and other physical and chemical properties also are determined largely by individual requirements. Detailed data on specifications have been published by the Bureau of Mines.[55]

Products for Trade and Industry

Clay goes into a variety of products; consumption is weighted heavily in favor of fired materials. Various methods are used in clay treatment before final use that alters the form, but except for calcining and cation exchange, these methods do not appreciably alter the chemical or mineralogical characteristics.

In manufacturing finished products, the previously mentioned equipment plus a kiln for fired or dried products is usually all that is needed. Kaolins for special use as paper coating may be bleached and further delaminated by grinding, deflocculation, and elutriation to special sizes; a final ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to provide a whiter product. Common bricks as well as tile, pet litter, lightweight aggregate, etc., require firing in a kiln. The kiln firing or drying operation produces a finished manufactured product.

Because of the many types of clay and different qualities within each type, the consumption pattern and hence 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.[56] Calcined kaolin grogs have also made inroads in refractory brick manufacturing, replacing imported calcined refractory-grade bauxite grogs. Bentonite production has been moving away from iron ore pelletizing lines and redirected toward the drilling mud and foundry uses that command premium prices. Bentonite products for waterproofing and sealing in construction and reservoir uses have also 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 1989; 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, and Wisconsin and also the District of Columbia.

Although most clays are mined by open pit methods, a few underground mines exist. In 1989, less than 2% of U.S. clay output was from underground mines. Pennsylvania, Ohio, and West Virginia accounted for the bulk of the underground materials, which consisted mostly of underclays associated with coal and suitable for refractory uses. States leading in output were Georgia, 9.8 million tons; Ohio, 3.5 million tons; Texas, 2.4 million tons; North Carolina, 2.3 million tons; California and Wyoming, 2.2 million tons each; and Alabama, 2.0 million tons.

Most of the large kaolin producers have principal operations in Georgia. In 1989, three large diversified firms accounted for about 60% of total domestic kaolin output. Altogether, 42 firms operated 130 mines in 13 States. Georgia, the largest producing State, accounted for 84% of the total output.

The ball clay industry is small, with 7 producers operating 24 mines in 5 States in 1989. Three of these were large diversified firms with widespread foreign and domestic mineral interests. Tennessee ball clay production represented almost 71% of the total output.

Fireclay producers were mostly refractories manufacturers that used the clays in firebrick and other refractories. Almost 70 mines were operated in 1989 by 26 firms.

Firms producing bentonite operated 220 mines in 13 States. Four 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 70% of the total output.

Bentonites are composed essentially of minerals of the montmorillonite group. The swelling-type is high in the sodium ion. Currently, the swelling-type is produced chiefly in Wyoming and Montana while the nonswelling-type is from mines in Mississippi and Texas. The United States is the world's largest producer and exporter of bentonitic clays.

Nine of the 17 fuller's earth producers and 12 of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia. These two States accounted for 57% of domestic production. Production, mostly small scale, was reported from seven other States in 1989. 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 both the world's largest producer and user.

Firms producing common clay and shale in 1989 were manufacturers of structural clay products, clay pipe, lightweight aggregates, and cement. Essentially all were integrated to the extent of owning or leasing and operating the deposits of clay used in making their products. Private mining contractors and haulers were beginning to make inroads into many of these operations. A few of the producers were diversified firms having interests in metals and other nonclay products. Some companies owned and operated several clay pits and plants located to cover a large market area. The economic radius for shipment of common clay or shale products is usually 200 miles or less. This promotes the existence of many local ownership companies, or in case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants.

Geology-Resources

Clay is a product of the mechanical and chemical breakdown of parent rocks. The products from these weathering reactions consist of mixtures of particles of different sizes and differing physical, chemical, and mineralogical properties. The nonplastic portion consists of altered and unaltered rock products (grit), which are usually quartz, micas, feldspar, and iron oxides. The plastic clays are usually high in clay content and low in grit. Clays may be further designated as residual or sedimentary. Residual clays are those occurring in the same location in which they were originally formed. Sedimentary clays are those that have been transported, usually by water, and deposited elsewhere.[57] Further alteration and classification are common during transportation. The Georgia and South Carolina kaolins are sedimentary; the North Carolina and the English china or kaolin clays are residual.[58] The Kentucky and Tennessee ball clays and the Missouri fire clays are sedimentary types. Most bentonites, montmorillonites, and fuller's earth in North America and elsewhere were formed in place from volcanic ash or tuff. The attapulgite-type fuller's earth deposits of Florida and Georgia were probably formed differently. Geologists have never found any evidence of volcanic materials associated with these deposits.[59]

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.

Common clays and shales are indigenous to most countries. In 1989, U.S. production was reported from 43 of the 50 States and Puerto Rico. Resources are enormous, but not all material is located ideally with respect to the potential market, nor are individual deposits necessarily suitable for a specific use. Most common clay or shale deposits are usable for manufacture of common brick, but the color or strength may not meet the requirements of the local market. Relatively few deposits are commercially suitable for manufacture of lightweight aggregate. Even with these limitations of location and use, the statement "virtually unlimited" is used to describe resources of common clay and shale.

U.S. reserves of clays, other than common clay and shale, which are virtually unlimited, owned or controlled by domestic producers are estimated to total about 700 million tons in the following categories: kaolin, 400 million; ball clay, 30 million; fire clay, 100 million; bentonite, 120 million; and fuller's earth, 60 million.

Georgia contains large quantities of high-quality kaolin suitable for paper-coating and paper-filler. A small area in Georgia and Florida contains sizable reserves of attapulgite-type fuller's earth. Bentonite for iron ore pelletizing and oil-well-drilling muds is chiefly from Wyoming. Fireclay deposits are widespread, such as those found in Missouri, but currently exploited deposits of highest quality fire clay are nearing depletion. Only a few States, namely Tennessee and Kentucky, have sizable deposits of ball clay.

Technology

Exploration.—As with other minerals, exploration for clays begins with an understanding of the geologic occurrence of deposits in question, followed by periods of sampling, testing, and appraisal. Once deposits have been located, they are either auger or core drilled, both to obtain sufficient samples for testing and storage and to delineate the size and quality of the deposits. The evaluation of bentonites and fuller's earth is handicapped by the absence of standard testing procedures or specifications. Generally, these two clays are produced to meet the purchaser's specifications. Kaolin samples are usually evaluated for filler applications by either wet or air-float processing and for ceramic uses. The grit, particle size, brightness, and leachability are all determined. Air-floated clays normally require only grit and brightness determinations. The kaolins, ball clays, and fire clays destined for ceramic and/or refractory uses are analyzed for grit, brightness, green and dry strengths, fired color, and iron and alumina contents. The common clays and shales are usually tested for the intended end use, such as bricks, structural-drain tiles, or lightweight aggregates. Usually, prepared specimens are tested for plasticity, green strength, shrinkage, vitrification temperature range, etc., and for lightweight aggregates, the bloating range.

Mining.—Most clays are mined either totally or selectively 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, and 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 underground operations employing mechanized room-and-pillar methods. Truck haulage from either the pits or blending areas to the processing plants is the most common; other methods involve use of rail transport, conveyor belts, and pipelines in the case of kaolin. Recovery is almost 100% of the minable beds in most open pit mines and perhaps 75% 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.

Beneficiation.—Processing of clays ranges from very simple and inexpensive crushing and screening required for some common clays to very elaborate and expensive methods necessary to produce paper-coating clays and high-quality filler clays for use in rubber, paint, plastic, and other products. Significant processing losses are involved only with kaolin and fuller's earth where about 40% and 30%, respectively, of the material delivered to the processing plants is discarded. Waste material from processing consists mostly of off-grade clays and minor quantities of quartz, mica, feldspar, and iron-bearing minerals.

There are several principal processing methods for the various types of clay.

Kaolin.—Processing includes any one or a combination of crushing, blunging with dispersant, rough sedimentation, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, and attrition grinding, slurrying, and delaminating.

Ball Clay.—Processing includes drying, shredding, pulverizing, air floating and slurrying.

Fire Clay.—Processing includes crushing, calcining, and blending.

Bentonite.—Processing includes weathering, drying, grinding, sizing, granulation, and additives for cation exchange.

Fuller's Earth.—Processing includes lunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Common Clay and Shale.—Processing includes crushing, blunging, extruding, and drying.

Imports of clays, for the most part, are precluded because transportation costs would then be noncompetitive.

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 the Chemical Marketing Reporter.

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; 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

One firm each in Texas, California, and Florida produces silica glass sand as a coproduct with kaolin. Byproduct flake mica is mined by one kaolin producer in North Carolina, and coproduct bauxite is mined by kaolin producers in Georgia and Alabama. 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. Transportation costs are critical for common clays and very important for most fire clays. The other clays, being less abundant and higher in unit value, can be marketed at greater distances from production centers. For example, paper-coating clay is produced domestically in Georgia, attapulgite-type fuller's earth is produced in Florida and Georgia, and the bentonite used for iron ore pelletizing is produced in Wyoming and Montana. Consumers have little choice but to use those clays even though in many cases the shipping costs exceed the value of the clay at the mines or processing plants.

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.

Import duties on clays have little impact on the amount of clays imported. A small but dedicated demand for certain prestigious English clays persists.

OPERATING FACTORS

In manufacturing finished clay products, the previously mentioned equipment plus a kiln for fired or dried products is usually all that is required by the energy intensive clay industry. Many clay producers, having successfully converted to coal from oil firing and gas firing, are not exploring the practicality of augmenting coal with wood chips as a fuel. 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 inherent in mining because few deposits require use of explosives and most are merely open pit earth-moving operations. Domestic mine employment in 1983 was reported to be approximately 2,000. Processing plants preparing the product for use or sale required about 10,000 workers or approximately five times the personnel in the mines.

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COBALT

By Kim B. Shedd

Ms. Shedd, a physical scientist with more than 10 years Bureau of Mines experience, has been the commodity specialist for cobalt since 1988. Domestic survey data and trade data were prepared by the Ferrous Data Section; international production tables were prepared by W. L. Zajac, Chief, International Data Section.

U.S. reported consumption of cobalt decreased slightly from consumption reported for 1988. For the second year in a row, domestic consumption exceeded cobalt imports, resulting in a reduction in industry stocks. The 1989 cobalt market was characterized by stable prices. Significant events included the Defense Logistics Agency (DLA) contract to upgrade cobalt metal in the National Defense Stockpile (NDS) and Brazil's initial production of electrolytic cobalt.

TABLE 1

SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Consumption:					
Reported	r5,616	r6,483	r6,645	r7,247	7,065
Apparent	7,118	r7,649	r7,986	r7,824	7,164
Imports for consumption	8,032	5,574	8,832	7,051	5,793
Stocks, Dec. 31[1]	1,273	1,355	2,043	1,766	1,439
Price: Metal, per pound[2]	$11.43	$7.49	$6.56	$7.09	$7.64
World: Production					
Mine	r47,374	r50,199	r40,902	p43,608	e43,360
Refinery	r27,460	r31,399	r27,956	p27,040	e26,237

eEstimated. pPreliminary. rRevised.

[1]Stocks held by consumers and chemical processors.

[2]Market price based on weighted average of Metals Week prices.

LEGISLATION AND GOVERNMENT PROGRAMS

The NDS goal of 38,737 metric tons of cobalt metal remained in effect during 1989. The actual yearend stockpile inventory reported by the DLA was 24,088 metric tons. In July, the DLA solicited bids to upgrade 515 metric tons (1,135,985 pounds) of NDS cobalt. The solicitation required that the cobalt provided met NDS Purchase Specification P-13-R6 grade B, and included the option to exchange NDS cobalt for higher grade cobalt from other sources. On September 22, DLA awarded the contract to Sherritt Gordon Ltd. of Toronto, Canada. Under the contract, Sherritt was to supply 186 metric tons (410,394 pounds) of cobalt from Norway at a price of $3.27 per pound in exchange for stockpile cobalt. The two other bidders were La Générale des Carrières et des Mines du Zaire (Gécamines), which offered to supply its own cobalt from Zaire, and The Hall Chemical Co., which offered Zambian cobalt. Although Sherritt's bid was higher than bids from the other companies, Sherritt won the award because of a clause citing the Buy American and Trade Agreements Acts. This clause provides top preference to domestic material over foreign material, followed by preference to material produced in countries designated under the Trade Agreements Act of 1979. Norway was a designated nation, but Zaire and Zambia were not.

On January 19, 1989, the Occupational Safety and Health Administration (OSHA) revised the permissible exposure limit for cobalt metal, dust, and fume from an 8-hour time-weighted average of 0.1 milligram per cubic meter (mg/m^3) of air to 0.05 mg/m^3. In addition, OSHA established 8-hour time-weighted average limits of 0.1 mg/m^3 for cobalt carbonyl and cobalt hydrocarbonyl. OSHA had no former permissible exposure limits for the latter two compounds.[1]

On April 28, 1989, the Environmental Protection Agency published proposed amendments to the effluent limitations and standards in the Secondary Tungsten and Cobalt Subcategory of the Nonferrous Metals Manufacturing Point Source Category of the Clean Water Act.[2] The proposed amendments were the result of settlement agreements with companies affected by the regulations. The amendments would increase the allowable amount of cobalt in various wastewater streams in the Secondary Tungsten and Cobalt Subcategory, but would not affect effluent limitations and standards in the Primary Nickel and Cobalt Subcategory.[3]

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 1989, the United States consumed nearly 30% of estimated world production. There was no domestic production, so demand was met primarily from imports, with the exception of about 17% from secondary sources (scrap). To ensure an adequate supply in case of a national emergency, cobalt metal is included in the NDS.

World cobalt production is concentrated in a limited number of geographic areas. More than half of the world's supply of refined cobalt comes from Sub-Saharan Africa, primarily Zaire and Zambia. Most of the cobalt produced in Zaire is

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 Tanzania in recent years. The United States prohibits imports of products "produced, manufactured by, marketed, or otherwise exported by a parastatal organization of South Africa" under section 303(a) of the Comprehensive Anti-Apartheid Act of 1986 (Public Law 99-440). The U.S. State Department has certified cobalt as a strategic mineral so that it is exempt from this prohibition.

PRODUCTION

There was no domestic mine or refinery production of cobalt in 1989. In September, Blackbird Metals Inc. signed agreements with Noranda Minerals Inc. and M. A. Hanna Co. for the sale of the Blackbird cobalt mine in Lemhi County, ID. The sale, which was dependent on several undisclosed conditions, was not closed by yearend.

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. Extra-fine cobalt metal powder was produced in the United States at two locations. Carolmet, owned by Metallurgie Hoboken-Overpelt S.A. (MHO) in Belgium, produced extra-fine powder from imported primary metal. GTE Products Corp. produced extra-fine powder from recycled materials.

Domestic chemical processors produced 2,197 metric tons of inorganic and organic cobalt compounds in 1989, as compared with 1,865 metric tons in 1988. Shipments (defined as sales, transfers, or consumption to make other compounds) were 1,904 metric tons, as compared with 1,816 metric tons in 1988. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

CONSUMPTION AND USES

Reported domestic consumption of cobalt decreased slightly in 1989 following 3 consecutive years of increases. Consumption in superalloys, the largest end use for cobalt, also showed a slight decrease. However, cobalt use in superalloys in the past few years has remained high, with only a small decrease since the record level reported for 1986.

An estimate for the cemented carbide industry was introduced to supplement reported data in the "cutting and wear-resistant materials" category. Because of the addition of the estimate, cobalt consumption in cutting and wear-resistant materials increased to 9% of total consumption. In addition to cemented carbides, this category also includes sintered and cast carbides, diamond bit matrices, and wear-resistant alloys. The data were revised back to 1985 (tables 2 and 3).

TABLE 2

U.S. REPORTED CONSUMPTION OF COBALT,[1] BY END USE

(Metric tons cobalt content)

End use	1985	1986	1987	1988	1989
Steel:					
Full-alloy	W	W	W	W	W
High-strength, low-alloy	W	W	W	W	—
Stainless and heat-resisting	r28	34	26	26	74
Tool	92	116	174	180	219
Superalloys[2]	r2,418	2,924	2,873	2,887	2,813
Alloys (excludes alloy steels and superalloys):					
Cutting and wear-resistant materials[3 4]	r566	r518	r654	r704	654
Magnetic alloys	660	r699	r666	869	861
Nonferrous alloys	W	W	W	W	27
Welding materials (structural and hard-facing)	W	W	W	W	W
Other alloys	55	54	43	25	17
Mill products made from metal powder	W	W	W	rW	W
Chemical and ceramic uses:					
Catalysts	r497	656	497	617	5819
Drier in paint or related usage	517	r674	799	892	718
Feed or nutritive additive	21	21	24	26	35
Glass decolorizer	19	18	17	16	16
Ground coat frit	328	350	360	332	352
Pigments	182	210	258	378	5319
Miscellaneous and unspecified	r233	r210	255	r295	5143
Total[6]	r5,616	r6,483	r6,645	r7,247	7,065

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1]Includes estimates.
[2]Data before 1986 not comparable because of the addition of statistical canvass coverage of the superalloy recycling industry.
[3]Includes wear-resistant alloys, diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.
[4]Data not comparable with those before 1985 because of the addition of an estimate for the cemented carbide industry.
[5]Data not comparable with those before 1989 because of a change in reporting method.
[6]Data may not add to total shown because of independent rounding.

TABLE 3

U.S. REPORTED CONSUMPTION OF COBALT,[1] BY FORM

(Metric tons cobalt content)

	1985	1986	1987	1988	1989
Chemical compounds (organic and inorganic) other than oxide	r854	r893	r1,015	r1,254	1,277
Metal[2]	r3,878	r3,833	r4,094	r4,458	4,107
Oxide	r477	559	512	517	497
Purchased scrap[3]	r408	r1,196	r1,025	r1,018	1,184
Total[4]	r5,616	r6,483	r6,645	r7,247	7,065

rRevised.
[1]Includes estimates.
[2]Data not comparable with those before 1985 because of the addition of an estimate for the cemented carbide industry.
[3]Data before 1986 not comparable because of the addition of statistical canvass coverage of the superalloy recycling industry.
[4]Data may not add to total shown because of independent rounding.

Apparent consumption, as calculated from net imports, consumption from recycled scrap, and changes in Government and industry stocks decreased 8% to 7,164 metric tons. Imports are the single largest component in the calculation of cobalt apparent consumption. U.S. imports of cobalt in 1989 decreased 18% from those in 1988. This decrease coincided with the conversion to the Harmonized Tariff Schedule (HTS). In comparing data spanning a change in reporting procedures, it is often difficult to distinguish actual trends in the data from differences resulting from changes in classification. The HTS is discussed in more detail in the Foreign Trade section of this chapter.

STOCKS

Industry stocks of cobalt metal and cobalt compounds decreased for the second year in a row. Stocks held by consumers and chemical processors were equivalent to those before the stock buildup in late 1987 (table 4).

PRICES

The producer price of $8.40 per pound of electrolytic cobalt established in November 1988 was maintained during 1989. The market price of electrolytic cobalt reported in Metals Week was stable, with a weighted average of $7.64 per pound for the year. Prices for these and other cobalt-containing materials are presented in table 5.

FOREIGN TRADE

Effective January 1, 1989, the United States adopted the HTS for reporting trade data. The HTS replaced the Tariff Schedules of the United States Annotated (TSUSA) system. Classification of cobalt-containing materials under the HTS differs from classification under the TSUSA, so trade data may not be directly comparable with data reported before 1989. For example, the TSUSA system had one category for cobalt metal imports in which both unwrought cobalt and cobalt waste and scrap were reported. The HTS has four categories for cobalt metal imports: unwrought cobalt; unwrought cobalt alloys; cobalt mattes and other intermediate products of cobalt metallurgy, waste and scrap; and wrought cobalt and cobalt articles. Changes in classification for imports of cobalt metal and chemicals are reflected in tables 6, 7, and 8. Import duties on cobalt materials were not affected by the change to the HTS. A full listing of cobalt-containing imports under the HTS and their duties are given in table 9.

The United States-Canada Free-Trade Agreement took effect January 1, 1989. Duties on cobalt chemicals, unwrought cobalt alloys, and wrought cobalt and cobalt articles originating in Canada were scheduled to decrease over a 5-year period (table 10).[4] Other cobalt materials originating in Canada were already duty free.

U.S. imports of unwrought cobalt and cobalt contained in chemicals decreased to an estimated 5,793 metric tons, valued at $100 million. This is not directly comparable with imports in 1988, which included waste and scrap.

The net import reliance as a percentage of apparent consumption was estimated to be 83%. The net import reliance would be 100% if no cobalt were recovered from secondary sources (scrap). Fifty-nine percent of U.S. cobalt imports were from ores originating in the south-central African countries of Zaire and Zambia. This includes significant amounts of cobalt imported from Belgium, where electrolytic Zairian cobalt is processed into metal powder, oxides, and salts by MHO. Thirty-one percent of U.S. cobalt imports in 1989 were from Canada and Norway.

In 1989, the United States exported an estimated 889 metric tons of unwrought cobalt and cobalt contained in chemicals, valued at $17.2 million. Major recipients were Mexico (18%), France (12%), and Canada (11%). The remainder was shipped to 40 other countries. Exports of unwrought cobalt, waste and scrap, increased 64% as compared with those of 1988.

Exports also included more than 171 metric tons, gross weight, of wrought metal and cobalt articles, valued at $7 million. The majority of these materials was sent to four countries: Canada (31%), Japan (16%), France (15%), and the United Kingdom (13%). The remainder was shipped to 18 other countries. In addition, 28 metric tons, gross weight, of material was

TABLE 4

U.S. STOCKS OF COBALT MATERIALS,[1] DECEMBER 31

(Metric tons cobalt content)

	1985	1986	1987	1988	1989
Chemical compounds (organic and inorganic) other than oxide	261	263	282	249	W
Metal	790	977	1,486	1,278	860
Oxide	81	W	105	76	W
Scrap	140	W	171	162	186
Total[2]	1,273	1,355	2,043	1,766	1,439

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Stocks reported by cobalt processors and consumers.
[2]Data may not add to totals shown because of independent rounding.

TABLE 5

YEAREND PRICES OF COBALT MATERIALS[1]

(Dollars per pound)

	1985	1986	1987[2]	1988	1989
Cobalt metal:					
Cathode or granules (shot)[3 4]	11.70	7.00	7.50	8.40	8.40
Fine powder (less than 1.6 micrometers)[5]	19.05	15.40	16.85	17.75	17.75
Powder (300-mesh, 400-mesh, 100-mesh)	14.87	14.47	13.84	14.74	14.71
S-grade powder (minus 48-mesh)	11.70	7.50	7.75	8.65	[6]8.65
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	9.98	6.08	8.80	9.70	9.42
Ceramic-grade (72% to 73% cobalt)	10.26	6.24	9.04	9.94	9.67
Metallurgical-grade (76% cobalt)	10.61	6.51	9.41	10.31	10.06

[1]Prices for 1985-88 are from Metals Week; 1989 prices are list prices from African Metals Corp., unless noted.
[2]Represents prices as of Jan. 21, 1988.
[3]See table 1 for cathode market price.
[4]250-kilogram drums.
[5]50-kilogram drums.
[6]Sherritt Gordon Ltd. list price.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

Form		1987	1988	1989
Metal:[1]				
Gross weight		8,442	6,675	5,444
Cobalt content[e]		8,442	6,675	5,444
Value	thousands	$122,791	$105,544	$91,960
Oxides and hydroxides:[2]				
Gross weight		361	337	380
Cobalt content[e]		267	249	273
Value	thousands	$5,293	$5,692	$6,598
Other forms:[3]				
Gross weight		410	424	281
Cobalt content[e]		123	127	75
Value	thousands	$2,004	$2,689	$1,426
Total:[4]				
Gross weight		9,213	7,436	6,105
Cobalt content[e]		8,832	7,051	5,793
Value	thousands	$130,088	$113,925	$99,984

[e]Estimated.
[1]Unwrought cobalt, excluding alloys; data before 1989 include waste and scrap.
[2]Data before 1989 are oxides only.
[3]1989 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.
[4]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census; minor adjustments by the Bureau of Mines.

exported under the category entitled, "Cobalt ores and concentrates." Canada was the major recipient of this material.

WORLD REVIEW

World refinery production decreased slightly from that of 1988. Sales from primary Western producers to Western consumers were estimated at 21,450 metric tons, relatively unchanged from 21,050 metric tons in 1988.[5] The balance of Western World demand was met from industry stocks.

Capacity

The data in Table 12 are rated capacity for refineries 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

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY

Country of origin	Metal[1]				Oxides and hydroxides[2]				Other forms[3]				Total content[4] [5]	
	1988		1989		1988		1989		1988		1989			
	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[4] (metric tons)	Value (thousands)	Cobalt content[4] (metric tons)	Value (thousands)	1988 (metric tons)	1989 (metric tons)
Belgium	352	$7,508	718	$14,197	215	$3,744	236	$4,147	15	$462	21	$380	526	909
Canada	1,581	23,651	1,211	19,905	25	397	25	415	18	244	—	—	1,618	1,229
Finland	99	3,475	40	1,506	38	489	57	865	46	558	18	316	173	98
France	21	506	11	475	5	224	6	248	—	—	—	—	25	15
Germany, Federal Republic of	131	2,623	97	1,987	—	—	—	—	([6])	11	—	—	131	97
Japan	51	647	22	560	—	—	([6])	4	2	373	—	—	53	22
Netherlands	24	152	—	—	—	—	—	—	—	—	—	—	24	—
Norway	625	9,257	593	9,170	—	—	—	—	—	—	—	—	625	593
South Africa, Republic of	2	46	223	3,687	8	142	—	—	5	63	16	230	13	239
United Kingdom	31	355	10	160	38	602	55	919	23	479	20	493	82	70
Zaire	2,442	38,866	1,076	19,065	—	—	—	—	—	—	—	—	2,442	1,076
Zambia	1,208	16,942	1,418	20,852	—	—	—	—	—	—	—	—	1,208	1,418
Other	108	1,516	26	396	7	94	—	—	17	499	([6])	8	130	26
Total[5]	6,675	105,544	5,444	91,960	337	5,692	380	6,598	127	2,689	75	1,426	7,051	5,793

[1]Unwrought cobalt, excluding alloys; data before 1989 include waste and scrap.
[2]Data before 1989 are oxides only.
[3]1989 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.
[4]Estimated from gross weights.
[5]Data may not add to total shown because of independent rounding.
[6]Less than 1/2 unit.

Source: Bureau of the Census; minor adjustments by the Bureau of Mines.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF ADDITIONAL COBALT MATERIALS, BY COUNTRY, 1989

Country of origin	Unwrought cobalt alloys		Other cobalt: matte, waste and scrap[1]		Wrought cobalt and cobalt articles	
	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)
Belgium	18	$445	(3)	$8	(3)	$2
Canada	(3)	5	43	602	35	610
Finland	—	—	20	761	—	—
France	40	1,647	20	286	1	34
Germany, Federal Republic of	2	122	20	263	3	58
Japan	10	687	29	511	21	2,045
Netherlands	—	—	18	77	(3)	2
South Africa, Republic of	(3)	3	(3)	2	—	—
United Kingdom	8	81	184	2,373	16	630
Other	12	311	30	172	8	247
Total[4]	90	3,301	364	5,054	84	3,627

[1]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.
[2]Customs value.
[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 Bureau of Mines.

TABLE 9

U.S. IMPORT DUTIES FOR COBALT-CONTAINING MATERIALS, EFFECTIVE JANUARY 1, 1989

Item	HTS No.	Most favored nation (MFN)	Non-MFN	Special[1] [2]
Chemical compounds:				
Cobalt acetates	2915.23.00	4.2%	30%	Free (A, E, IL)
Cobalt carbonates	2836.99.10	4.2%	30%	Do.
Cobalt chlorides	2827.34.00	4.2%	30%	Do.
Cobalt oxides and hydroxides	2822.00.00	2.6 cents/kg	44 cents/kg	Do.
Cobalt sulfates	2833.29.10	1.4%	6.5%	Do.
Cobalt matte, waste and scrap	8105.10.90	Free	Free	XX
Cobalt ores and concentrates	2605.00.00	Free	Free	XX
Unwrought cobalt alloys	8105.10.30	5.5%	45%	Free (E, IL)
Unwrought cobalt, other	8105.10.60	Free	Free	XX
Wrought cobalt and cobalt articles	8105.90.00	5.5%	45%	Free (A, E, IL)

XX Not applicable.
[1]See table 10 for duties on cobalt materials originating in Canada.
[2]A, Generalized System of Preferences; E, Caribbean Basin Economic Recovery Act; IL, United States-Israel Free Trade Area.

Source: International Trade Commission.

closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Albania

Trial production was reported at the nickel-cobalt refinery at Elbasan, southeast of Tirana. The plant was built by the Federal Republic of Germany firm Salzgitter Industriebau GmbH, with technical assistance from Inco Tech Ltd., a subsidiary of Inco Ltd. Cobalt oxide was to be produced from domestic nickeliferous iron ore.

Australia

Nickel-cobalt sulfide and cobalt sulfide were produced as a byproduct of nickel mining and refining by Western Mining Corp. 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.

Queensland Nickel signed long-term contracts for lateritic nickel ore from Indonesia and New Caledonia. The ore was to replace feed from the Greenvale deposit, which was expected to be depleted within a few years. Cobalt sulfide produced at the Yabulu nickel refinery in Townsville, Queensland, was refined by Outokumpu Oy in Finland.

MIM Holdings Ltd. worked on developing a method to recover cobalt from its Mount Isa copper concentrate at the company's Hydrometallurgical Research Laboratories in Brisbane. During the year, a pilot plant was being built to test the method. The process was reported to involve flotation and bacterial leaching, followed by precipitation of cobalt sulfate. Production of cobalt metal was to be considered.

Resolute Resources Ltd., of Perth, reportedly planned to develop its nickel deposit at Bulong, near Kalgoorlie in Western Australia. Based on a preliminary feasibility study, the company could process 1 million metric tons of ore per year with a sulfuric acid leaching process, from which an estimated 13,000 metric tons nickel and 800 metric tons cobalt in a sulfide precipitate could be produced. Total indicated reserves reportedly were more than 100 million metric tons ore.[6]

Botswana

The quantity of metal produced in copper-nickel-cobalt matte by BCL Ltd. decreased from the record high established in 1988. Production of nickel, copper, and cobalt in 1989 was reportedly 39,025 metric tons, of which 207 metric tons was cobalt.[7] The drop in production was attributed primarily to depletion of high-grade concentrates stockpiled during a furnace overhaul in 1987. During the year, the company developed a new copper-nickel mine in the Selebi North deposit, with the intention of maintaining current ore production levels into the future.

Brazil

Cia. Niquel Tocantins, a Brazilian nickel producer, started production of electrolytic cobalt at its nickel plant in Sao Miguel Paulista, Sao Paulo State. This represented

TABLE 10

U.S. IMPORT DUTIES FOR COBALT-CONTAINING MATERIALS UNDER THE UNITED STATES-CANADA FREE-TRADE AGREEMENT

Item	HTS No.	Effective date				
		Jan. 1, 1989	Jan. 1, 1990	Jan. 1, 1991	Jan. 1, 1992	Jan. 1, 1993
Chemical compounds:						
Cobalt acetates	2915.23.00	3.3%	2.5%	1.6%	0.8%	Free
Cobalt carbonates	2836.99.10	3.3%	2.5%	1.6%	0.8%	Free
Cobalt chlorides	2827.34.00	3.3%	2.5%	1.6%	0.8%	Free
Cobalt oxides and hydroxides	2822.00.00	2 cents/kg	1.5 cents/kg	1 cent/kg	0.5 cent/kg	Free
Cobalt sulfates	2833.29.10	1.1%	0.8%	0.5%	0.2%	Free
Unwrought cobalt alloys[1]	8105.10.30	4.4%	3.3%	2.2%	1.1%	Free
Wrought cobalt and cobalt articles	8105.90.00	4.4%	3.3%	2.2%	1.1%	Free

[1]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).

Sources: Federal Register and International Trade Commission.

TABLE 11

U.S. EXPORTS OF COBALT IN 1989, BY COUNTRY[1]

Country of destination	Metal[2]		Oxides and hydroxides		Acetates		Chlorides		Total content[4] (metric tons)	Total value[3] (thousands)
	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)		
Australia	2	$73	24	$340	—	—	—	—	19	$413
Austria	22	285	—	—	—	—	—	—	22	285
Brazil	30	332	22	263	21	$146	—	—	50	741
Canada	65	1,587	35	301	12	72	7	$164	95	2,124
China	(5)	5	—	—	50	245	—	—	12	250
France	108	2,664	2	47	—	—	—	—	109	2,711
Germany, Federal Republic of	35	1,515	(5)	3	—	—	—	—	35	1,518
Hong Kong	1	18	—	—	—	—	12	39	4	57
Indonesia	—	—	—	—	44	228	—	—	11	228
Italy	7	179	21	198	—	—	—	—	23	377
Japan	16	623	71	712	—	—	—	—	67	1,334
Mexico	6	178	144	1,515	198	463	6	45	159	2,200
Netherlands	6	263	31	198	5	30	—	—	29	491
Taiwan	—	—	88	575	23	115	—	—	69	690
United Kingdom	26	733	14	551	23	130	—	—	41	1,414
Venezuela	(5)	9	28	395	—	—	—	—	21	404
Other	31	990	122	976	17	47	—	—	123	2,013
Total[6]	355	9,452	603	6,073	393	1,476	25	248	889	17,249

[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 12

WORLD ANNUAL COBALT PRODUCTION CAPACITY, DECEMBER 31, 1989

(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	[r]5,000
Total[6]	[r]42,000

[e]Estimated. [r]Revised.
[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.

the first production of cobalt metal in Brazil. Before installation of the cobalt circuit, cobalt carbonate from Tocantins' nickel refinery was sent to Falconbridge Nikkelverk in Norway to be refined. At yearend, the cobalt circuit was reported to be producing 20 metric tons of cobalt per month. The company hoped to increase capacity to 600 metric tons per year by 1991 or 1992. The cobalt was expected to replace imports for domestic consumption, with some also possibly available for export.

Canada

Falconbridge Ltd. changed ownership in September when it accepted a joint offer from Noranda Inc. of Canada and Sweden's Trelleborg AB to purchase all outstanding common shares. Noranda and Trelleborg planned to own and manage the company on an equal basis. Falconbridge's 1989 cobalt production from mines in Sudbury was 740 metric tons, down from 840 metric tons in 1988. An additional 500 metric tons of cobalt was produced in 1989 from custom feed smelting.[8]

Inco Ltd. produced 1,510 metric tons of cobalt in 1989, as compared with 1,410 metric tons in 1988.[9] Inco's 1989 cobalt deliveries, including cobalt contained in alloys and engineered products, were 1,456 metric tons, an 8% decrease from deliveries in 1988.[10]

Sherritt Gordon produced 613 metric tons of cobalt, 34% less than production in 1988.[11] The decrease was attributed to a cutback in production to balance demand for the company's cobalt products and to decreased production as a result of unexpected arsenic impurities in the nickel-cobalt feed. A 10-year feedstock contract between Inco and Sherritt expired at the end of 1989. During 1988 and 1989, Sherritt arranged contracts for feed from the Namew Lake Mine in Manitoba, and the Redstone Mine near Timmins, Ontario. At yearend, the company continued to pursue additional sources of nickel-cobalt feed. In September, Sherritt won the contract for the NDS cobalt upgrading program (see Legislation and Government Programs section of this chapter.)

Geddes Resources Ltd. continued exploration at its Windy Craggy copper-cobalt-gold-silver deposit northwest of Haines, AK, in northwestern British Columbia. According to the company's annual report,[12] the proven and probable reserves at a 1% copper cutoff grade were estimated at 113.8 million metric tons averaging 1.92% copper, 0.08% cobalt, 0.2 gram per ton gold, and 3.7 grams per ton silver. Additional possible reserves were estimated at 51.6 million metric tons averaging 1.82% copper, 0.08% cobalt, 0.2 gram per ton gold, and 4.3 grams per ton silver. Because the reserve estimates did not take into account mining dilution, they were considered "geological reserves" by the company. Metallurgical, engineering, and economic studies were performed in 1989, and an environmental baseline study was submitted to the British Columbia Government. During 1989, Northgate Exploration Ltd. increased its interest in Geddes to 37%, and Cominco Ltd. purchased a 17% interest.

Finland

Outokumpu Oy's production of cobalt products increased 14% in 1989 to 1,295 metric tons contained cobalt.[13] Outokumpu's Keretti Mine in southeastern Finland was closed in May 1989. Since its opening in 1913, an estimated 30 million metric tons of ore had been mined, producing concentrates containing 60,000 metric tons of cobalt.[14]

France

The French Government tendered several 30 to 80 metric ton lots of Government stockpile cobalt during 1989. Gécamines purchased some of the stockpiled cobalt, reportedly to maintain market stability.

Japan

Cobalt metal was one of seven materials included in Japan's rare metals stockpile. The Metal Mining Agency of Japan reported a supply of 51 days in the stockpile at the end of fiscal year 1989 (April 1, 1989 through March 31, 1990), 35.7 days in the Government stockpile, and 15.3 days in the private stockpile. Stockpile goals, to be achieved by March 1992, were 60 days of Japanese consumption, divided into 42 days in the Government stockpile and 18 days in the private stockpile.

Japanese cobalt consumption in 1989 was reported to increase 11% to 2,585 metric tons compared with that of 1988. Cobalt use by industry as compared with that of 1988 was as follows: catalysts increased 35% to 373 metric tons; hard metal tools increased 18% to 302 metric tons; special steels increased 17% to 787 metric tons; tubes, plates, rods, and wire increased 17% to 333 metric tons; magnetic materials decreased 7% to 555 metric tons; and other uses decreased 3% to 235 metric tons.[15]

Norway

Cobalt production at the Falconbridge Nikkelverk refinery was 1,946 metric tons, almost equal to production in 1988 at 1,951 metric tons.[16] Feedstock for the refinery was in the form of matte, mostly from Sudbury in Canada (60%), BCL Ltd. in Botswana (25%), and Noril'sk in the U.S.S.R. (10%).[17] Cobalt from Falconbridge Nikkelverk was to be supplied to the NDS under the cobalt upgrading program (see Legislation and Government Programs section of this chapter.)

Philippines

At yearend, ownership of the Nonoc Mining and Industrial Corp. nickel production facility remained with the Philippine Government's Asset Privatization Trust in spite of attempts to sell at auctions and through negotiations during the year. The facility, located in Surigao del Norte, Nonoc Island, was one of the state-owned mining companies the Government intended to privatize.

South Africa, Republic of

Cobalt was produced as a byproduct of the platinum industry in the Transvaal Province by Rustenburg Platinum Mines Ltd., Impala Platinum Ltd., and Western Platinum Ltd.

The Zinc Corp. of South Africa Ltd. (Zincor) investigated methods of improved cobalt removal during zinc processing. Increased cobalt levels were the result of treating concentrates from Black Mountain. A design and feasibility study for a cobalt recovery plant was completed in 1988. However, no decision was made in 1989 on whether to proceed with building a plant for byproduct production of cobalt.

Zaire

Gécamines was the world's largest cobalt producer, providing more than one-third of the estimated world refinery production. The company's cobalt production decreased 6% from that of 1988. Gécamines stated that it planned to continue producing at levels that will maintain a balance with demand, and intentionally reduced its large inventories during 1988 and 1989.[18] Insufficient overburden removal and ore extraction from the open pit mines had also been reported as a contributing factor toward decreased production.

A comprehensive review of copper and cobalt production in Zaire was published by a former Gécamines engineer.[19] Geology of the deposits and operations at the mines, concentrators, and metallurgical plants were described.

Zambia

Zambian production data for 1985-88 in tables 13 and 14 have been revised based on information from Zambia Consolidated Copper Mines Ltd. (ZCCM) annual reports. The data now represent production during the ZCCM fiscal year (fiscal year 1988 was from April 1, 1988 to March 30, 1989). The content of concentrates in table 13 is derived from reported cobalt content of concentrates, when available, and cobalt content of ore milled and percentage of cobalt recovery to concentrates, for plants not reporting content of concentrates. These figures were formerly estimated from metal production figures assuming a 75% recovery from concentrate to metal.

ZCCM closed its Chambishi cobalt refinery and its Nkana cobalt refinery in Kitwe for a period during May and June for routine maintenance. As a result, cobalt production for that quarter was down 20% to 863 metric tons, as compared with 1,079 metric tons produced during the same quarter in 1988.[20] Production of refined cobalt metal from January through December 1989, as reported by the Mines Development Department of the Zambian Ministry of Mines, was 4,488 metric tons.[21]

The addition of ion exchange columns to the electrolyte circuit of ZCCM's Chambishi cobalt refinery in 1988 was reported.[22] Nickel contents of cobalt metal produced at Chambishi were decreased to about 0.06 to 0.08%.

A preliminary study on the modernization of ZCCM's Nchanga concentrator was undertaken.[23] The focus of the study was on options for replacing the many small flotation cells used in the plant. The study concluded that column flotation was not recommended for the roughing circuit, but could be investigated for the sulfide cleaning circuit. Further investigation for the roughing circuit was to be directed toward the use of large flotation cells.

Zimbabwe

Delta Gold NL, an Australian company, considered mining a portion of the Great Dyke, a 500-km precious metals and chromite deposit that crosscuts Zimbabwe north to south. Minor amounts of cobalt would be contained in nickel-copper matte produced as a byproduct of platinum group metal and gold production. The matte was to be toll refined in Zimbabwe.

CURRENT RESEARCH

The Bureau of Mines received an R&D 100 Award from Research & Development Magazine for a process developed to recover cobalt from copper leach solutions. The ion exchange/solvent extraction/

TABLE 13

COBALT: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons cobalt content)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Albania[e 3]	600	600	600	600	600
Australia[4]	1,134	[r e]1,237	[r e]1,261	[r e]1,200	1,000
Botswana[5]	222	163	181	291	275
Brazil[e]	100	150	150	150	200
Canada[6]	2,067	[r]2,297	2,490	2,398	[7]2,694
Cuba[8]	1,490	1,553	1,566	1,752	2,000
Finland[9]	[r]720	627	190	([10])	[7]—
Morocco[9]	—	—	224	253	[7]121
New Caledonia[e 11]	675	700	750	800	800
Philippines	911	92	—	—	—
South Africa, Republic of[e]	690	690	720	720	730
U.S.S.R.[e]	2,700	2,800	2,800	2,850	2,850
Zaire[9]	29,200	33,373	22,517	25,400	25,000
Zambia[9 12]	6,773	5,869	7,365	7,090	7,000
Zimbabwe[e 13]	[r]92	[r]48	[r]88	[r]104	90
Total	[r]47,374	[r]50,199	40,902	43,608	43,360

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through May 30, 1990. 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 German Democratic Republic, 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: 1985—3,036; 1986—2,914; 1987—2,715; 1988—2,775 (estimated); and 1989—2,375 (estimated).

[5]Reported cobalt content of pelletized nickel-copper matte.

[6]Figures represent total cobalt content of all products derived from ores of Canadian origin, including cobalt oxides shipped to the United Kingdom for further processing and nickel-copper-cobalt mattes shipped to Norway for further processing.

[7]Reported figure.

[8]Determined from reported nickel-cobalt content of granular and powder oxide, oxide sinter, and sulfide production.

[9]Cobalt content of concentrates.

[10]Revised to zero.

[11]Series represents estimated recovery from 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: 1985—5,186 (revised); 1986—5,000; 1987—5,800; 1988—6,000; and 1989—6,000.

[12]Year beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1985—10,539; 1986—8,656; 1987—11,198; 1988—10,687; and 1989—10,000 (estimated).

[13]Estimated cobalt content of ore.

TABLE 14

COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons cobalt content)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Albania: Oxide[e]	—	—	—	r350	500
Brazil: Metal	—	—	—	—	70
Canada: Metal (including metal powder; may include oxide)	r2,070	r2,233	2,505	2,335	32,123
China: Metal[e]	270	270	270	270	270
Finland:					
Metal (including metal powder)	NA	NA	497	229	292
Salts	NA	NA	483	903	1,003
Total	r1,427	r1,348	980	1,132	31,295
France: Chloride (solution)	124	158	136	176	180
Japan: Metal (may include salts)	1,276	1,338	124	109	399
Norway: Metal	1,637	r1,574	1,576	1,951	31,946
South Africa, Republic of:[e]					
Metal (powder)	200	200	200	200	200
Sulfate	300	300	300	320	325
Total	500	500	r500	520	525
U.S.S.R.: Unspecified[e]	4,800	5,300	5,300	5,300	5,300
Zaire: Metal	r10,791	r14,518	11,871	10,026	39,429
Zambia: Metal[4]	4,565	4,160	4,694	4,871	4,500
Zimbabwe: Metal	(5)	(5)	(5)	(5)	—
Total of which:	r27,460	r31,399	27,956	27,040	26,237
Metal[6]	20,809	24,293	21,737	19,991	18,929
Salts[6]	424	458	919	1,749	2,008
Unspecified	6,227	6,648	5,300	5,300	5,300

[e]Estimated. [p]Preliminary. [r]Revised. NA Not available.

[1]Table includes data available through May 30, 1990. 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 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]Revised to zero. Material previously listed under Zimbabwe in this table was a semifinished product that was shipped elsewhere (e.g. to Norway) for refining.

[6]Excludes Finland for 1985 and 1986; included with "Unspecified."

electrowinning process uses feed material currently produced on a large scale and readily available industrial equipment. All process streams are recycled or used for product recovery, minimizing the potential for environmental damage.

The Bureau of Mines researched a continuous flotation process to recover a bulk sulfide concentrate from Missouri lead ore tailings. It was estimated that up to 50% of the cobalt originally present in the ore reports to the tailings during processing for lead and other metals. Reprocessing of these tailings produced a final concentrate containing more than 50% of the cobalt in less than 10% of the original tailings weight.[24]

Results of a study comparing two methods for recovering cobalt, molybdenum, nickel, and tungsten from spent hydroprocessing catalysts were reported by the Bureau of Mines.[25] Both the anhydrous chlorination process and the caustic-acid leaching process appeared to be technically feasible. Preliminary economic evaluation favored the chlorination process.

The Bureau published a study on the separation and recovery of metals from mixed, contaminated superalloy scrap.[26] The objective of the research was to maximize recovery of cobalt and nickel. Of the many methods studied, oxygen pressure leaching of zinc-treated or atomized scrap with hydrochloric acid was preferred. Chlorine gas could be substituted for hydrochloric acid if processing zinc-treated scrap.

The Cobalt Development Institute of Slough, 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

Future trends in cobalt consumption are dependent on the performance of a variety of industries. The largest single use of cobalt is in superalloys, which are used primarily in aircraft turbine engines. Relatively high demand for cobalt in superalloys is expected to continue as a record backlog of orders for commercial aircraft is filled in the next 3 to 5 years.

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, Gécamines and ZCCM, have recently proposed specifications for five grades of cobalt.[27] 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

About 60% of the cobalt used in the United States is consumed as primary cobalt metal. This is either in the form of cathode (electrolytic cobalt or flakes), granules (shot), or metal powder. Secondary cobalt metal, or scrap, constitutes

about 15% of U.S. consumption. Cobalt oxide (about 7% of cobalt consumed) 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. The remainder of the cobalt used is in the form of cobalt chemical compounds. 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

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 1989, Zaire was the world's leading producer of refined cobalt, followed by the U.S.S.R., Zambia, Canada, Norway, and Finland. These six countries represented more than 90% of world cobalt refinery production. Zairian and Zambian production was from domestic ores. The U.S.S.R. and Canada produced cobalt from both domestic and imported raw materials. Cobalt was produced in Norway and Finland from imported raw materials. World producers of refined cobalt and producers of intermediate cobalt-containing products are listed in tables 15 and 16.

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 the platinum industry, cobalt production in most other countries is a byproduct of nickel production.

Operating Factors

Environmental Requirements.—The Environmental Protection Agency regulates releases of cobalt into the environment under various programs. OSHA regulates workplace exposures by setting permissible exposure limits for cobalt metal, dust, and fume; cobalt carbonyl; and cobalt hydrocarbonyl.

TABLE 15

WORLD PRODUCERS OF REFINED COBALT[1]

Country	Company	Cobalt products
Albania	Government-owned	Oxide.
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
	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.
	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 1989.

TABLE 16

WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS[1]

Country	Company	Cobalt-containing products
Australia	Queensland Nickel Pty. Ltd.	Cobalt sulfide.
	Western Mining Corp.	Nickel-cobalt sulfide.
	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.
	Rio Tinto (Zimbabwe) Ltd.	Do.

[1]Companies with production during 1989; excludes companies producing refined cobalt.
[2]Cobalt may not be recovered.

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COLUMBIUM (NIOBIUM) AND TANTALUM

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 10 years of research and commodity experience with the Bureau of Mines, has served as the commodity specialist for columbium and tantalum since 1983. Domestic survey and trade data were prepared by Mss. Cheryl M. Jackson and Robin A. Johnson, mineral data assistants; and columbium and tantalum world production data, by country, were prepared by Mrs. Audrey D. Wilkes, international data coordinator.

The United States remained dependent on imports of columbium and tantalum materials, and the net trade deficit for these minerals was at the highest level since 1981. Most columbium price quotations rose slightly, whereas tantalum concentrate prices declined significantly.

Overall reported consumption of columbium in the form of ferrocolumbium and nickel columbium was down, in line with a decline in steel production and a soft superalloy industry. The overall tantalum industry, which had showed signs of some improvement in recent years, was also down. Factory sales of tantalum capacitors were at the lowest level since 1986. However, much interest was being generated relating to tantalum's use in certain armor-piercing penetrator weapon systems.

Fansteel Inc., a pioneer in and a major domestic processor and producer of tantalum, announced the sale of certain inventory and equipment pertaining to its tantalum product lines.

LEGISLATION AND GOVERNMENT PROGRAMS

Under the offset concept for the National Defense Stockpile (NDS), 57% of the goal for columbium concentrates and 37% of the goal for tantalum minerals were met (table 3). The Report to the Congress on NDS requirements, presented by the Secretary of Defense in April 1989, recommended that goals for the columbium group be increased by 7.67 million pounds of recoverable columbium, that stockpile columbium metal powder and ferrocolumbium be upgraded to 42,000 pounds and 200,000 pounds of high-purity columbium metal, respectively, and that stockpile tantalum metal powder be upgraded to 40,000 pounds of high-purity tantalum metal. The recommendations were based on the U.S. Department of Defense findings concerned with military requirements for strategic and critical materials. Additionally, Defense's planned targets of opportunity for fiscal year 1990 included the purchase of 200,000 pounds of tantalum oxide contained in tantalum minerals and 600,000 pounds of high-purity ferrocolumbium.

STRATEGIC CONSIDERATIONS

Many of the applications for columbium and tantalum are either directly or indirectly defense-related because of their uses in the aerospace, communications, energy, and transportation industries. Thus, both metals are classified as strategic and are part of the NDS.

The high degree of import reliance for columbium and tantalum is a 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 es-

TABLE 1

SALIENT COLUMBIUM STATISTICS

(Thousand pounds of columbium content unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Mine production of columbium-tantalum concentrates	—	—	—	—	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials[e]	2,000	W	W	NA	NA
Production of ferrocolumbium	W	W	W	NA	NA
Consumption of primary products:					
Ferrocolumbium and nickel columbium[e]	5,968	4,995	5,179	5,876	5,409
Exports: Columbium metal, compounds, alloys (gross weight)[e]	120	120	130	120	NA
Imports for consumption:					
Mineral concentrates[e]	1,290	1,320	2,010	1,750	2,680
Columbium metal and columbium-bearing alloys[e]	1	5	42	32	26
Ferrocolumbium[e]	4,699	3,432	4,016	4,238	5,316
Tin slags[e 2]	W	W	W	NA	NA
World: Production of columbium-tantalum concentrates[e]	32,708	32,149	r20,600	r36,961	30,299

[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 2

SALIENT TANTALUM STATISTICS

(Thousand pounds of tantalum content unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Mine production of columbium-tantalum concentrates	—	—	—	—	(1)
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials[e]	1,100	W	W	NA	NA
Exports:					
Tantalum ores and concentrates (gross weight)[2]	122	71	103	214	8
Tantalum metal, compounds, alloys (gross weight)	369	392	413	487	347
Tantalum and tantalum alloy powder (gross weight)	143	160	193	278	211
Imports for consumption:					
Mineral concentrates[e]	230	280	220	400	1,100
Tantalum metal and tantalum-bearing alloys[3]	32	46	60	128	82
Tin slags[e 4]	W	W	W	NA	NA
World: Production of columbium-tantalum concentrates[e]	695	473	r605	r783	828

[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.

TABLE 3

COLUMBIUM AND TANTALUM MATERIALS IN GOVERNMENT INVENTORIES AS OF DECEMBER 31, 1989

(Thousand pounds of columbium or tantalum content)

Material	Stockpile goals	National Defense Stockpile inventory		
		Stockpile-grade	Nonstockpile-grade	Total
Columbium:				
Concentrates	5,600	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 4,850,000 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.

tablished for the NDS. However, inventories for both materials are substantially under set goals. The United States will continue to depend on foreign sources of supply, and present supply patterns are expected to continue. Consequently, a degree of vulnerability exists. Most of the foreign sources are not strategically located for the United States, and some have questionable stability.

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

Unreported quantities of columbium- and tantalum-bearing concentrates were produced and shipped from a mine and milling operation in Rockford, AL. There were three processors of columbium- and tantalum-bearing source materials that were integrated from raw material processing to columbium and tantalum end products. They were Cabot Corp. and Fansteel Inc. 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.

In December, Fansteel, North Chicago, IL, reported the sale of certain inventory and equipment pertaining to its tantalum product lines to NRC, Newton, MA. Fansteel also sold all of its majority stock interest in V Tech-Fansteel Inc., a Japanese producer of tantalum capacitor powder, to Hermann C. Stark Berlin KG. Additionally, operations at Fansteel's columbium and tantalum source material processing plant in Muskogee, OK, were shut down. Fansteel withdrew from the production of tantalum products and elected to use its resources to remodel its specialty metals business to serve markets that offer superior growth opportunities.[1]

CONSUMPTION AND USES

Overall reported consumption of columbium as ferrocolumbium and nickel columbium was down by 8% compared with that of 1988. Consumption of columbium by the steelmaking industry decreased by 7%, affected by a small decrease in raw steel production. There was also a slight decrease in the percentage of columbium usage per ton of steel produced. Demand for columbium in superalloys was down by 14% to the lowest level since 1982. However, that portion used in the form of nickel columbium increased by about 10% to more than 400,000 pounds.

Overall tantalum demand was down as reflected in the 29% decrease in tantalum shipments reported by the Tantalum Producers Association, with shipments declining more than 50% from the peak-year shipments of 1979. However, shipment data for tantalum carbide in 1989 were not available. Industry sources attributed much of the downturn in demand to a weak electronics industry, a buildup in inventories by capacitor manufacturers, and the continuing improvements in the efficiency of tantalum capacitor powders.

Factory sales of tantalum capacitors declined by 20% to the lowest level since 1986, as reported by the Electronic Industries Association. Weak demand for tantalum capacitor products in the automotive and computer components markets contributed to the decline. In April, the Black & Decker Corp. acquired Emhart Corp., including its subsidiary Mallory Capacitor Co. with its tantalum capacitor business. However, Black & Decker reportedly will dispose of several Emhart businesses, including capacitor manufacturing.[2] Sprague Technologies Inc., a major manufacturer of tantalum capacitors, initiated a restructuring plan. This included the company's decision to exit certain unprofitable product lines and to concentrate on its passive component businesses of tantalum and aluminum capacitors, networks, and hybrids.[3]

An application that could increase future domestic tantalum demand is its use in advanced weapon systems. Because of its ductility, density, and physical properties, tantalum was being considered as a substitute for depleted uranium, tungsten, and copper in certain armor-piercing penetrator systems.

PRICES

The Metals Week published price for pyrochlore concentrates produced in Canada, quoted since December 1985 at $2.60 per pound of contained columbium pentoxide (Cb_2O_5), f.o.b. Canada, for concentrates with a nominal content of 57% to 62% Cb_2O_5, was discontinued in February. In June, the published price of regular-grade ferrocolumbium containing 63% to 68% columbium increased from $6.00 to $6.58 per pound of contained columbium, f.o.b. shipping port, where it remained through December.

The Metals Week published price for high-purity ferrocolumbium containing 62% to 68% columbium closed from a range of $16.00 to $17.50 per pound of contained columbium, f.o.b. shipping point, to $17.50 in April, where it remained through December. The published spot price for columbite ore rose from a range of $2.00 to $2.50 per pound of contained Cb_2O_5 and tanta-

TABLE 4

MAJOR DOMESTIC COLUMBIUM AND TANTALUM PROCESSING AND PRODUCING COMPANIES IN 1989

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
Fansteel Inc.[3]	Muskogee, OK	X	X	—	—	X	X	—
Do.[3]	North Chicago, IL	—	X	—	—	—	—	—
Kennametal Inc.	Latrobe, PA	—	—	X	X	—	—	—
NRC Inc.[4]	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] Certain of the company's tantalum inventory and equipment were sold to NRC Inc. in Dec. 1989.
[4] Jointly owned by Bayer U.S.A. Inc. and Hermann C. Starck Berlin KG.

TABLE 5

REPORTED SHIPMENTS OF COLUMBIUM AND TANTALUM MATERIALS

(Pounds of metal content)

Material	1988	1989
Columbium products:		
Compounds, including alloys	995,880	993,575
Metal, including worked products	418,700	465,800
Other	(1)	—
Total	1,414,580	1,459,375
Tantalum products:		
Oxides and salts	16,640	7,260
Alloy additive	76,910	77,890
Carbide	rNA	NA
Powder and anodes	r706,190	448,400
Ingot (unworked consolidated metal)	2,300	1,000
Mill products	345,100	275,200
Scrap	5,300	10,200
Other	—	—
Total	r1,152,440	819,950

rRevised. NA Not available.
[1] Included with "Compounds, including alloys."
Source: Tantalum Producers Association.

TABLE 6

CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF FERROCOLUMBIUM AND NICKEL COLUMBIUM IN THE UNITED STATES

(Pounds of contained columbium [1])

	1988	1989
END USE		
Steel:		
Carbon	2,000,855	1,799,218
Stainless and heat-resisting	909,173	885,486
Full alloy	(2)	(2)
High-strength, low-alloy	1,995,702	1,823,685
Electric	—	—
Tool	(3)	(3)
Unspecified	27,376	64,959
Total	4,933,106	4,573,348
Superalloys	917,716	793,039
Alloys (excluding alloy steels and superalloys)	(4)	(4)
Miscellaneous and unspecified	24,778	42,967
Total consumption	5,875,600	5,409,354
STOCKS		
Dec. 31:		
Consumer	NA	NA
Producer [5]	NA	NA
Total stocks e	NA	NA

eEstimated. 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.

lum pentoxide (Ta_2O_5), c.i.f. U.S. ports, to a range of $3.00 to $3.50 in July, where it remained through December. At yearend, the price for nickel columbium had closed from a range of $17.50 to $19.50 per pound of contained columbium to $19.50, 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 $49 to $51 per pound, fell to $35.00 to $37.50 by midyear, and continued to fall to finish the year at $26 to $28. The Metal Bulletin published price for tantalite fell progressively from $47 to $52 per pound of contained Ta_2O_5 to $29 to $35 by yearend. The Metal Bulletin published price for tantalite produced by Greenbushes Ltd. of Australia, on the basis of 40% contained Ta_2O_5, rose from $47.50 per pound to $50 in February, where it remained through December. A published price for tantalite from the Canadian producer, Tantalum Mining Corp. of Canada Ltd. (TANCO), was not available. Tantalum capacitor-grade powder was reportedly selling in the range of $120 to $130 per pound, and tantalum carbide was reportedly selling at around $80 per pound.

FOREIGN TRADE

On January 1, the United States adopted the tariff schedules nomenclature of the internationally established Harmonized System, as required by the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418). The new nomenclature, TSUS codes, and rates of duty for 1989 are shown in table 10.

Net trade for columbium and tantalum continued at a deficit and was at the highest level since 1981. Overall trade volume and value for imports were up more than 40% and 60%, respectively.

Imports for consumption of columbium concentrates rose by more than 30% to the highest level since 1980. Imports were estimated to contain 2 million pounds of columbium and a small quantity of tantalum at an average grade of approximately 58% Cb_2O_5 and less than 1% Ta_2O_5.

Imports for consumption of tantalum mineral concentrates increased substantially. Imports were estimated to contain 1.1 million pounds of tantalum and 680,000 pounds of columbium at an average grade of approximately 35% Ta_2O_5 and 25% Cb_2O_5.

Imports for consumption of synthetic tantalum-columbium concentrates continued to decline: 170,000 pounds valued at $2.2 million compared with 263,000 pounds valued at $1.5 million in 1988. These figures are not included in the salient statistics data.

WORLD REVIEW

Industry Structure

Brazil and Canada were the major producers of columbium raw materials feedstock, while tantalum raw materials were 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 11 and 12, respectively.

Capacity

The data in table 13 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 operat-

TABLE 7

U.S. FOREIGN TRADE IN COLUMBIUM AND TANTALUM METAL AND ALLOYS, BY CLASS

(Thousand pounds, gross weight, and thousand dollars)

Class	1988		1989		Principal destinations and sources, 1989
	Quantity	Value	Quantity	Value	
EXPORTS[1]					
Tantalum:					
Unwrought and waste and scrap	328	5,260	167	3,412	West Germany 10, $1,831; United Kingdom 11, $605; Canada 10, $385; Japan 4, $315.
Unwrought powders	278	23,758	211	21,451	West Germany 69, $6,581; United Kingdom 36, $4,237; France 36, $4,188; Japan 47, $3,820; Spain 14, $1,684.
Unwrought alloys and metal[2]	NA	NA	11	1,099	West Germany 3, $351; Netherlands 2, $183; Austria ([3]), $164; Canada 2, $150; Japan 1, $91.
Wrought	159	20,076	180	21,715	Japan 56, $8,203; West Germany 23, $4,005; United Kingdom 51, $3,328; France 17, $2,126.
Total	XX	49,094	XX	47,677	West Germany $12,800; Japan $12,400; United Kingdom $8,200; France $6,400.[4]
IMPORTS FOR CONSUMPTION					
Columbium:					
Oxide[5]	e1,200	e6,000	1,454	9,470	Brazil 1,061, $6,279; West Germany 393, $3,191.
Ferrocolumbium[2]	e[6]6,520	e[6]22,424	8,178	28,657	Brazil 8,178, $28,654; Japan ([3]), $3.
Unwrought alloys, metal, and powders[2]	NA	NA	26	514	Brazil 24, $485; Austria 2, $15; West Germany ([3]), $12; United Kingdom ([3]), $2.
Unwrought metal and waste and scrap	11	154	([7])	([7])	—
Unwrought alloys	30	199	([8])	([8])	—
Wrought	2	108	([7])	([7])	—
Tantalum:					
Unwrought waste and scrap	309	10,341	159	7,142	West Germany 87, $5,190; Taiwan 15, $651; France 6, $304; Sweden 5, $272; United Kingdom 10, $265.
Unwrought powders[2]	NA	NA	45	2,880	West Germany 16, $1,434; Japan 10, $591; Australia 10, $515; Canada 7, $202.
Unwrought alloys and metal[2]	NA	NA	35	1,573	Australia 21, $1,017; West Germany 5, $389; Brazil 9, $119.
Unwrought metal	121	7,028	([9])	([9])	—
Unwrought alloys	3	168	([9])	([9])	—
Wrought	5	485	2	431	West Germany 1, $261; Canada 1, $120; Austria ([3]), $20; China ([3]), $12.
Total	XX	46,907	XX	50,667	Brazil $35,500; West Germany $10,500; Australia $1,500.[4]

e Estimated. NA Not available. 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] New tariff category effective Jan. 1, 1989.

[3] Less than 1/2 unit.

[4] Rounded.

[5] New tariff category effective July 1, 1988.

[6] Brazil only.

[7] Data not available, included in nonspecific tariff classification effective Jan. 1, 1989.

[8] Included in "Columbium: Unwrought alloys, metal, and powders" effective Jan. 1, 1989.

[9] Included in "Tantalum: Unwrought alloys and metal" effective Jan. 1, 1989.

Sources: Bureau of the Census and Bureau of Mines.

ing plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Mine capacity for columbium and tantalum is based on published reports, maximum production statistics, and estimates where capacity information is either incomplete or unavailable.

Australia

For its fiscal year, Greenbushes reported that the company's production of tantalite fell short of budget by approximately 30,000 pounds of Ta_2O_5 content with unit cost of production higher than anticipated. Treated ore increased more than 30% to 2.4 million tons, with tantalum oxide produced in tantalite concentrates increasing to 269,100 pounds. The chemical plant, which operated on a one shift basis, produced 32,700 pounds of Ta_2O_5 and 11,800 pounds of Cb_2O_5. Tantalum oxide contained in tantalum glass (slag) production rose by 70% to 82,600 pounds. Greenbushes' tailings retreatment plant was recommissioned, and this operation produced 67,900 pounds of Ta_2O_5 contained in tantalite.

Centamin Ltd., a Perth-based gold producer, reportedly will restart tin and tantalum production at its Moolyella deposit in the Pilbara region of Western Australia in early 1990. The deposit, which was purchased from Endeavour Resources Ltd., had been placed on care and maintenance in recent years. Known reserves reportedly will permit the production of more than 600 tons of tin and more than 60 tons of tantalum in concentrates per year for up to 5 years.

The Pan West tantalum project in Pilbara, Western Australia, jointly owned by Pancontinental Mining Ltd. and Goldrim Mining Australia Ltd., was nearing startup. When fully operational, the Wodgina mine is expected to have a production capacity of about 200,000 pounds of contained Ta_2O_5 in concentrate annually. Pancontinental was reported to have discovered a tantalum deposit at Mount Farmer in the Murchison region of Western Australia. The initial find was estimated to contain minable ore resources of more than 15,000 tons with an average grade of about 0.29% Ta_2O_5. Further exploration at the site was planned. Additionally, drill testing at Caitlin Creek

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF COLUMBIUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1988		1989	
	Gross weight	Value	Gross weight	Value
Brazil	5	14	12	281
Canada	3,665	7,200	4,879	7,368
Hong Kong[1]	53	347	—	—
Total	3,723	7,561	4,891	7,649

[1] Presumably country of transshipment rather than original source.

Sources: Bureau of the Census and Bureau of Mines.

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF TANTALUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1988		1989	
	Gross weight	Value	Gross weight	Value
Australia	34	439	118	2,322
Austria[1]	—	—	1	62
Belgium-Luxembourg[1]	—	—	244	3,036
Bolivia	—	—	3	75
Brazil	169	1,829	244	2,873
Canada	36	455	154	2,429
China	133	1,483	—	—
Germany, Federal Republic of[1]	86	1,190	2,085	26,918
Hong Kong[1]	304	3,603	77	1,279
Japan[1]	—	—	120	1,796
Netherlands[1]	140	936	491	7,417
Singapore[1]	—	—	52	747
Thailand	255	3,425	118	2,073
United Kingdom[1]	199	1,113	29	566
Zaire	54	555	112	1,124
Zimbabwe	—	—	2	43
Total[2]	1,410	15,027	3,850	52,762

[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 Bureau of Mines.

TABLE 10

U.S. IMPORT DUTIES ON COLUMBIUM AND TANTALUM MATERIALS

Item	HTSUS No.	Rate of duty effective Jan. 1, 1989	
		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	Free	Free
Tantalum ores and concentrates	2615.90.6060	Free	Free
Columbium oxide	2825.90.1500	3.7% ad valorem [1 2 3]	25.0% ad valorem
Potassium fluotantalate	2826.90.0000 [4]	3.1% ad valorem [1 5]	Do.
Ferrocolumbium	7202.93.0000	5.0% ad valorem [6 7]	25.0% ad valorem
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] 2.9% ad valorem for products of Canada.
[4] Nonspecific tariff classification.
[5] 2.4% ad valorem for products of Canada.
[6] Free from beneficiary countries under the CBERA and for products of Israel.
[7] 4% ad valorem for products of Canada.
[8] 4.4% ad valorem for products of Canada.
[9] 3.9% ad valorem for products of Canada.

near Ravensthorpe, Western Australia, confirmed ore resources containing about 275,000 pounds of Ta_2O_5. Pancontinental reportedly has an 80% interest in this exploration project.

Brazil

Cia. Brasileira de Metalurgia e Mineração (CBMM) reportedly completed construction of a 40-ton-per-year columbium metal plant at its Araxa complex in Minas Gerais State. CBMM had been producing columbium metal on an experimental basis in a venture with the State-owned Fundacao de Tecnologia Industrial at Lorena, Sao Paulo State.

Paranapanema S.A. Mineração Indústria e Construção, Brazil's largest tin producer, was nearing completion of a plant at its Pitinga tin property in the Amazonas State to produce columbium- and tantalum-bearing concentrates. When construction is completed, the concentrates produced at the plant will be shipped to Paranapanema's processing plant in Sao Paulo State for conversion to columbium and tantalum oxides. Planned annual production at the processing plant reportedly will be about 2 million pounds and

TABLE 11

PRINCIPAL WORLD COLUMBIUM AND TANTALUM RAW MATERIAL PRODUCERS

Country	Company/mine	Material type
MINING OF COLUMBIUM- AND TANTALUM-BEARING ORES		
Australia	Greenbushes Ltd.	Columbium/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).	Do.
	Mineração Catalão de Goiás S.A. (Catalão).	Columbium.
Canada	Cambior/Teck Corp. (Niobec)	Do.
	Tantalum Mining Corp. of Canada (Tanco).	Tantalum.
China	Government-owned	Columbium/tantalum.
U.S.S.R.	do.	Do.
PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING TIN SLAGS		
Australia	Greenbushes Ltd.	
Brazil	Cia. Industrial Fluminense. [1]	
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	Gesellschaft Für Elektrometallurgie MBH (GFE). [1] Hermann C. Starck Berlin KG.	

[1] A wholly owned subsidiary of Metallurg Inc., New York.

TABLE 12

PRINCIPAL WORLD PRODUCERS OF COLUMBIUM AND TANTALUM PRODUCTS

Country	Company	Products[1]
Australia	Greenbushes Ltd.	Cb and Ta oxide/carbide.
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	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	Ta capacitor powder.
	Taiyo Mining & Industrial Co. Ltd.	FeCb.
	V Tech-Fansteel Inc.[3]	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.
	Fansteel Inc.[4]	Cb and Ta oxide/metal, K-salt, 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]	Do.
	Teledyne Wah Chang Albany Div.	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] Fansteel Inc. sold its majority stock interest in the company to Hermann C. Starck Berlin KG in Dec. 1989.
[4] Certain of the company's tantalum inventory and equipment were sold to NRC Inc. in Dec. 1989.
[5] Jointly owned by Bayer U.S.A. Inc. and Hermann C. Starck Berlin KG.

200,000 pounds of columbium and tantalum oxides, respectively.

Canada

As reported by Teck Corp. and Cambior Inc., production of Cb_2O_5 at the Niobec Mine at St. Honoré, Quebec, a 50-50 joint venture, was a record 7.7 million pounds, attributable to additional tonnages milled and a better recovery. Ore milled was 883,000 tons, as the mill operated on the average of 2,418 tons of ore per day. Average recovery was 61% with Cb_2O_5 grade of concentrate at 71%. Yearend ore reserves were virtually unchanged at about 12 million tons assaying 0.65% Cb_2O_5.

India

Sartin, a subsidiary of Saru Smelting of Delhi, commissioned India's first tin smelter near Cuttack in the Orissa State, with plans to provide 10% of the country's tin needs. Sartin reportedly was created to take advantage of Government funding that encourages development of domestic tin deposits by Madhya Pradesh State Mining Corp. Ltd. (MPSM). MPSM's production of tin concentrates had been minimal because the Government had decided that the slags and tin concentrates are strategic materials to be stockpiled and not sold or exported. Tin slags produced by the smelter have a combined columbium and tantalum oxide content of 30%. In 1986, MPSM had planned to build a tantalum treatment plant, but the plan was canceled because of prevailing low tantalum prices.

Japan

Production of ferrocolumbium rose to 812 tons from the 715 tons produced in 1988. Columbium ore imported for ferrocolumbium production fell to about 900 tons, with Canada providing more than 90% of the total. Ferrocolumbium imports rose to 3,957 tons from the 3,704 tons reported in 1988. The bulk of the imports came from Brazil.

Thailand

Renovations of the Thai Pioneer Co. Ltd. tin smelter reportedly were nearing completion with startup of tin production anticipated by yearend. The 4,000-metric-ton-per-year smelter, closed since midyear 1982 because of a lack of feed material and financial difficulties, also produced tantalum-bearing tin slags. The new tin concentrate supply was expected to be secured from tin mine operations in central and northern Thailand.

OUTLOOK

Columbium

Columbium is used principally as an additive in steelmaking, which has accounted for about 80% of the re-

TABLE 13

WORLD COLUMBIUM AND TANTALUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(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	300
World total (may be rounded)[3]	47,000	2,300

[1] Includes capacity at operating facilities as well as facilities on standby basis.
[2] Includes estimated byproduct recovery as tin slag.
[3] Excludes centrally planned economies.

ported 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 outlets for the use of columbium. Thus, future columbium demand growth will continue to be directly related to the worldwide performance of the steel industry. A boost for columbium consumption in steelmaking could be the drastic escalation in price 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 around 15%. Future growth for this end use will be affected mainly by the demand for columbium-containing superalloys from the aircraft industry, which has an up and down cyclical history. The major components of U.S. supply-demand relationships for columbium in 1979–89 are given in table 15.

Tantalum

During the 1980's, more than 60% of the tantalum consumed in the United States was used to produce electronic components, mainly tantalum capacitors, with major markets in recent years being computer and communication systems. However, overall tantalum demand growth in this sector has been slowed 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 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 1979–89 are given in table 16.

BACKGROUND—COLUMBIUM

Columbium and niobium are synonymous names for the chemical element with the 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 has the special property of exhibiting superconductivity, which is the virtual loss of electrical resistance at very low temperatures (about 9° K).

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%.

American Society for Testing and Materials (ASTM) Specification A550 covers three grades of ferrocolumbium, designated as 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, the other main columbium additive, 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 virtually any form and shape. Purity of unalloyed metal is usually more than 99%, with attention mainly given to iron, tantalum, and zirconium as metallic impurities and carbon, oxygen, nitrogen, and hydrogen as interstitial impurities. Alloys with hafnium, tantalum, tungsten, titanium, 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 steels. These high-strength and corrosion resistant steels are used in applications such as high-strength linepipe, structural members, lighter weight components in cars and trucks, and exhaust manifolds. Additionally, 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

TABLE 14

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]				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988	1989	1985	1986	1987	1988	1989
Australia: Columbite-tantalite	242	309	351	498	[5]1,224	50	64	60	70	141	85	109	115	164	263
Brazil:															
Columbite-tantalite	589	604	983	1,371	939	135	139	226	315	216	170	175	285	398	272
Pyrochlore	64,816	63,354	37,657	74,390	57,924	27,223	26,610	15,816	31,244	24,328	—	—	—	—	—
Canada:[e]															
Pyrochlore	10,900	11,500	9,490	[r]11,530	12,000	4,900	5,160	4,270	5,190	5,400	—	—	—	—	—
Tantalite	—	—	—	200	650	—	—	—	8	20	—	—	—	[5]60	[5]160
Malaysia: Columbite-tantalite	168	474	503	—	—	25	71	75	—	—	12	33	35	—	—
Mozambique:															
Microlite	14	[e]13	—	—	—	NA	NA	—	—	—	7	7	—	—	—
Tantalite	9	[e]9	—	—	—	NA	NA	—	—	—	3	3	—	—	—
Namibia: Tantalite	7	18	30	33	31	3	3	3	3	2	1	3	5	5	5
Nigeria:															
Columbite	223	29	106	110	110	90	12	45	46	46	13	2	6	6	6
Tantalite	[e]2	—	—	—	—	([6])	—	—	—	—	1	—	—	—	—
Portugal: Tantalite	4	13	—	—	—	1	3	—	—	—	1	4	—	—	—
Rwanda: Columbite-tantalite	61	—	—	—	—	18	—	—	—	—	13	—	—	—	—
South Africa, Republic of: Columbite-tantalite	([6])	—	([6])	([6])	([6])	([6])	—	([6])	([6])	([6])	([6])	—	([6])	([6])	([6])
Spain: Tantalite	40	[e]26	[e]22	24	24	NA	NA	NA	NA	NA	[5]10	7	6	6	6
Thailand: Columbite-tantalite	952	267	403	273	[5]240	162	46	69	46	41	257	73	109	74	65
Zaire: Columbite-tantalite	324	[e]110	[e]110	66	[5]93	88	30	30	17	24	91	31	31	19	26
Zimbabwe: Columbite-tantalite	88	73	82	146	[5]71	13	11	6	22	11	31	26	13	51	25
Total	78,439	76,799	49,737	88,641	73,306	32,708	32,149	20,600	36,961	30,229	695	473	605	783	828

[e] Estimated. [p] Preliminary. [r] Revised. NA Not available.

[1] Excludes columbium- and tantalum-bearing tin slags. Production of tantalum contained in tin slags was, in thousand pounds: 1985—877; 1986—623 (revised); 1987—543; 1988—1,145; and 1989—799, according to data from the Tantalum-Niobium International Study Center. Table includes data available through June 30, 1990.

[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 Bureau of Mines estimates based, in most part, on 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.

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 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 are quite low in 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 titanium, thorium, 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 17 and

TABLE 15

COLUMBIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand pounds columbium content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	—	(1)	(1)	(1)	—	—	—	—	—	—	(1)
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	8,342	9,728	7,960	[e]4,353	W	W	W	W	W	NA	NA
Industry stocks, Jan. 1	5,459	6,631	8,581	8,332	W	W	W	W	W	NA	NA
Total U.S. supply	13,801	16,359	16,541	12,685	W	W	W	W	W	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	6,631	8,581	8,332	[e]5,971	W	W	W	W	W	NA	NA
Exports[e]	50	171	91	88	78	80	77	72	85	100	90
Government accessions	—	—	—	26	—	—	213	—	—	—	—
Industrial demand	7,120	7,607	8,118	6,600	5,750	7,670	7,550	7,060	7,300	7,900	7,600
U.S. DEMAND PATTERN											
Construction	2,350	2,360	3,166	2,706	2,300	2,920	3,320	3,110	3,140	3,710	3,580
Machinery:											
Metalworking machinery	235	210	284	214	173	230	227	211	200	200	190
Special industry machinery	690	627	853	644	517	614	604	564	610	590	570
Total	925	837	1,137	858	690	844	831	775	810	790	760
Oil and gas industries	997	1,215	1,624	1,122	748	1,070	1,130	920	950	790	760
Transportation	2,278	2,435	1,623	1,518	1,495	1,990	1,890	1,690	1,530	1,740	1,670
Other	570	760	568	396	517	846	379	565	870	870	830
Total U.S. primary demand	7,120	7,607	8,118	6,600	5,750	7,670	7,550	7,060	7,300	7,900	7,600

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

[1] A small unreported quantity was produced.

[2] Includes concentrates, ferrocolumbium, tin slags, and other.

are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination.

Technology

Exploration.—Columbium deposits of economic interest are most likely to be found in alkalic rock complexes and associated carbonatites. Aerial photography and geological mapping can be used to reveal alkalic complexes, which frequently occur with circular geometry and concentric rock arrangement. Test pitting and panning can be used to explore placer deposits for columbium by virtue of the high specific gravity of columbium minerals. The columbium content of samples can be determined rapidly by means of truck-mounted spectrographic equipment and X-ray fluorescence spectroscopy.

Mining.—Pyrochlore has been mined mainly by mechanized open pit, underground stoping methods, or a combination of both. Currently all mining for pyrochlore in Brazil is open pit, whereas in Canada, underground mining is being done via a large-diameter blasthole method. Ore, with host rock, is usually dislodged from a working face with explosives. Beneficiation of the ore, after it has been finely ground, is achieved primarily by various flotation procedures combined with magnetic separation to remove iron minerals. A chloridizing and leaching process can also be employed to lower lead, phosphorus, sulfur, and barium 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 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 ox-

TABLE 16

TANTALUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand pounds tantalum content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	—	([1])	([1])	([1])	—	—	—	—	—	—	([1])
Secondary[e]	51	121	95	89	40	130	90	75	125	130	120
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	1,914	2,280	1,580	[e]1,087	W	W	W	W	W	NA	NA
Industry stocks, Jan. 1	[3]2,948	2,753	3,261	3,452	W	W	W	W	W	NA	NA
Total U.S. supply	4,913	5,154	4,936	4,628	W	W	W	W	W	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	2,753	3,261	3,452	[e]3,195	W	W	W	W	W	NA	NA
Exports[e]	721	706	222	340	262	383	320	312	376	564	470
Government accessions	—	—	—	33	—	—	254	—	—	—	—
Industrial demand	1,439	1,187	1,262	1,060	1,181	1,680	800	820	840	930	820
U.S. DEMAND PATTERN											
Electronic components	950	862	882	703	733	1,052	444	484	504	610	540
Transportation	115	70	102	121	165	218	131	123	126	70	70
Machinery:											
Chemical equipment	127	72	83	69	47	60	48	44	34	30	20
Metalworking machinery	242	152	192	138	189	264	102	112	59	60	50
Total	369	224	275	207	236	324	150	156	93	90	70
Other	5	31	3	29	47	86	75	57	117	160	140
Total demand	1,439	1,187	1,262	1,060	1,181	1,680	800	820	840	930	820
Total U.S. primary demand (industrial demand less secondary)	1,388	1,066	1,167	971	1,141	1,550	710	745	715	800	700

[e] Estimated. [p] Preliminary. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1] A small unreported quantity was produced.
[2] Includes concentrates, tin slag, and other.
[3] New stock series beginning Jan. 1, 1979.

ide through treatment of ferrocolumbium produced from pyrochlore concentrates. This technology is being used to produce commercial quantities of columbium oxide suitable for the manufacture of high-purity ferrocolumbium, nickel columbium, and columbium metal.

In the extraction of columbium from other mineral concentrates and tin slags, modern technology makes use mainly of digestion with hydrofluoric acid followed by liquid-liquid extraction with methyl isobutyl ketone (MIBK). This procedure efficiently recovers both columbium and tantalum in the form of separate streams that then can be further processed individually into oxides and metal. Columbium oxide is precipitated from the columbium stream by ammonia and then purified and calcined.

TABLE 17

WORLD COLUMBIUM RESERVES AND RESERVE BASE, 1989

(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
Centrally planned economies	NA	NA
World total (rounded)[3]	7,800,000	9,300,000

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] Negligible.
[3] Excludes centrally planned economies.

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.

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 18. 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 1989, 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, and the published price for nickel columbium was $19.50 per pound of contained columbium.

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.

TABLE 18

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]	3.75	2.97

[e] Estimated.

It combines readily with other refractory metals such as tungsten and hafnium to form alloys having high-temperature strength and stability. Tantalum forms highly stable anodic films and exhibits a rectifying, or electronic valve, action in an electrolyte. Tantalum is twice as dense as steel with a specific gravity of 16.6.

Definitions, Grades, and Specifications

Metallic forms of tantalum are produced chiefly in unalloyed form or alloyed with up to about 10% tungsten. Unalloyed metal and alloys with tungsten are available as ingot, plate, sheet, strip, bar, rod, wire, and tubing, in accordance with ASTM Specifications B364, B365, and B521. Allowable impurity levels do not exceed 0.3% in most cases; the main impurities are columbium and oxygen, plus tungsten in the case of unalloyed tantalum. Purity of tantalum metal powder is usually about 99.9%. Depending on powder usage, impurities that must be controlled consist mainly of calcium, carbon, columbium, iron, nickel, nitrogen, oxygen, silicon, and sodium. Commercial tantalum carbide usually contains about 93% tantalum and about 6.3% carbon.

Products for Trade and Industry

The major end use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. Applications for tantalum capacitors include computers, communication systems, and instruments and controls for aircraft, missiles, ships, and weapon systems. The tantalum capacitor exhibits reliable performance and combines compactness and high efficiency with good shelflife. Because of its high melting point, good strength at elevated temperatures, and good corrosion resistance, tantalum is combined with cobalt, iron, and nickel to produce superalloys that are employed in aerospace structures and jet engine components. Tantalum carbide, used mostly in mixtures with carbides of such metals as columbium, titanium, and tungsten, is used in cemented-carbide cutting tools, wear-resistant parts, farm tools, and turning and boring tools. Because of its excellent corrosion resistant properties, tantalum mill and fabricated products

are used in the chemical industry in applications such as heat exchangers, evaporators, condensers, pumps, and liners for reactors and tanks.

Geology-Resources

The principal source of tantalum is an isomorphous series of minerals containing columbium, iron, manganese, and tantalum oxides. Tantalum and columbium have strong geochemical affinity and are found together in most rocks and minerals in which they occur. Tantalite-columbite occurs mainly as accessory minerals disseminated in granitic rocks or in pegmatites associated with granites. The microlite-pyrochlore mineral series is also a source of tantalum. These minerals consist essentially of complex oxides of calcium, columbium, sodium, and tantalum in combination with hydroxyl ions and fluorides. Microlite occurs mainly in the albitized zones of granite pegmatites, often associated with tantalite or columbite. Struverite is a low-grade source of tantalum recoverable from tin mining wastes in Southeast Asia. Struverite is a variation of the titanium mineral rutile. Tantalum is also obtained through byproduct recovery from tantalum-bearing tin slags, principally from smelters in Brazil and Southeast Asia.

Reserve and reserve base data for tantalum are shown in table 19 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.—Mining developments generally are small, relatively high-cost intermittent operations that depend on the recovery of byproduct or coproduct minerals for economic viability.

Both alluvial and residual tantalum and tantalum-containing tin deposits are normally mined by hand, by hydraulic monitors, by dredges, or by mechanized open pit mining. The mining of pegmatite deposits, which may be either open pit or underground, is carried out by blasting, transporting, and crushing the rock to free the tantalum and associated coproduct minerals. The materials are then concentrated by wet gravity methods (sluices, jigs, spirals, and tables) and finally separated from associated minerals by gravity and electrostatic and electromagnetic processes.

Tantalum is recovered from slags produced at tin smelters located 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 consoli-

TABLE 19

WORLD TANTALUM RESERVES AND RESERVE BASE, 1989

(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
Centrally planned economies	NA	NA
World total[3]	48,000	76,000

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] Negligible.

[3] Excludes centrally planned economies.

dated 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 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.

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 20. 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 occuring 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 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.

TABLE 20

TIME-PRICE RELATIONSHIPS FOR TANTALUM

Year	Average annual price, dollars per pound of contained columbium 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	27.17
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

[1] 60% basis, combined tantalum and columbium pentoxides.

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.

[1] Fansteel Inc. 1989 Annual Report. 24 pp.

[2] The Black & Decker Corp. 1989 Annual Report. 44 pp.

[3] Sprague Technologies Inc. 1989 Annual Report. 24 pp.

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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 16 years with the Bureau of Mines. She worked as a research geologist with the U.S. Geological Survey and Roan Consolidated Mines, 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 Bureau of Mines, a position she has held since 1983.

Mr. Edelstein is a physical scientist (geologist) with more than 15 years of combined experience working for the Bureau of Mines in minerals processing research, process evaluation, and mineral commodities. He has been a copper commodity specialist for 7 years as well as the specialist for the copper byproduct metals, selenium and tellurium.

Domestic survey data were prepared by Stephen Hayes, Lisa Conley, and Lisa Christian, mineral data assistants, and Imogene Bynum, mineral data supervisor.

World production of copper from primary and secondary sources was higher than in 1988 and nearly in balance with the record 10.9 million metric tons of copper consumed. Copper consumption grew largely owing to increased consumption by the semifabricating plants of Asia and Europe. Copper demand by U.S. wire and brass mills remained at about the same level. Copper mine supply was constrained by disruptions in Africa, Canada, Mexico, and Papua New Guinea. Most of the production gains reflected continued expansions at mines in Chile and the United States. At yearend, visible refined inventories increased slightly to an estimated 634,000 tons, slightly less than 4 weeks of market economy countries (MEC) consumption.[1] The U.S. producers' delivered price averaged $1.31 per pound, which offered considerable profits for most producers, who were benefiting from cost-cutting of the recent past.

With higher prices and funds available for investment, announcements of new projects and intentions to reopen older mines were commonplace. Exploration expenditures for copper were at the highest level in several decades, particularly in Canada, Chile, and the United States. Rationalization of the industry continued with mines and plants changing owners and companies adapting marketing strategies to the changing international flow of copper.

LEGISLATION AND GOVERNMENT PROGRAMS

Copper Study Group

During a negotiation session in Geneva, Switzerland, February 20-24, an agreement was reached on the terms of reference for the formation of an International Copper Study Group. Formation of the study group had been initiated more than 2 years previously by the United States. According to the terms of reference, the organization could come into existence if a sufficient number of countries, accounting for at least 60% of world trade in copper, notified the United Nations Conference on Trade and Development of their intention to join the group by June 30, 1990. However, if the trade represented by those signifying their intent to join fell short of 60%, the interested countries could decide among themselves to inaugurate the study group anyway. The agreement also provided for 3-year temporary or provisional memberships, which allowed interested countries to join without making an initial long-term commitment.

State Legislation

Following months of debate, Nevada State Legislature approved the first mined lands reclamation laws in the State's history. Assembly Bill 958, passed on June 24, gave enforcement responsibility to the Nevada Div. of Environmental Protection and created several funding mechanisms to support administration of the program. One fund would pay the cost of administering the abandoned mines hazard abatement program, which would be the responsibility of the Nevada Department of Minerals. The bill required that the mining industry pay for all of the State's costs associated with administering and enforcing reclamation laws.[2]

The U.S. Supreme Court upheld a lower court ruling that found a 5% cap on royalties paid by companies in Arizona to mine State trust lands deprives the State of its fair share of minerals value. The ruling was expected to result in Arizona passing new mineral leasing laws that would order higher royalty payments for minerals mined on nearly 10 million acres of land granted to the State by the Arizona Enabling Act of 1910.

Montana State Bill 410 was expected to end the longstanding differences of opinion between mining companies and the State Department of Revenue. The bill proposed to increase the gross proceeds and metal mines license tax. Instead of a sliding-scale based on gross value of metals produced, currently ranging from 0.5% to 1.5%, the tax would be raised to a flat 1.8% rate. Mines would no longer pay a separate fee into the Resource Indemnity Trust (RIT) Fund, but a portion of the flat fee would go into the RIT account. Instead of the General Fund getting two-thirds and the Hardrock Trust getting the remainder, the revenue would go 61.5% to the General Fund, 8% to the Hardrock Mining Impact Trust Account, 15.5% to RIT, and 15% to the area of production. The bill reportedly had broad industry support.[3]

Trade Legislation and Actions

In an official exchange of letters with the United States, the Commission of the European Community (EC) agreed not to propose renewal of quotas on the export of scrap and waste of copper and copper alloys. As a result, all quotas and systems of licensing associated with scrap exports expired on December 31, 1989. In return, the United States agreed to end a General Agreement on Trade and Tariff (GATT) grievance that had been filed in response to a November 1988 petition by the U.S.

TABLE 1

SALIENT COPPER STATISTICS

(Metric tons unless otherwise specified)

		1985	1986	1987	1988	1989
United States:						
Ore produced	thousand metric tons	165,190	172,476	202,632	r223,576	237,262
Average yield of copper	percent	0.61	0.60	0.57	0.60	0.62
Primary (new) copper produced:						
From domestic ores, as reported by:						
Mines		1,104,823	1,144,213	r1,243,596	r1,416,928	1,497,458
Value	millions	$1,631	$1,666	$2,262	r$3,764	$4,323
Smelters		939,257	1908,087	1972,141	11,042,954	11,120,445
Percent of world total		11	10	11	12	12
Refineries		1,003,713	r 21,073,981	1,126,908	21,406,020	1,351,748
From foreign ores, matte, etc., as reported by refineries		53,528	W	W	W	125,085
Total new refined, domestic and foreign		1,057,241	r1,073,981	1,126,908	1,406,020	1,476,833
Refined copper from scrap (new and old)		371,787	405,944	414,738	r446,427	476,918
Secondary copper recovered from old scrap only		503,407	477,469	497,937	r518,179	543,596
Exports:						
Refined		37,937	12,452	9,197	58,325	130,189
Unmanufactured[3]		435,000	442,000	387,000	557,000	721,000
Imports for consumption:						
Refined		377,725	501,984	469,159	331,671	300,110
Unmanufactured[3]		443,932	697,523	568,448	511,360	515,000
Stocks, Dec. 31: Total industry and COMEX:						
Refined		320,000	r224,000	r112,000	98,000	106,000
Blister and materials in solution		146,000	r136,000	150,000	r121,000	132,000
Consumption:						
Refined copper (reported)		1,976,038	2,102,625	2,125,699	r2,210,424	2,203,143
Apparent consumption, primary and old copper (old scrap only)		2,144,436	r2,136,982	2,196,807	r2,211,545	2,182,349
Price: Weighted average, cathode, cents per pound, producers		66.97	66.05	82.50	120.51	130.95
World:						
Production:						
Mine	thousand metric tons	r7,988	r7,993	8,306	p8,537	e8,887
Smelter	do.	r8,630	r8,816	8,923	p9,285	e9,535
Refineries	do.	r9,408	r9,602	9,833	p10,332	e10,727
Price: London, Grade A, average cents per pound[4]		64.27	62.28	80.88	117.92	129.15

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

1Includes production from foreign ores and concentrates.

2Includes primary copper produced from foreign ores, matte, etc., to avoid disclosing company proprietary data.

3Includes copper content of alloy scrap. Export and 1989 import copper content of alloy scrap were estimated from gross weight.

4High-grade prior to 1988.

Copper and Brass Fabricators Council (CBFC). The CBFC charged that the EC scrap quotas were a violation of GATT and were having adverse impacts on domestic producers.

In response to an industry petition by the Non-Ferrous Metals Producers Committee, the U.S. Trade Representative, and the Department of Commerce in a joint decision, determined that both the primary copper and lead industries should be identified under Section 409(b) of the 1988 U.S.-Canadian Free Trade Agreement Act of 1988. In the decision, it was found that these industries may face increased imports of subsidized copper and lead products from Canada once tariffs were lowered according to the Free Trade Agreement, and that deterioration of the competitive position could occur. Based on 409(b) identification, the industry could ask for assistance under the trade laws.

ISSUES

Mine and Plant Labor

Productivity at all mines that produced copper as a principal product was 19.6

worker-hours per ton of recoverable copper produced by open pit, underground, and leach methods. Average productivity, including mine, mill, and leach operations was 41 worker-hours per ton for five operating underground mines and 17.7 worker-hours per ton of recoverable copper for 15 open pit mines. Total workers at U.S. mines and mills averaged 12,400 in 1989. Arizona (8,514 workers) led in average number of mine and mill workers, followed by New Mexico (1,487 workers) and Utah (1,084 workers).

The number of union members in the U.S. nonferrous metals industry, including the copper industry, decreased in recent years. The ties of workers to unions were weakened by frequent mine closings, wage concessions, and effects of a poor economy over long periods of time. When mines were acquired by new owners, such as at the Sierrita Mine in Arizona and the Continental East Mine in Montana, new working systems were set up with the workers opting not to reinitiate union rules. Job classifications at both mines were reduced from several hundred to fewer than 15, and workers were offered raises for learning multiple jobs. Small group seminars emphasized healthy working relationships, and at regular meetings, managers sought employee advice. At many mines, management layers were streamlined and managers became multidisciplined, as did workers.[4] At some mines, employees participated in profit-sharing plans, such as at Montana Resources Inc.'s Continental East Mine, where it amounted to 10% of pretax net profits. Otherwise, a unified salary rate of $9.73 per hour (about $20,000 per year) prevailed for the Continental East workers.

In May, workers at the Troy Mine, MT, voted not to accept the United Mine Workers of America (UMWA) as their collective bargaining agent. The UMWA won certification in 1987, but efforts to negotiate a contract with ASARCO Incorporated failed. Late in 1988, an employee group mounted a petition calling for a new election and Asarco withdrew its recognition of the union and stopped contract talks. The National Labor Relations Board ruled against UMWA charges that Asarco unlawfully withdrew union recognition.

Labor contracts with Magma Copper Co. and Asarco were set to expire July 1, 1989, but both were replaced with new agreements that increased base wages and various benefit plans. Asarco and the United Steel Workers union settled on a new 3-year contract covering 1,600 employees that included wage increases of $1.85 per hour over 3 years; an increase in pension payments of $4.00 per month for each year of service; and additional death and dismemberment insurance. Although the wages were slightly higher than before the pay was slashed in 1986, the cost-of-living clause in the contract remained suspended. Magma agreed to increase the weighted average base wage for 3,100 hourly employees by $1.00 per hour in the first year and 25 cents in the second and third years. A premium of 0.6% was to be added to base wages as copper prices varied in 5 cent increments above 95 cents per pound, capping at $1.70 per pound.

Although statistics show that many metal companies were tying employee wages to incentive bonuses as a means of rewarding higher production when profits were high and limiting costs during slow periods, some copper producers reportedly seemed to be reluctant to institute such plans.[5] It was estimated that 75% of all gainsharing plans in the U.S. mining industry had been installed in the past 5 years. A variety of factors was used to calculate bonuses. Production was most often used in determining bonus size, but safety, ore grade, development advance, cost savings, profits, commodity price, and housekeeping were also used. Penalties were commonly included to encourage safety. Magma arranged to give its employees bonuses linked to copper prices and established production targets; even so, the company eventually found this plan placed Magma in the position of being among the highest cost of U.S. producers.

Magma and labor unions attempted to resolve disputes concerning interpretation of the bonus rules that were part of the 1986 contract. In 1986, the unions had accepted large cuts in wages and benefits in exchange for certain productivity-based bonuses. Although Magma insisted that the production requirement only related to production arising from Magma's own operation, the union contended that ore processed by Magma for Cyprus Minerals Co. should have been included in the calculations for fulfilling production quotas. The bonuses were linked to the copper price and meeting 80% of Magma's production quotas. Magma announced that it would not pay fourth quarter 1988 and second quarter 1989 bonuses to its unionized workers because production and sales quotas under the plan were not met. An independent arbitrator ruled in favor of the company and determined that no bonus was due for the fourth quarter of 1988; arbitration of the 1989 bonus had not been settled.

Bonuses averaging $1,500 per person were paid in December 1989 to about 680 hourly employees at Cyprus Miami Mining Corp.'s copper operations. The bonuses were about equal to those paid in May 1989. The December bonuses were in recognition of achieving a record-breaking year in 1989. Cyprus Minerals announced that as of January 1, 1990, Cyprus Miami employees with at least 20 years of service would receive an additional week of vacation. Cyprus Miami had a total of about 1,020 workers.[6]

Cost of Production

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 increased slightly to about 54 cents per pound in 1989, according to Bureau of Mines Minerals Availability System estimates. Including recovery of capital, the average production cost was 60 cents per pound.

Asarco reported that the cost to produce copper was higher in 1989 compared with that of 1988.[7] Startup difficulties with its new milling and concentrating facilities at the Mission complex in Arizona resulted in reduced production and higher costs. Production rates at the Hayden, AZ, smelter also did not meet expectations, thereby increasing costs.

Cyprus Minerals reported that inflation, especially in mining and processing costs, and increased costs and taxes resulting from Federal and State legislation and regulation, were making cost reduction more difficult.[8] The company planned major capital investments for plant and equipment modernization in 1990 to increase operation efficiency. Cyprus' mine production costs, including depreciation, averaged 68 cents per pound for the year, compared with 65 cents in 1988, according to the company annual report. The increase in 1989 was caused partly by price sensitive costs, such as employee incentive compensation plans and service costs associated with acquisitions, and partly by Cyprus' efforts to maximize production during the year. Average mine production costs reached a high of 76 cents per pound during the fourth quarter as a result of reduced recoveries at Twin Buttes Mine. Milling difficulties resulted from blending ores from four pits. Not only did the mill

TABLE 2

PRODUCTIVITY[1] IN THE U.S. COPPER INDUSTRY, BY ACTIVITY

		1985	1986	1987[r]	1988[r]	1989
COPPER MINE PRODUCTION						
Ore concentrated and leached	metric tons	165,190,000	172,476,000	202,632,000	223,576,000	237,262,000
Copper recovered	do.	1,003,990	1,041,520	1,154,181	1,341,279	1,438,267
Average yield of copper	percent	0.61	0.60	0.57	0.60	0.62
Copper from in situ leach	metric tons	82,948	79,031	70,136	49,299	34,485
Total production[2]	do.	1,086,938	1,120,551	1,224,317	1,390,578	1,472,752
MINE AND SX-EW PLANT LABOR						
Average annual workers[3]		9,854	10,154	11,924	11,873	12,421
Employee-hours worked		18,831,046	20,326,091	23,197,110	25,707,013	29,371,885
PRODUCTIVITY AT MINES						
(hours per ton)		17.32	18.14	18.95	18.49	19.94
REFINED COPPER PRODUCTION						
Electrolytic copper	metric tons	1,231,612	1,241,309	1,276,933	1,525,470	1,541,542
PRODUCTIVITY AT PLANTS[4]						
(hours per ton)		9.15	10.27	9.48	8.19	8.17
INDUSTRY PRODUCTIVITY						
(hours per ton)		26.47	28.41	28.43	26.68	28.11

[r]Revised.

[1]Employee hours per metric ton mined and processed.

[2]Production from byproduct mines not included.

[3]Includes mine, mill, SX-EW 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 also included. Mines producing copper as a byproduct are not included.

[4]Bureau of Mines estimates based on unpublished Dept. of Labor data.

Sources: U.S. Department of Labor and Mine Safety and Health Administration. Bureau of Mines, production statistics.

recovery fall and costs rise, but more importantly, they were not able to produce copper for sale when prices were high. Recoveries at Miami were reduced because of mining in an area that contained a lower grade of oxide ore.

Cyprus Minerals also faced increased electricity costs at two of its operations. In a hearing held by the Arizona Corporation Commission, Cyprus Sierrita protested the full rate increase that Tucson Electric Power was seeking. The rate increase would cost the company an additional $7 million per year. It took 19 kilowatt hours of electricity to grind 1 ton of ore, and the mine processed about 30 million tons of ore annually. In addition, Cyprus Miami faced increased electricity charges from the Salt River Project with which the company had a long-term contract. The Salt River Project board voted in July to increase Cyprus Miami's fuel cost adjustment factor, causing it to increase by $285,000 per month. The fuel cost adjustment factor rose or fell with the price of fuel. The electrical contract was negotiated before Inspiration built the electric furnace at its smelter to comply with air quality standards.[9]

At Magma, costs were above budget as a result of mining lower grade ore to take advantage of the higher copper prices and an expanded development program. The company restarted limited development of the Kalamazoo ("K") ore body, which would extend the life of the mine, increase extraction tonnage, and improve overall mining costs. The new column cell technology used at the San Manuel concentrator proved cost effective, reducing energy and maintenance costs by 9.5% over the year. Cost efficiency was further improved through complete reinstrumentation of the concentrator for better process control.[10]

Phelps Dodge Corp. completed a $48 million in-pit crushing and conveying project at Morenci, AZ, which significantly reduced haulage costs in the pit. Expansions to the Morenci ($44 million) and Tyrone ($20.5 million) solvent-extraction and electrowinning (SX-EW) plants were also completed during the year. Costs at these plants were reported to be less than 30 cents per pound of copper. The corporation's average production costs for copper in 1989 were reported to be marginally higher than those of 1988 largely because of increased supply costs, total material mined, depreciation, and costs that derived principally from increased capital expenditures.[11]

At the White Pine Mine, MI, gains in efficiency were achieved through a 29% reduction in the work force over that of 1981 levels. As productivity increased, production costs dropped from a 2-year average in the early 1980's of 99 cents per pound, to 62 cents per pound mined and processed, before silver byproduct credits. Meanwhile, the ore grade dropped from 1.46% in 1979 to about 1.1% in 1989. Company efforts focused on modernizing equipment and mining methods. Over the next few years, about $5 million per year was to be provided annually for new underground equipment. New cost targets were set at or below 60 cents per pound.

Industry Restructuring, Investments, and Earnings

U.S. copper mining companies continued to report record profits during the year. Ownership changes and company restructuring continued. With more money

TABLE 3

ESTIMATED PRODUCTION COSTS AT PRODUCING COPPER MINES[1]

(January 1989 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	$0.34	$0.15	$0.20	$0.17	$0.51	—	$0.51	$0.09	$0.60
Canada[7]	17	.33	.30	.37	.63	.36	—	.37	.13	.52
Chile	7	.17	.18	.09	.06	.37	$0.01	.38	.05	.43
Peru	5	.23	.25	.25	.07	.65	.02	.67	.14	.81
Philippines	7	.32	.40	.26	.42	.56	.04	.60	.10	.71
United States	17	.17	.28	.18	.11	.52	.01	.54	.06	.60
Zaire	4	.27	.14	.25	.29	.37	.01	.38	.03	.41
Zambia	9	.44	.38	.31	.09	1.04	.11	1.14	.07	1.22
Other	40	.30	.29	.30	.36	.53	.01	.55	.21	.76
Total or average	109	.25	.26	.23	.23	.51	.02	.53	.11	.63
Life-of-the-mine production costs:[8]										
Australia	3	$0.55	$0.26	$0.25	$0.40	$0.66	—	$0.66	$0.09	$0.75
Canada[7]	17	.30	.28	.33	.51	.40	—	.40	.13	.53
Chile	7	.19	.24	.08	.06	.46	$0.01	.47	.05	.52
Peru	5	.18	.26	.33	.21	.56	.01	.57	.14	.71
Philippines	7	.26	.34	.26	.24	.63	.03	.66	.10	.77
United States	17	.17	.27	.18	.09	.53	.01	.54	.06	.60
Zaire	4	.27	.14	.22	.22	.40	.01	.41	.03	.45
Zambia	9	.49	.37	.31	.09	1.08	.11	1.18	.07	1.25
Other	40	.31	.38	.30	.38	.60	.02	.62	.20	.82
Total or average	109	.25	.28	.20	.19	.54	.02	.56	.09	.65

[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 grades for 1989.
[7]Includes INCO's and Falconbridge's Sudbury nickel-copper operations.
[8]Based on life-of-the-mine production rates and ore grades. Does not necessarily reflect 1989 operating grade and production.

Source: Bureau of Mines, Minerals Availability System (MAS) cost analysis. Prepared by Kenneth Porter.

available, interests shifted toward reinvestment, expansion, opening of closed mines, and renewed exploration efforts. Phelps Dodge, the largest producer, reported a net income of $267 million, including a write-down in the fourth quarter of certain nonproducing assets. The assessed valuation of operating copper mines in Arizona reportedly increased 43% compared with 1988, to more than $860 million.[12]

Asarco reported an operating income of $206 million from the sales of copper. Over the past 4 years, Asarco concentrated on acquisition and ore reserve development to shift from being a custom smelter and refiner for others to being a fully integrated producer. In 1989, the company announced a $270 million project to expand production at Mission and Ray Mines by 40% with financing to come from company funds. Asarco acquired a 49.9% interest in Montana Resources Inc., a partnership that owned and operated the Continental East Mine in Montana, for $100 million and purchased the Pima, AZ, mill for about $6 million. Asarco also acquired a significant share in Mexicana de Cobre S.A. through its 34% share of Mexico Desarrollo Industrial Minero S.A. de C.V. (MEDIMSA). MEDIMSA acquired Mexicana de Cobre for $1.36 billion.

In May, Metall Mining Corp. of Toronto purchased the Copper Range Co. for $83 million. Each of the 1,000 workers received about $65,000 for their shares in the company. In addition, each employee will gain an additional $18 per share if the mine meets the 5-year production and efficiency goals set by Metall. It was announced that the Copper Range name, which originated in 1899, would be retained to preserve the historical significance of the company. Copper Range became the first wholly owned mining operation of Metall, which also held minority interests in several Canadian and Papua New Guinea operations. Metall Mining's parent company, Metallgesellschaft AG, based in the Federal Republic of Germany, retained a 62% interest in the Toronto company.

Cyprus Mineral's record earnings of $250 million after taxes was more than the combined earnings of the past 3 years, largely as a result of increased copper production and higher prices. Since the July 1985 spinoff from Amoco Minerals Co., Cyprus had made more than 20 acquisi-

tions, including coal, copper, lithium, molybdenum, talc, and silver mines. Early in 1989, Cyprus acquired the Warrenton Refining Co., a Missouri producer of copper ingot and wirebar from scrap. By yearend, Cyprus had made arrangements to purchase MCR Product Co.'s copper rod mill in Chicago, IL.

Rio Tinto Zinc (RTZ) Corp. completed its acquisition of British Petroleum PLC's (BP) minerals group for $3.6 billion on June 30, 1989. The name Kennecott Corp. was restored as the official title of the properties. The primary asset of Kennecott was its Utah Copper Corp. Bingham Canyon Copper mine, smelter, and refinery in Utah. In 1989, Kennecott's expenditures were $200 million, of which $76 million was spent at Utah Copper. Plans for a second $227 million construction project at Bingham Canyon were announced. Construction was to begin in June 1990, with completion scheduled for the last half of 1992.

Magma had a record net income of $58.5 million. Earnings were stronger because of lower labor costs and higher copper prices. Magma's earnings included a $3.5 million pretax write-down of assets in the fourth quarter, related to the closure of the company's MCR Products' rod casting facility in Chicago, IL. A change in sales strategy toward increased cathode sales resulted in just 53% of Magma's 1989 production being sold as rod, compared with 93% in 1988. Of equal importance was the change in arrangements for procuring smelter feedstock, which now would include increased toll and purchased concentrates. The company was restructured into four operating divisions: the San Manuel Mining Div., Pinto Valley Mining Div., Superior Mining Div., and the Smelting and Refining Div.

Plexus Resource Corp., in a property exchange with Cyprus Minerals acquired the rights to the Bornite Project, a copper-gold-silver property about 45 miles east of Salem, OR. Cyprus acquired the rights to develop the Lyon property in Nevada, as well as a 2% share of the net proceeds from Bornite. Rio Gold Mining Ltd., a Canadian company, acquired the Hillsboro-Copper Flat Mine in New Mexico from Inspiration Development Co., the owner, and from Cobb Resources Inc., the lessee.

Mine Environmental Issues

Several sites in Montana continued to be the focus of environmental concern during the year. The Montana Water Quality Bureau received a report about high concentrations of metals in water from seepage at a tailings impoundment site at Asarco's mine near Troy. A local environmental group reported an average of 0.0036% copper in water at several sites.[13] Atlantic Richfield Co. (ARCO) filed a motion in the U.S. District Court protesting the limitless cost responsibility for cleaning mine and smelter wastes located between Butte and Milltown Dam, just east of Missoula. ARCO wanted the court to dismiss a Federal lawsuit filed last June by the Environmental Protection Agency (EPA) to recover $6.3 million spent replacing the arsenic-polluted water supply at Milltown, relocating families at Mill Creek, and demolishing the Anaconda Smelter. ARCO reportedly had spent about $20 million in reclamation costs in Montana, mostly in the Butte area. The 6-year, $25 million cleanup of the site, which stretched from Silver Bow Creek in Butte to Milltown Reservoir near Missoula, was considered to be the country's largest and among the most controversial of the Superfund cleanup efforts.

Late in the year, Cyprus protested the proposed inclusion of two tracts, the Upper and Lower Burro Creek, into the Arizona wilderness system. Withdrawal of these two areas from development would have a significant impact on its $24 million expansion project and drastically reduce the Bagdad Mine's projected 30-year life. The New Mexico State Environmental Improvement Div. approved the Cyprus plan, estimated to cost $1 million, for revamping and reopening the Deming concentrator. Originally built as a custom concentrator for small regional mines, the plant also treated lead-zinc ores from the old Groundhog Mine. The plant was to be used for processing Pinos Altos ores.[14] According to the company annual report, Cyprus spent more than $28 million on environmental protection measures in 1989.

The U.S. Forest Service awarded a $3.1 million contract to a Port Angeles, WA, firm for cleanup of 8 million tons of tailings at Holden, WA. The tailings covered a large part of the valley near Holden Village, about 12 miles above Lake Chelan. The Holden Mine, the only major copper producer in Washington at the time, closed in late 1956 because of poor markets.

Smelter Environmental Issues

According to the company annual report, Asarco received notice from EPA that it and numerous other parties were responsible, under CERCLA, for correction of hazardous substance releases at the following locations on the dates indicated: The Commencement Bay area in Tacoma, WA (1982); Pitcher Mining Field in Oklahoma (1982); YAK drainage tunnel in Leadville, CO (1983); the Tacoma Smelter site (1984); southeastern Cherokee Co. in Kansas (1985); the East Helena Smelter (1987); and the Ruston, WA, area (1988). In 1987, part of an Asarco subsidiary's (Federated Metals Co.) former scrap processing plant in Houston was listed on the Texas Superfund Registry. Asarco was also involved in litigation under CERCLA and State law involving alleged hazardous substance releases at the company's former Perth Amboy, NJ, smelter site and at its Globe Plant in Denver, CO. Asarco had established financial reserves for these programs, spending $13.4 million in 1989, $13.7 million in 1988, and $19.2 million in 1987 on environmental compliance. Asarco had spent more than $12 million to clean up the Tacoma, WA, smelter since it closed in 1985. The demolition of the 565-foot-tall stack was expected to cost about $3 million. Because of the contaminants, EPA had declared the smelter site a Federal Superfund Site for cleanup, one of 36 in the Pacific Northwest.

PRODUCTION

Mine Production and Reserves

Copper was mined in 13 States during 1989, with Arizona maintaining its lead with 60% of the total, followed by New Mexico and Utah. There were 68 copper-producing mines, up from 65 mines in 1988. Of these, 22 were copper mines, and 46 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 1.79 million tons in 1989, compared with 1.62 million tons in 1988. The increase was largely the result of improvements at operating mines, although some new mines were brought on-stream during the year. Annual SX-EW capacity was expanded by about 50,000 tons to 358,000 tons and by 1992 was expected to reach 434,000 tons. Some companies' reserves were reevaluated in light of higher copper prices, and the mill-head grade decreased at some mines as lower graded ore became economic to mine.

As a result of sustained higher copper prices, interest was being shown in reopening several long-closed U.S. copper mines. Among those planned for production were the Centennial No. 6 Mine near Kearsarge, MI; the Continental and Copper Flat Mines in New Mexico; an SX-EW project at the Yerrington Mine in Nevada; several small mines near Butte, MT; and the Superior Mine, the Oracle Ridge copper-silver property, the Johnson Camp Mine, and the Emerald Isle Project, all in Arizona. A tentative agreement was reached for the restart of the Arbiter electrowinning plant in Montana. Anaconda Enviro-Refining Co. planned to convert copper and other metal concentrates into finished metals at the Arbiter plant.

Cyprus signed a letter of intent with Sharon Steel Corp. in August to consider a joint venture at the Continental Mine in New Mexico after it had completed evaluating the geology, assets, and accounts. Production would be limited to the open pit mine at first, which had a 4,500-ton-per-day concentrator. The underground mine and its 2,700-ton-per-day concentrator would not be operated. In addition, the nearby Hanover Mountain deposit was reported to have reserves of 9 million tons of mixed oxide and sulfide mineralization that averaged 0.63% copper. Portions of this property reportedly could be used for leaching and SX-EW recovery.[15]

Magma approved a plan for the rehabilitation of the Superior Mine, AZ, which closed in 1982 because of low copper prices. Expenditures for this project were expected to be $12 million, with production at the rate of 12,700 tons per year scheduled for late 1990. The mine life was estimated to be about 8 years. The mine was about 1 mile deep and had been flooded to about 3,000 feet. In addition, two promising vein structures to the south of the present workings were being explored. The new project would require a new shaft and concentrator. In 1989, Magma resumed development of a small part of the Kalamazoo ore body, which had been suspended during the fourth quarter of 1988. The company planned to mine at the 2,950-foot level using high-performance work teams for cost reduction. Ore production from this section of the mine was expected to begin in the third quarter of 1990.

Rio Gold Mining Ltd., a new company from British Columbia with headquarters in Denver, CO, announced intention of reopening the Copper Flat Mine, NM, which closed in 1982; and the mill was dismantled and sold. Once financing of the $37 million project was secured, the mine was expected to be commissioned within 1 year. Production was expected to be about 18,000 tons of copper, 12,000 ounces of gold, 300,000 ounces of silver, and 386 tons of molybdenum per year. At a cutoff grade of 0.25% copper, a minable reserve of 48 million tons averaging 0.45% copper was reported.

An $8 million loan with Chemical Bank of New York was approved for Michcan to reopen the Centennial No. 6 Mine in Michigan. Michcan, a group of investors that included Peninsula Copper Industries (PCI) of Hubbell, MI, also received a $350,000 loan to assist in dewatering the 5,000-foot mine shaft. PCI produced copper oxide, which was used in wood preservatives and automobile safety airbag propellants. The 4,000 tons per year production from the Centennial Mine would be used for copper oxide production. Copper oxide production was to be expanded from 8 to 11.5 million pounds annually. PCI held 29.5% of Michcan, with American Chemet Inc. and a New York investment group holding the rest.

In addition to reopening older mines, increased interest also was shown in exploration for and development of new projects. Exploration expenditures were increased by Phelps Dodge, which reported spending $50 million on exploration, advanced mine evaluations, research, and development. Nearly 80% of the 1989 exploration expenditures were in the United States with emphasis on copper, mixed base metal sulfides, and precious metals. In addition to its acquisitions program, Cyprus also expanded its exploration efforts in 1989 to include copper with funds increased to $15.2 million, up $7 million over that of 1987. Exploration efforts were conducted in Australia, Canada, Chile, Mexico, New Zealand, and the United States. Cyprus Northshore Mining Corp. was exploring the former Minnamax copper-nickel property adjacent to its Babbit taconite mine. The property was partially developed in the 1970's by Amax Inc. with shaft sinking and underground work.

Chevron Minerals Co. was reported to have sold the Bald Mountain Mine in Maine to Boliden International Mining. Ore reserves at Bald Mountain were sufficient to support a 15-year mining operation. Two mining companies, Crown Butte Mines Inc. and Noranda Minerals Corp. reportedly were considering the development of a copper and gold mine located 2 miles north of Yellowstone Park. Sunshine Mining and Noranda sought $150 million to further finance exploration and development of the Montanore, MT, property, which was expected to be in production by 1992. Western World Mining Co. had petitioned the planning commission of Yuba County, CA, for a permit to operate a copper mine in Big Oak Valley. Mine plans called for the open pit removal of 1.4 million tons of copper-zinc ore, averaging 2% copper, over a 6-year period. However, local public opposition prevented the permit from being granted. The project had been started in 1971 by Superior Oil Co. Plexus Resource Corp. planned to expedite development of the Bornite Project, OR. The deposit was estimated to contain 2.54 million tons of ore grading 2.49% copper in a bornite-rich breccia pipe, extending to a depth of 800 feet.

RTZ indicated that development of Kennecott's North Ore Shoot Extension in Utah could begin in 1990. The deposit contained a minable reserve of 11.2 million tons of ore grading 2.9% copper within a resource of 118.5 million tons of ore. Production at the annual rate of 25,000 tons of copper and 31,000 ounces of gold could begin as early as 1993. The company's Flambeau deposit in Wisconsin was scheduled to commence production in 1992.

Expansions at established operating mines also continued during the year. Asarco announced a 3-year expansion program to improve its mining, milling, and smelting capacity. At the Ray Mine, about $130 million would be spent to install an in-pit crusher and new mill and concentrator. An 18-mile pipeline was to be built to pump slurry from the new mill to tailings ponds. Asarco estimated that output at Ray would be boosted by about 20,000 tons of ore per day. The entire plan would boost Ray Mine output by 37,000 tons of copper per year. The Pima mill and concentrator would be reopened and refurbished for about $94 million.

Cyprus reported total copper production of about 270,000 tons in 1989.[16] With a $21 million expansion at the Bagdad Mine, the company production target was 295,000 tons in 1990. Bagdad was to be expanded by 10% to 104,000 tons of copper in concentrate per year by adding a fifth grinding line. Cyprus' ore reserves (table 4) were based on a long-term copper price projection of 75 cents per pound and reevaluation of Bagdad ores. This was offset in part by the reclassification of Twin Butte's reserves from copper to cooper-molybdenum reserves, according to the company annual report.

TABLE 4

MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1989

Company and deposit	Percent company ownership	1989			Company share, thousand tons copper	Deposit and company percent of grand total
		Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)		
Cyprus Minerals Co.[1]						
Copper deposits	100.0	891,853	0.44	3,924	3,924	11.0
Copper-molybdenum deposits	100.0	504,123	.34	1,714	1,714	4.8
Total reserves		1,395,976	.40	5,638	5,638	15.8
ASARCO Incorporated[2]						
Copper deposits:						
Mission Complex, AZ	100.0	302,060	.67	2,024	2,024	5.7
Ray, AZ	100.0	582,458	.69	4,019	4,019	11.3
Silver Bell, AZ	100.0	91,938	.47	432	432	1.2
Continental, MT	49.9	380,972	.28	1,067	532	1.5
Total copper deposits		1,357,428	.56	7,542	7,007	19.6
Byproduct deposits:						
Coeur, ID	50.0	339	.83	3	2	([3])
Galena, ID	37.5	1,067	.54	6	2	([3])
Troy, MT	75.0	21,334	.70	149	112	0.3
Leadville, CO	50.0	709	.18	1	1	([3])
West Fork, MO	100.0	8,303	.04	3	3	([3])
Total byproduct deposits		31,752	.51	162	119	.3
Total reserves		1,389,180	.55	7,704	7,126	19.9
Phelps Dodge Corp.[4]						
Morenci, AZ	85.0	641,540	.79	5,068	4,308	12.1
Chino, NM	66.7	294,011	.70	2,058	1,372	3.8
Tyrone, NM	100.0	49,804	.73	364	364	1.0
Burro Chief, NM, leach[e]	100.0	217,724	.35	762	762	2.1
Total reserves		1,203,079	.75	8,252	6,806	19.0
Copper Range Co.[5]						
White Pine, MI	100.0	162,982	1.08	1,760	1,760	4.7
Contiguous leased	100.0	17,670	1.44	254	254	.7
Total reserves		180,652	1.12	2,014	2,014	5.4
Kennecott Corp.[6]						
Bingham Canyon	100.0	650,452	.70	4,579	4,579	12.2
Magma Copper Co.[7]						
Magma Superior	100.0	3,991	5.70	228	228	.6
San Manuel:						
Oxide pit	100.0	38,288	.42	160	160	.5
Oxide pit[8]	100.0	9,524	.89	85	85	.2
In situ leach ores	100.0	234,601	.35	828	828	2.3
Underground sulfide	100.0	88,555	.72	641	641	1.8
Underground sulfide[8]	100.0	128,530	.64	824	824	2.3
Kalamazoo underground:						
Sulfide reserves	100.0	10,207	.72	73	73	.2
Deep sulfide[8]	100.0	280,903	.73	2,056	2,056	5.8

TABLE 4—Continued

MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1989

Company and deposit	Percent company ownership	1989			Company share, thousand tons copper	Deposit and company percent of grand total
		Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)		
Pinto Valley:						
Dump leach (sulfide)	100.0	353,839	.12	414	414	1.2
Miami tailings leach	100.0	30,557	.33	101	101	.3
Open pit sulfide	100.0	342,719	.39	1,340	1,340	3.8
Undeveloped sulfide[8]	100.0	287,685	.39	1,134	1,134	3
Total reserves		1,809,399	.44	7,884	7,884	22.1
Grand total, major companies	XX	6,628,738	.55	36,071	34,047	94.4

XX Not applicable.
[1]Source: Cyprus Minerals Co. 1989 Annual Report, p. 44.
[2]Source: ASARCO Incorporated 1989 Annual Report, pp. 7, 17.
[3]Less than 1/2.
[4]Source: Phelps Dodge Corp. 1989 Annual Report, p. 11.
[5]Source: Metal Mining Corp. Annual Report 1989, p. 8.
[6]Source: RTZ Corp. Acquisition of BP Minerals Issue, 1989.
[7]Source: Magma Copper Co. 1989 10K Report, pp. 17, 18.
[8]Additional reserves in and around shaft pillars and in lowest mine levels, not included in stated mine plan in 1989. 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.

Copper Range expected to spend about $30 million on larger scale replacement equipment that would boost the copper production to about 60,000 tons per year over the next 3 to 4 years. In addition to improvements underground, the mill was to be expanded.

Kennecott redefined the Bingham Canyon reserves to incorporate lower grade material and announced plans to increase production by about 32,000 tons of ore per day. The new project included an expansion of the coarse ore stockpile facility, addition of a fourth grinding line, a new flotation circuit with 21 3,000-cubic-foot flotation cells, expansion of the molybdenum plant at the Copperton concentrator, and installation of a fourth filter press at the smelter. As a result, mill capacity would increase from 70,000 tons to 102,000 tons of ore per day, in addition to the ore that continued to be processed through the older Bonneville and Magna concentrators. Total copper production would be about 245,000 tons per year.

Magma completed its expansion of Pinto Valley Division's Miami Unit SX-EW plant. Production began during the year from the tailings leach project associated with the plant expansion. According to the company annual report, Pinto Valley's total production included 260,000 tons of concentrate and 9,500 tons of electrowon copper cathode.

New Butte Mining PLC conducted limited underground mining near the Missoula Horsetails, which were relatively untouched parts of the heavily mined main Lexington vein in Butte, MT. New Butte was operating under a small-miners exclusion that permitted only a limited (about 32,600 tons) amount of ore to be mined each year. Once the Montana Department of State Lands approved its mining permit, the company planned to expand production. After the Missoula Horsetails and Chief Joseph vein systems, the Gray Rock area was to be the next production site.

In 1989, Phelps Dodge invested $217.4 million in copper mining expansion and improvement projects. About $112 million was allocated to the expansion of the Morenci, AZ, SX-EW operations. New capacity of 63,500 tons per year was to come on-stream in mid-1991. The expansion also involved development of the Northwest Extension adjacent to the Morenci Mine. A $48 million, in-pit crushing and conveying project was completed during the year. According to the company annual report, Phelps Dodge had a record production of 534,967 tons of copper from its Morenci, AZ, and Chino and Tyrone, NM, operations, including 106,322 tons from electrowinning.

Smelter Production

Total U.S. smelting capacity was 1.8 million tons, a slight increase compared with 1988. Cyprus Lakeshore, AZ, roaster was included. At Lakeshore, concentrates from other mines were roasted before treatment in a vat-leach, SX-EW system. Nine primary plants, including the Lakeshore roast-leach plant, operated during the year with a total capacity of 1.35 million tons of copper. Five secondary smelters operated with a combined capacity of 416,000 tons of copper anode.

Asarco announced plans to retrofit its El Paso reverberatory furnaces with Contop flash smelting units at a cost of $30 million. The retrofit was expected to improve sulfur capture, improve quality of sulfuric acid recovered, and reduce production costs by about 17%. At its Hayden, AZ, plant, Asarco installed a new electric slag cleaning furnace in the third quarter.

A flashback at Cyprus' Miami, AZ, smelter occurred in September, closing the smelter for 2 weeks and injuring one worker. Cyprus settled a concentrate contract dispute with Magma and entered into a new smelting and refining agreement. The Magma smelter, Cyprus' Miami smelter, and the Casa Grande roast-leach plant were anticipated to meet Cyprus' current smelting needs. In 1989, Cyprus sold 78,000 tons of concentrates overseas, according to the company annual report. Copper concentrates from Cyprus' newly refurbished Deming mill were to go to the Asarco El Paso smelter for toll smelting. Sales of siliceous flux products from the Pinos Altos Mine to copper smelters in the region would not continue because the flux ore body at Pinos Altos was depleted during the year.[17]

According to the company annual report, Magma's smelter treated 853,000 tons of concentrate. In 1989, Magma significantly increased the amount of purchased concentrates. The smelter was able to achieve its installed capacity of about 1 million tons of concentrate per year. In addition to the new Cyprus concentrate contract of about 272,000 tons per year, Magma also secured a 140,000-ton-per-year, multiyear concentrate purchase contract with Compania Minera de Cananea S.A. of Mexico.[18]

Texas Copper Corp., a consortium of Mitsubishi Metal Corp. (51%) and four other Japanese companies, announced that the design capacity of its intended Texas City smelter would be 182,000 tons per year of copper. The smelter was expected to operate on a toll basis with each shareholder providing concentrates according to their percentage of ownership. The majority of concentrates was expected to come from South America. About 12,000 tons of total copper production was expected to be from scrap. The proximity to the Florida sulfuric acid market and ease of concentrates transport were important factors in selecting a gulf coast location. Construction of the $200 million smelter could begin in 1991, depending on the progress of environmental permitting.

Refinery Production

Ten electrolytic, six fire refineries, and twelve SX-EW plants were operating at yearend. Increased refinery production resulted from the continued expansion at electrowinning plants, startup of the Lakeshore roast-leach process, and electrolytic refinery expansion at Magma and Kennecott facilities. Two secondary plants also expanded capacity during the year. Total U.S. refinery capacity at primary and secondary plants was 2.42 million tons, up by nearly 10% over that of 1988. Of the total, 636,000 tons of capacity was at secondary electrolytic and fire-refining plants.

At the end of October, the American Telephone and Telegraph Co. (AT&T) announced that its Nassau Metals Corp. operations, including its electrolytic copper refinery and wirerod plant, were for sale. Nassau's facility, one of the largest secondary copper processing plants in the United States, was constructed in 1978 and provided Western Electric with between 40% and 45% of its copper.

According to the company annual report, Magma had a record electrolytic cathode production of 243,000 tons, including 66,200 tons refined for others. Production from the company's SX-EW plants accounted for 22% of refined cathode produced, with the San Manuel Div. producing 77.4% of the SX-EW production. Magma operated three SX-EW plants with the following capacities: San Manuel oxide plant, 68,000 tons per year; Pinto Valley waste leach, 7,260 tons per year; and the Miami in situ leach plant, 9,000 tons per year. Four new sections were added to the San Manuel electrolytic refinery during the year that will enable the plant to produce more than 272,000 tons of cathode per year.

Magma announced the closure of its MCR Products Co. (Chicago) rod mill as of January 1, 1990. The move reflected basic changes in Magma's marketing plans. Magma was to continue to supply rod from its San Manuel rod plant, which had a capacity of 164,000 tons of rod per year. MCR had a capacity of 127,000 tons per year of rod.

This was the first full year of operation for Phelps Dodge's 40,000-ton-per year SX-EW plant at the Chino Mine, NM. In December, a 100% expansion of the Morenci, AZ, SX-EW plant was completed, raising the capacity to about 91,000 tons of cathode per year. The company's Tyrone plant had a capacity of 50,000 tons per year. The company was anticipating SX-EW production to comprise about 50% of its total production over the long run. Phelps Dodge reported that it was the world's largest producer of copper rod. Its U.S. facilities, located at Norwich, CT, and El Paso, TX, were capable of producing about 380,000 tons per year of rod. The El Paso refinery also initiated a $9 million modernization program that was to improve production costs.

Copper Sulfate Production

Copper sulfate was produced from copper scrap, blister copper, copper precipitates, electrolytic refinery solutions, and spent electroplating solutions. U.S. production of copper sulfate was a little lower than in 1988, while imports increased significantly. In October, Kocide Chemical Corp. discontinued production of copper precipitates from in situ leaching at the Van Dyke property, AZ. Closure reportedly was the result of technical problems, including a buildup of soluble iron and diminished flow rates. Precipitates had been used for production of copper sulfate at the company's Casa Grande Plant. Data supplied by domestic producers for 1989 indicated that 64% of their shipments were for agricultural uses, 24% for industrial uses such as wood preservatives, and 12% for water treatment. In agriculture, copper sulfate was used principally as a fungicide for treatment of citrus and vegetable crops.

Copper Powder Production

Copper powder production and consumption were at about the same level as in 1988, which was about one-half that of 1979. Copper powder consumption was highly dependent on the automobile industry, which comprised the largest single end-use market. Copper powder used to manufacture self-lubricating bearings accounted for about 70% of the granular powder used. Pure copper powder was also used in the electrical and electronic industries. Copper flakes were used for antifouling paints, decorative and protective coatings, and printing inks. Nonstructural applications included brazing, cold-soldering, mechanical planting, metals and medallions, metal-plastic decorative products such as floor tile and epoxy resins, and various chemical and medical applications. American Metal Market commercial-grade copper powder prices ranged from $1.64 to $1.80 per pound, reflecting the higher refined copper prices.

TABLE 5

COPPER SULFATE PRODUCERS IN THE UNITED STATES IN 1989

Company	Plant location
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.
Tennessee Chemical Co.	Copperhill, TN.

Granular copper powder can be produced by a number of methods, including atomization, electrolysis, hydrometallurgy, and solid-state reduction.

Sulfuric Acid Production

Sulfuric acid was produced as a byproduct of copper smelting. Seven copper smelters produced a total of 3.1 million tons of sulfuric acid; in addition, some sulfuric acid was produced at Cyprus' Lakeshore concentrate roaster. Copper Range does not produce sulfuric acid at its smelter. According to the company annual report, Magma's new smelter produced 744,250 tons of sulfuric acid and was largely responsible for the significant increase in acid production over that of 1988. About 280,000 tons was used in Magma's leach operations and 464,000 tons was sold. Magma reported that the smelter captures greater than 97% of the input sulfur.

CONSUMPTION

U.S. apparent and reported demand for copper, which trended upward since 1983, were essentially unchanged in 1989. However, the trend for an increasing domestic self-sufficiency for copper continued. Domestic production of primary refined copper and copper recovered from old scrap accounted for about 93% of domestic demand. Imports of brass mill products, as reported by the CBFC, declined by 7%.

Refined copper or directly melted scrap was consumed at about 20 wire-rod mills, 40 brass mills, and more than 1,000 foundries, chemical plants, and miscellaneous manufacturers. According to Bureau of Mines estimates, 72% of the copper, as a percentage of apparent consumption, was consumed in electrical applications; 15% in construction; 6% in machinery; 3% each in transportation and miscellaneous uses; and 1% in ordnance. Copper used in electrical wiring and devices in all end uses, except ordnance, was included under electrical applications.

Although demand for unwrought copper (refined plus direct-melt scrap) was stagnant, demand for copper semifabricates declined. According to Copper Development Association estimates, mill shipments to domestic markets declined by about 3%. Much of the decline in total shipments was accounted for by a decline in imports of brass mill products. Shipments to the building construction, industrial machinery and equipment, and transportation equipment sectors declined by about 2%, 6%, and 7%, respectively. According to Copper Development Association, building construction was the largest end use sector, accounting for 41% of shipments, followed by electrical and electronic products, 24%; industrial machinery and equipment, 13.5%; transportation equipment, 11.5%; and consumer and general products, 10%.

While demand in most industry sectors was weak, the brass tubing market was undergoing restructuring, and several new plants were announced. Water tubing demand was negatively impacted by the housing slump, but demand for thin-walled and inner-grooved copper tubing used in air-conditioning and refrigeration was strong and supply was tight. At least two major domestic air-conditioning manufacturers who switched to aluminum reversed their position and returned to copper tubing. A decline in imported air-conditioning units and a decline in imported tube boosted demand for domestically produced air-conditioning tube. Domestic mills announced a series of expansions to boost their production of air-conditioning and refrigeration tube. Kobe Copper Products Inc. announced plans to boost air-conditioning and refrigeration tube capacity from 400 tons per month to 1,000 tons per month at its Pine Hall, NC, plant. The plant, adjacent to Halstead Industries' tube mill, was a joint venture among Kobe Steel, Halstead, and three other Japanese companies. American Brass increased capacity at its Franklin, KY, plant to 30,000 tons per year, and Wolverine Tube was constructing a new redraw mill at Booneville, MO. Cerro Copper Products, which completed a second expansion of its redraw capacity in Selbina, MO, announced plans to build a new fully integrated tube plant.

Several other expansions or new plants were announced during the year. PMX Industries, a subsidiary of Poongsan Corp. of the Republic of Korea, announced plans to open an 80,000-ton-per-year sheet mill in Cedar Rapids, IA. Some of the plant equipment was to be purchased from Canada's Arrowhead Metals, which closed its brass mill during the year. Other announced plant expansions included Plume and Atwood's Connecticut mill and MRM Industries, who relocated expanded facilities from Connecticut to Sikeston, MO. North Coast Brass and Copper, formerly Chase Brass and Copper Co., announced its intent to close its 60,000-ton-per-year sheet mill in Ohio.

PRICES

The average annual price for copper was at a record-high level in 1989. Industry stocks remained near the low level established during the second half of 1988. At the prevailing rates of consumption, stocks represented only about an 18-day supply. With stocks at such a low level by historical measure, prices were volatile and sensitive to real or perceived changes in supply availability. The Commodity Exchange of New York (COMEX) spot price fell by almost 10 cents per pound over a 2-day period in March. The decline coincided with economic indicators showing a potential softness in the market, a rise in exchange stocks, and cancellation of a planned 3-day strike in Peru. On average, prices declined throughout the first 7 months of the year, having reached record levels in December 1988.

Copper prices rose during the third quarter. The COMEX spot price peaked at $1.42 per pound in mid-September. The price rise coincided with strong industry demand, a decline in COMEX stocks, and the announcement of an additional production setback in Chile. To insure an orderly expiration of its September copper contracts, COMEX raised its margin requirement for all September contracts to 100% of their value. A slight increase in refined copper inventories, uncertainties about sustaining the strong demand for copper, and the prospect for increased primary production in 1990 contributed to a fourth quarter decline in prices. Yearend prices were at the lowest point of the year.

December 27 was the last trading day for the standard-grade copper contract on the COMEX. Beginning January 1990, only the high-grade contract, first introduced in July 1988, was traded. COMEX delisted the remaining inventory of standard-grade copper, causing reported stocks between the end of December and the beginning of January to decline by 7,000 tons. Standard-grade stocks were expected to be withdrawn from warehouses by contract holders during the first half of 1990. Prices on COMEX remained in backwardation during most of the year with forward contracts trading at a discount to spot purchases. A normal or contango market, where forward contracts sell at a premium

to spot purchases, briefly returned in July and August for 3-month forward contracts. Copper prices were at the low point for the year. However, 12-month forward contracts remained in backwardation throughout the year. The market backwardation was attributed to industry expectation that new primary copper production would lead to supply surplus and lower prices.

Producer prices for refined copper closely tracked that of COMEX prices, because domestic producers had adopted a COMEX-based pricing system. Producer premiums to COMEX ranged between 4 and 5 cents per pound throughout the year, but generally declined slightly with lower prices. Though copper scrap prices generally tracked refined copper prices up and down, the spread in price between refined prices and scrap prices was more of an inverse relationship. High prices for refined copper generally attracted more scrap to the marketplace, depressing its price relative to refined prices. For example, during the September price surge, the spread between the price refineries paid for No. 1 copper scrap and the producer price for refined copper was more than 20 cents per pound. This narrowed to only about 13 cents at yearend. Thus, when prices rose, processing margins increased for secondary smelters and for brass mills, who adjusted product prices to reflect the refined value of contained copper.

Though the average annual delivered producer price for copper cathode, as reported by Metals Week, was $1.31 per pound, the price realized by producers varied depending on their pricing, delivery charges, and sales policies. The average price realized by Asarco for the year was $1.28 per pound, compared with $1.17 in 1988, according to the company annual report. Magma, on the other hand, reported average sales prices of $1.22 and $1.14 for 1989 and 1988, respectively, in its annual report. Some of the realized price difference between the two companies was ascribed to guaranteed forward sales contracts made the previous year by Magma in anticipation of lower copper prices. Cyprus, which reported a 1989 realized price of $1.27 per pound, implemented price protection strategies in 1989 in the advent of a decline in copper prices. About 30% of Cyprus' anticipated 1990 production was reportedly sold forward at prices ranging from $0.80 to $1.00 per pound. Magma entered into contracts to supply cathode to fabricators in Asia, selling forward about one-third of the company's anticipated production at prices that averaged $1.02 per pound over 1990 and 1991. Similarly, Copper Range sold forward contracts covering 45,000 tons of copper at a minimum average price of $1.00 per pound for 1990 and $0.98 per pound for 1991, according to Metall Mining's annual report.

WORLD REVIEW

Despite an increase in world refined production, the close balance between the supply and demand for refined copper that prevailed during 1988 continued throughout 1989. World consumption kept pace with the growth in production, and total stocks of refined copper changed only slightly throughout the year. However, with stocks representing only 4 to 5 weeks of supply, extremely low by historical standards, the price of refined copper was sensitive to even small changes in availability. Though total estimated world stocks remained unchanged during the first quarter, commodity exchange stocks rose by more than 50%. Coincidentally, copper prices declined steadily during the first half of 1989. Prices had risen to historic high levels in December 1988. In addition, several disruptions to the production of primary copper, which had threatened availability during the traditional yearend 1988 buying season, were resolved during the first quarter of 1989. A renewed price rise during the third quarter of 1989 coincided with strong industry demand and additional disruptions to supply. Prices declined to the lowest levels of the year when both exchange and industry inventories rose slightly and some supply disruptions were settled.

Industry Structure

Consumption.—While total world consumption of refined copper rose, consumption in the United States remained at about the same level. Weak demand in Canada from the depressed U.S. automobile market and the closure of a major Canadian brass mill was balanced by increased Mexican demand. The increase in Mexican demand was ascribed to an overall economic recovery. Demand for refined copper in Europe, according to the World Bureau of Metal Statistics, rose by about 4%, buoyed by strong demand in France, the Federal Republic of Germany, Italy, and Spain. The growth in the Federal Republic of Germany was attributed to strong domestic and export demand for sheet products; in France to strong domestic and export demand for wire mill products; and in Italy and Spain to a boom in construction demand for wire, tube, and sheeting. In Asia, an overall demand increase of about 10% was fueled by strong demand in Japan and Taiwan. In Japan, increased consumption resulted from a boom in construction and domestic automotive and consumer electronic consumption. Demand in Taiwan increased along with increased exports.

Supply Disruptions.—Though world mine and refined production increased, an anticipated copper surplus failed to materialize owing to sustained strong demand and significant disruptions to production. In January, an explosion at Corporacion Nacional del Cobre de Chile's (CODELCO-Chile) new flash smelter at Chuquicamata, resulted in an estimated 20,000 tons of lost production. In September, CODELCO-Chile suffered a month-long setback at its El Teniente underground mine, where a landslide cut production by about 25%. Repeated acts of sabotage throughout the first half of the year led to production curtailments at the 170,000-ton-per-year Bougainville mine in Papua New Guinea. Bougainville Copper imposed a force majeure on June shipments of concentrates following closure of the mine in mid-May. At yearend, the mine remained shuttered and near-term prospects for reopening the mine were poor. In June, a 3-week strike at the Metallurgie Hoboken-Overpelt S.A. (MHO) Olen refinery in Belgium led both MHO and La Générale des Carrières et des Mines du Zaire (Gécamines) to declare a force majeure on shipments. Gécamines had a toll refining agreement with MHO. A 107-day strike at Highland Valley, Canada's largest copper producer, began in July and also led to declaration of a force majeure. The strike resulted in the loss of about 56,000 tons of copper in concentrate compared with 1988 production.

The Government of Mexico, failing in its attempt to sell its interest in Cia Minera de Cananea S.A. to private investors, declared Cananea to be bankrupt and, on August 20, shut down the mine and dismissed the workers. It was not until the end of October that an agreement was reached with the unions to allow the reopening of the mine. The agreement called for a 25% reduction in the work force and a 33% increase in

wages for remaining employees. Though less severe than the previous year, strikes continued to impact Peruvian production. Production by Centromin in Peru was affected by strikes in February and sabotage in July. A nationwide strike by the National Federation of Mining Unions closed Southern Peru Copper Company's (SPCC) Toquepala and Cuajone Mines in August, as well as Minero Perú's Ilo refinery and Cerro Verde Mine.

In the Philippines, mine production fell by more than 13% compared with 1988. Atlas Consolidated Mining and Development reported significant losses because of heavy rains in January, February, and June; typhoons in August; labor problems in the second half of the year; and disruption of its new underground conveyor system by a landslide. Water saturation of the mine and a 26-day shutdown of the mill reduced output by Philex Mining Corp. Production by Lepanto Consolidated Mines fell by 50% during the first half of the year owing to closure of its roasting plant. Benguet Corp.'s Dizon Mines also reported lower output for 1989.

Mine Expansions.—Despite setbacks, mine production in Chile increased significantly. CODELCO-Chile invested $410 million dollars in capital projects, resulting in production increasing by 111,000 tons to 1,218,000 tons of copper.[19] The largest gain was at the Chuquicamata Div. where a 51,000-ton-ore-per-day concentrator expansion was completed in March. Production at Chuquicamata rose to 660,000 tons of copper in 1989. Expansions of smelting, refining, and sulfuric acid plants were also underway. Production at the Salvador Div., which began processing relatively high-grade slag from the Chuquicamata smelter, rose by about 50% to 130,000 tons of copper. In addition, production from the Quebrada "M" open pit, which began during the second half of the year, and an expansion of the Porterillos smelter was partially completed. The above gains in production more than offset production declines of 7,000 and 26,000 tons at the Andina and El Teniente Mines, respectively. Andina and El Teniente suffered from declining ore grades, and El Teniente also suffered severe mine stability problems.

In Canada, eight copper and copper coproduct mines with a combined annual capacity of about 75,000 tons of copper started production during the year. Minnova Inc. began production from its Ansil copper-zinc mine in Quebec and the Samatosum silver-zinc-copper mine in British Columbia. Noranda reopened the Gaspé Mine, closed in 1987 owing to a major underground fire. Other reopened mines included the Mobrun Mine, the Shebandowan nickel-copper mine, the Heath Steele and adjacent Stratmat zinc-lead-copper mines, and the Callinan zinc-copper mine at Flin Flon. In addition to the above new or reopened projects, steps were taken to extend mine life at the Gibralter Mine, the Similkameen Mine, and BHP-Utah Mines Ltd. open pit on Vancouver Island. With the relocation of the former Highmont mill to the Lornex millsite, Highland Valley Copper increased its mill capacity by about 10,000 tons per day.[20]

Samincor's Neves Corvo Mine in Portugal was brought into production early in the year, and by yearend, was operating at or near its projected annual capacity of 120,000 tons of copper in concentrate. Ore grades at the underground massive-sulfide mine were reported to average between 8% and 11% copper. In Australia, production rose significantly owing to expanded production from the large Olympic Dam copper-uranium-gold project, the Selwyn Mine, and the Horseshoe Lights Mine, all of which began production in 1988. Production also increased from the Gecko copper-gold mine, which reopened in 1988.

New Mine Projects and Investments.—The sustained high price for copper projected declines in ore grades and reserves, and a long-term outlook for a copper supply deficit stimulated investments in new copper production and in expansions of existing facilities. In Chile, development of the Sur open pit at Andina began during 1989, and partial production was expected to begin in 1990. At El Teniente, development of the Mina Sur and Mina Norte extensions continued. A 2-stage, 24,000-ton-ore-per-day expansion of the Colon concentrator was planned for completion in 1991. While production from the State-controlled Empresa Nacional de Minería (ENAMI) and the private sector only rose by a combined 20,000 tons in 1989, numerous expansions and new mine developments were underway, which could boost non-CODELCO capacity by as much as 750,000 tons of copper by 1992. Most notable was La Escondida Mine, where development was running ahead of schedule and under budget. Production startup was now projected for yearend 1990. The long-term production rate was expected to be 320,000 tons of copper per year in concentrates. Exxon Minerals International Inc. signed an investment agreement with the Chilean Government that included $400 million for expansion of its Los Bronces Mine from 49,000 tons of copper per year to 130,000 tons per year by 1992. Other smaller projects that were underway included the joint development of the 40,000-ton-per-year Quebrada Blanca sulfide and oxide leach project by Cominco Resources and ENAMI; the 20,000-ton-per-year Los Pelambres underground sulfide flotation project owned in part by the Midland Bank and Anaconda Chile SA; the 40,000-ton-per-year Cerro Zaldivar sulfide flotation project, acquired by Outokumpu Resources in 1989; and numerous smaller oxide leaching projects with a combined capacity in excess of 60,000 tons of copper per year.

In Indonesia, expansion of Freeport-McMoRan Copper Co.'s mine and concentrator from 20,000 tons of ore per day to 32,000 tons was initiated early in the year. In August, further expansion of the facilities to 52,000 tons of ore per day was approved. The expansions were to accommodate production from the Grasberg copper-gold deposit discovered in 1988, about 2.5 kilometers from their existing Ertsberg operation. Production from Grasberg was to begin in 1990.

In Canada, Geddes Resources Ltd. continued exploratory drilling and was proposing to develop a 120,000-ton-per-year copper mine on its Windy Craggy property in the northwestern corner of British Columbia. The company reported proven and probable reserves of 114 million tons of ore grading 1.9% copper. The company was proceeding with the environmental permitting process. Numerous other Canadian deposits, including the Louvicourt Township property and the Estrades property in Quebec, the Duck Pond property in Newfoundland, the Hanson Lake property in Saskatchewan, and the Mount Milligan property in British Columbia were being considered for development.[21] Other new projects included a 20,000-ton-per-year mine in Burma, mill expansions at RTB Bor's mines in Yugoslavia scheduled for completion by 1992, and modernization and expansion of the Erdinet Mine in Mongolia.

Smelting and Refining Production.—World smelter and refinery production during 1989 rose with increased availability of copper concentrates. Refined copper

production from scrap, which had increased markedly in response to higher prices during 1988, remained high in 1989 at about 2 million tons and comprised about 22% of refined copper production. Production increases of secondary refined copper in the United States were tempered by the static secondary recovery in Europe, the largest producer of refined copper from scrap. According to Bureau of Mines estimates, the Western European countries produced about 710,000 tons of refined copper from scrap, compared with only 540,000 tons for the North American countries. The increase in smelter production lagged behind that of both mine and refinery production. The expansion of world SX-EW production, which bypasses the smelting step, helped to boost primary refined production.

Increased concentrate production, smelter setbacks, and a decision by Japanese smelters to maintain their relatively low operating rate led to a surplus of copper concentrates. Consequently, treatment and refining charges rose significantly during the first quarter of the year. A tight supply of concentrates, which had prevailed over the past several years, had led to low treatment and refining charges. According to Commodity Research Unit Ltd. of London, United Kingdom, combined spot treatment and refining charges rose by 45% during the first half of the year to about 29 cents per pound of copper. However, by yearend, charges had returned to 1988 levels. Disruptions to mine production and increased smelter utilization rates again led to a tight supply in the custom concentrate market. However, refined copper production was not affected by the return of tight supply. Stocks of concentrate, accrued by smelters earlier in the year, were able to supplement new production.

Limited surplus primary smelter capacity and expanding mine production served to stimulate numerous smelter expansion plans. In Chile, several smelter projects were being considered at yearend. In addition to the ongoing expansion of the Ventanas smelter and refinery, expansion of the Paipote smelter was planned, and construction of two new ENAMI smelters was being considered. In the Philippines, the Philippine Associated Smelting and Refining Co. (PASAR) announced plans to expand its smelter by 34,000 tons per year to 172,000 tons per year, and in Thailand, Padaeng Industry Co. planned construction of a 100,000-ton-per-year smelter by 1995. In addition to the new smelter planned in the United States, Mitsubishi announced plans to retrofit its Naoshima smelter with a new smelter, equal in capacity to its existing two smelting furnaces. In Mexico, startup of the Santa Rosalia smelter was delayed until 1990 owing to delays in refurbishing the shuttered smelter. In June, Finland's Outokumpu Oy and a consortium of Portuguese companies initiated a feasibility study on constructing a major smelter in Portugal. Other potential sites for new smelters included Brazil and Indonesia.

Capacity

Compared with that of 1988, world mine capacity increased by 6%, smelter capacity by 3.3%, and refinery capacity by 1.5%. Copper mine, smelter, and refinery capacity for 1989 is shown in table 6. World capacity utilization (82%) at mines continued to be low in 1989 owing to the extensive 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 6 are rated annual production capacity for mines, smelters, and refineries 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.

Capacity at mines represents the potential copper production contained in concentrates for many producers, but for some major producers—such as Chile, the United States, and Zambia—it represents copper recoverable at the smelter level, based on known recovery factors. SX-EW capacity is counted as smelter-level capacity only when the material must be further refined. It is otherwise counted as mine and refinery capacity, bypassing the smelter level. Past and present production potential are taken into consideration when rating a mine, especially where an engineering estimation is not available or seems inappropriate in the case of decreased ore grades. Generally, the rated capacity is based on 360 days per year and two to three 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.

OUTLOOK

Trends in Consumption

U.S. demand for refined copper from 1950 to 1989 rose an average of 1.3% per year and was anticipated to remain less than 2.3 million tons per year through 1991. World demand increased at about 3.6% per year over the same period. Demand rates for select periods within the 1950-2000 time span have varied significantly, as shown in table 7 and in figures 1 and 2. Particularly noticeable in the United States are the lower growth rates that have existed since 1980. Growth in other countries during this same period was more robust, accounting for the higher 1963-89 average growth rate of 2.5% per year for market economy countries (MEC).

In general, copper demand is largely dependent on economic growth. High demand for copper products is associated with a high standard of living and increased electrical uses. The growth of plastics, fiber-optic cable, and aluminum as competing materials continued to impact several copper markets, but the outlook remains positive for growth in copper consumption, which has related historically to industrial growth. In the United States, a high degree of correlation since 1960 (R^2 value of 0.90) between the Gross Private Domestic Investment (GPDI) and the demand for copper in electrical uses indicates the strong tie between copper demand and economic growth.

Copper consumption has been increasing in the electrical sector as a share of end-use markets since 1960, so that in 1989 this sector comprised more than 70% of U.S. copper demand. Statistical projections provided by the Bureau of Mines Branch of Economic Analysis indicated that, by using an independent forecast for the GPDI as a comparative basis, copper consumption

TABLE 6

WORLD MINE, SMELTER, AND REFINERY CAPACITIES IN 1989

(Thousand metric tons, primary and secondary copper)

Continent and country	Rated capacity		
	Mine	Smelter	Refinery
North America:			
Canada	953	629	610
Mexico	354	285	190
United States	1,790	1,807	2,446
Total	3,097	2,721	3,246
Central and South America:			
Brazil	58	160	194
Chile	1,752	1,454	1,208
Peru	443	362	272
Other[2]	5	7	6
Total	2,258	1,983	1,680
Europe:			
Albania	19	15	14
Austria	—	45	45
Belgium	—	172	495
Bulgaria	103	140	140
Czechoslovakia	11	25	26
Denmark	—	5	5
Finland	19	100	70
France	—	17	47
German Democratic Republic	12	45	105
Germany, Federal Republic of	—	389	362
Hungary	—	4	14
Italy	—	72	104
Netherlands	—	8	—
Norway	22	35	40
Poland	465	395	432
Portugal	110	10	10
Romania	45	60	50
Spain	40	196	252
Sweden	84	110	107
Turkey	72	81	123
U.S.S.R.	680	1,053	1,070
United Kingdom	—	75	155
Yugoslavia	142	180	165
Other	3	—	—
Total	1,827	3,232	3,831
Of which:			
Centrally planned economies	1,335	1,737	1,837
Market economy countries	492	1,495	1,994

Continent and country	Rated capacity		
	Mine	Smelter	Refinery
Africa:			
Botswana	26	25	—
Morocco	27	—	—
Namibia	45	60	—
Zaire	779	525	250
Zambia	627	464	625
Zimbabwe	19	34	33
Other[1]	3	2	3
Total	1,747	1,366	1,074
Asia:			
Burma	18	—	—
China	400	585	475
India	75	65	47
Iran	97	70	145
Japan	22	1,212	1,196
Korea, North	15	—	25
Korea, Republic of	2	185	175
Malaysia	30	—	—
Mongolia	180	—	—
Oman	20	22	20
Philippines	244	138	138
Taiwan	—	60	62
Other	2	—	—
Total	1,105	2,337	2,283
Of which:			
Centrally planned economies	595	585	500
Market economy countries	510	1,752	1,783
Oceania:			
Australia	372	295	287
Indonesia	150	—	—
Papua New Guinea	344	—	—
Total	866	295	287
Total world	10,900	11,934	12,401
Of which:			
Centrally planned economies	1,936	2,322	2,337
Market economy countries	8,964	9,612	10,064

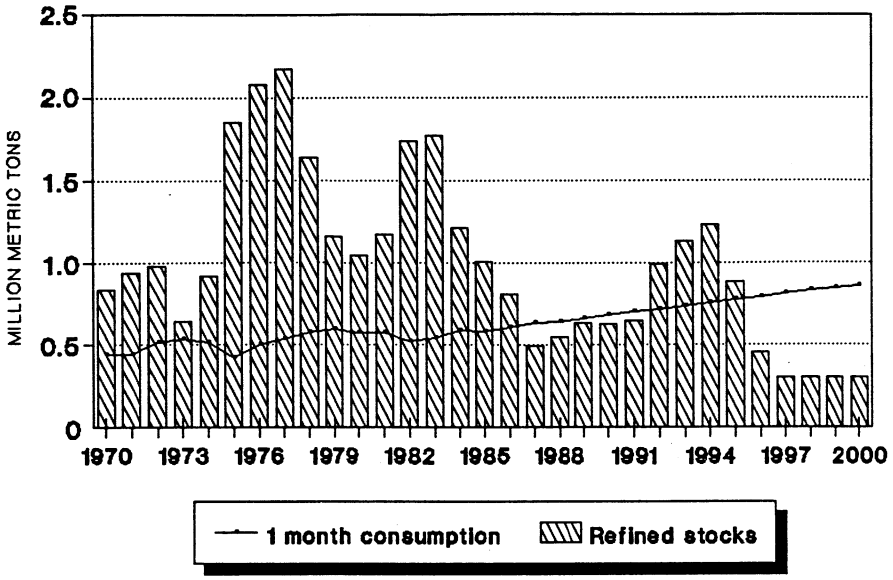
[1]Includes mine capacity of 1,000 tons for Republic of Congo (Brazzaville), a centrally planned economy.
[2]Includes mine capacity of 5,000 tons for Cuba, a centrally planned economy.

in electrical uses alone could reach 2.29 million tons by the year 2000 in the United States.

Although the correlation is high between total U.S. copper consumption and the GPDI, it is not as high as for electrical uses. The GPDI correlates very poorly with copper consumed for other end-use sectors. One explanation has been the increased U.S. consumption of imported manufactured goods containing copper, which were not reflected in the measure of copper consumed at U.S. semifabricating plants, but which were included in the dollar-valued GPDI. Another reason is that the impact of substitution has been higher in other sectors. Shearson Lehman Hutton also found a high historical correlation with

FIGURE 1

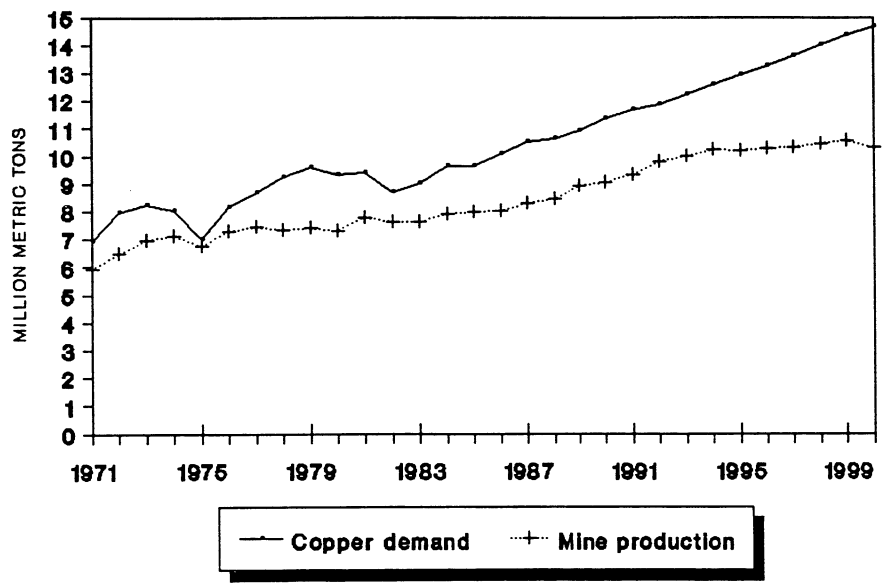
MARKET ECONOMY COUNTRIES' REFINED INVENTORIES AND AVERAGE MONTHS' CONSUMPTION



Source: Bureau of Mines; Aug. 1990

FIGURE 2

WORLD CONSUMPTION AND PRIMARY (MINE) SUPPLY



Source: Bureau of Mines; Aug. 1990.

Organization for Economic Cooperation and Development (OECD) Countries' industrial activity and the level of total OECD copper consumption.[22]

Trends in Supply

World mine production has grown steadily since World War II, interrupted only by short periods of severe depression or long-term labor strikes. Financial investment in expanding capacity at new and existing mines has exceeded $10 billion since 1987. Much of the new capacity developed in the 1980's and 1990's stems from a more intensive prospecting and reserve development period that took place during the 1950's and 1960's. The long period of poor profits for the copper industry through much of the 1970's and 1980's lent credence to a perception that exploration in nonferrous metals was a poor investment. In addition, although many large deposits already had been discovered, the large sums of money required for further development were not available. The location of some of the largest deposits further increased financial risks. Political and economic stability was poor in some nations with large copper resources. In other countries, such as the United States, environmental and other licensing procedures made new mine development costs prohibitive in some areas. Although new arrangements for investment sharing and methods of financing are possible among mining companies, banks, and Governments, sufficient capital to develop some of these deposits may be a future problem.

The direction of mine supply growth, forecasted from 1989 to the year 2000, is shown in table 8. Also shown is the amount of capacity still in exploration stages that has been incorporated in the country forecasts for the latter part of the 1990's. Although speculated for possible initiation during the latter half of this period, no firm development plans had been made for these projects, and their implementation, therefore, was speculative.

Copper and copper alloy scrap is also a major source of copper. Although the potential supply of world scrap is significant, the rate of old scrap recovery is limited by copper's long life in its essential uses. The historical recovery of old scrap has averaged an estimated 18% of world copper consumption. Although old scrap recovery has been higher in the United States, it seldom has exceeded 22% of world consumption.

TABLE 7

COPPER CONSUMPTION TRENDS

Period	United States	Market economy countries	World total
		Copper consumed (thousand metric tons)	
1950	1,337	2,502	2,774
1963	1,712	4,489	5,531
1983	2,013	7,079	8,963
1989	2,181	8,587	10,962
2000 (forecast)	2,700	11,100	14,680
		Annual growth rates (percent)	
1950-63	1.27	3.20	3.62
1963-89	1.00	2.50	2.67
1983-2000 (forecast)[1]	1.90	2.60	2.90
1989-2000 (forecast)	1.95	2.43	2.70

[1]Forecast 1983-2000 adapted from Mineral Facts and Problems, Bulletin 675, 1985 Edition, Bureau of Mines.

Source: Bureau of Mines.

Forecast Supply and Demand Trends

Copper demand is forecast to grow at a 1.9% rate in the United States and at a 2.7% rate in the world between 1989 and the year 2000. While consumption in the United States, Europe, and Japan was expected to increase at a relatively lower rate, other countries were expected to surpass these rates as their economies develop. Significant increases in world copper demand could be driven by economic recovery in the centrally planned economy (CPE) countries and by increased domestic consumption in the less developed countries (LDC) and newly industrialized countries. Rejuvenation and building of new plants, equipment, and infrastructure in these countries could consume major amounts of copper. However, the problems of some African, Southeast Asian, and South American countries could continue or could deteriorate further. Consumption in these countries, therefore, was expected to exhibit minimal growth.

The projected balance between supply and demand forecasts is shown in figures 1 and 2. Estimated MEC refined inventories are compared with projected average monthly MEC consumption in figure 1, and world consumption is compared with primary (mine) supply in figure 2. Both illustrations indicate the potential for tight copper supply in the latter part of the 1990's. Historically, when inventories were less than 1 month's supply at prevailing rates of consumption, price pressures became significant. Supplies are anticipated to be impacted negatively during 1990 and 1991 by the continued shutdown of the Bougainville Mine, Papua New Guinea. A significantly positive supply influence will result from the anticipated early 1991 startup of the large Escondida Mine in Chile. Although some inventory surpluses are anticipated through 1993, it is not anticipated that the depressed market conditions of the middle 1970's and early 1980's will reoccur, causing inventories to accumulate to 4 months or more of supply.

BACKGROUND

Definition, Grades, and Specifications

Copper is traded in many forms that relate to different stages of processing. For example, at the mine copper may be sold as ore, concentrate, or precipitate. Copper ore may contain as little as 0.40% copper or more than 10% copper, depending on its source. Copper concentrates are produced by milling and concentrating copper ore and may contain between 18% and 40% copper. Copper precipitate or cement copper is recovered from leach solutions by chemical precipitation with scrap iron and may contain as much as 90% copper.

Smelter products include copper matte, blister, slag, and anode. Slag is the waste formed in smelting through the combination of a flux, such as limestone and silica, with the gangue or waste portion of the ore and, although 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 is oxidized and removed as sulfur dioxide, and the enriched copper melt is poured as blister copper. Blister contains 97% to 98.5% 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, transferring the copper ions of the anode 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 for recovery 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. An alternative to electrolytic refining is fire refining of blister or of scrap, in which case, the fire-refined product is cast into ingots, bars, billets, or cakes and is not processed electrolytically.

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 made from refined copper, scrap, or alloys are large cylindrical shapes used for extruding tubing or

TABLE 8

WORLD COPPER MINE CAPACITY

(Thousand metric tons, recoverable copper)

Region	1989	1990	1991	1992	1993	1994	1995	2000
Africa:								
Zambia	627	612	620	608	594	594	521	393
Zaire	779	814	814	829	829	809	822	825
Other[1]	341	332	304	310	308	305	283	167
Total	1,747	1,758	1,738	1,747	1,731	1,708	1,626	1,385
Asia:								
Middle East	119	196	226	226	242	254	252	257
Philippines	244	226	216	212	211	229	248	255
Centrally planned economies	595	610	615	615	615	615	615	615
Other	147	147	147	147	153	153	123	147
Total	986	983	978	974	979	997	986	1,017
Europe:								
Market economy countries	492	453	452	455	465	457	424	403
Centrally planned economies	1,335	1,340	1,313	1,333	1,333	1,333	1,333	1,361
Total	1,827	1,793	1,765	1,788	1,798	1,790	1,757	1,764
Central and South America:								
Chile	1,752	1,815	2,079	2,322	2,323	2,433	2,452	2,604
Peru	443	422	450	437	470	470	405	474
Other[2]	63	67	68	68	68	84	142	221
Total	2,258	2,304	2,597	2,827	2,861	2,987	2,999	3,299
Oceania:								
Australia	372	399	443	422	435	400	400	376
Indonesia	150	170	200	200	230	230	230	260
Papua New Guinea	344	372	372	372	372	372	372	370
Total	866	941	1,015	994	1,037	1,002	1,002	1,006
North America:								
Canada	953	973	946	923	921	1,006	989	890
Mexico	354	383	385	380	378	372	372	354
United States	1,790	1,907	1,999	2,058	2,074	2,210	2,248	2,195
Total	3,097	3,263	3,330	3,361	3,373	3,588	3,609	3,439
Total mine capacity	10,900	11,244	11,656	11,931	12,035	12,340	12,249	12,275
Of which:								
Market economy countries	8,964	9,287	9,721	9,976	10,080	10,385	10,295	10,293
Centrally planned economies	1,936	1,957	1,935	1,955	1,955	1,955	1,954	1,982
MEC capacity in exploration[3]	—	—	1	11	60	82	135	855
U.S. capacity in exploration[3]	—	—	—	—	42	59	59	108
Total planned capacity[4]	10,900	11,244	11,655	11,920	11,933	12,199	12,055	11,312

[1]Includes capacity of 1,000 tons for Republic of Congo (Brazzaville), a centrally planned economy.
[2]Includes capacity of 5,000 tons for Cuba, a centrally planned economy.
[3]Capacity in exploration stages without announced intention to develop and financial arrangements secured.
[4]Probable capacity, including announced properties in process of development.

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 is administered by the Copper Development Association and is widely used by ingot-makers, brass mills, and foundries in the United States. The major classes are coppers that 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, phosphorus, and silicon but only small amounts of zinc; copper-nickels, which contain nickel as the principal alloy metal; nickel silver, which contains copper, nickel, and zinc as the principal metals; leaded coppers, which are cast alloys containing 20% or more of lead, but no zinc or tin; and special alloys, which are copper alloys with compositions not covered in the above groups. Master alloys and hardeners are copper-based 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.

Products for Trade and Industry

At least four physicochemical properties, singly or in combination, account for the widespread use of copper and its alloys. Foremost among these is electrical conductivity. Among the electrically conductive metals, copper is second in conductivity only to silver. Electrical uses, which account for about 70% of copper demand, include electrical power transmission, motors and generators, housing and industrial wiring, automotive and appliance wiring, telecommunications, electronic circuit boards, specialized electronic equipment, and numerous other electrical and electronic applications.

The chemical stability and workability of copper are among the reasons that copper and its alloys have been extensively used in tubing and valves for systems carrying potable water, saltwater, and other aqueous fluids. Because of its good thermal conductivity, again being second only to silver in thermal conductivity, copper and its alloys were extensively used as materials of construction for heat exchangers used in motor vehicles, refrigeration, air-conditioning units, and numerous other applications. Because of its resistance to salt, copper was widely used in marine environments and automotive brake components.

Copper also was used widely, for other than electrical conductivity, in industrial machinery and transportation equipment. Because of its aesthetic appeal and resistance to weathering, copper was used in construction for roofing, flashing, decorative hardware, and guttering and downspouts. Miscellaneous uses of copper included ammunition, industrial and agricultural chemicals, pigments, fine instruments and watches, jewelry, cooking utensils, decorative items, and coinage.

Electrical uses of copper have accounted for an increasing market share over the past 20 years. Growth in consumer and business electronics and building wire demand have contributed to electrical demand growth, while materials substitution in plumbing, automotive radiators, coinage, etc., and increased imports of copper-containing manufactured goods such as automobiles, machinery, and air-conditioning units have reduced or stabilized demand for other uses. The growth in electrical demand has occurred, despite the substitution of aluminum in overhead power transmission lines; development of microwave, digital, and fiber-optic technologies for telecommunications; and downsizing of motors and switch gear. Specialty alloys, such as beryllium copper used for electronic connectors, have experienced strong growth in demand. The growth in electrical uses and the shift from wire bar technology to continuous cast wire rod has increased the demand for electrolytic copper at the expense of fire refined material. In 1989, only one domestic secondary refinery produced fire refined wire bar.

Industry Structure

Copper smelting operations have been traced back to at least 5000 B.C., but modern history and growth in demand for copper began with the discovery and commercial development of electricity in the latter part of the 19th century.[23] World copper production was estimated to be only about 50,000 tons in 1850. However, by the turn of the century, it reached an estimated 500,000 tons per year. By 1912, world mine production had reached 1 million tons. World production continued to grow, almost uninterrupted, to almost 9 million tons in 1989. More than 90% of cumulative world mine production has occurred since 1900; 60% since 1960.

In 1989, copper was mined in about 60 countries. The top 13 producing countries accounted for 85% of production. The United States and Chile were the leading producers, each accounting for about 17% of production. Copper was smelted in 40 countries and refined in 42 countries. Industrialized countries in Europe and the Far East, which lacked sufficient raw materials, encouraged mine production in the LDC's to assure supplies. These countries have long dominated world smelting and refining capacity. Thus, in 1989, Japan was second only to the United States in smelter and refinery production despite having only nominal mine production. To assure its supply of concentrates, Japanese smelters and refiners invested heavily in world mine capacity, particularly in Chile, but also in other countries. In 1989, Japanese companies owned a 15% and 33% interest, respectively, in the Chino and Morenci Mines in the United States.

European smelting-refining companies, similarly lacking in copper resources, invested in mines in Africa, Asia, and Oceania. The new Escondida Project in Chile, slated to come on-stream at the beginning of 1991, was owned by a consortium of Australian, British, and Japanese companies and, in exchange for concentrate supply contracts, financed in part by interests in Japan, Finland, and the Federal Republic of Germany. Similarly, U.S.-based Freeport-McMoRan Inc., owners of Freeport Indonesia Inc., secured a $500 million loan package to expand its concentrator and develop its Grasburg, Indonesia, deposit from banks in eight countries, one-half of which will receive Freeport concentrates.

However, in recent years the concentrate exporting countries have sought to increase their local smelting and refining capacities to supply growing domestic demand for refined copper and to maximize foreign exchange earnings. Traditional copper concentrate exporting countries with expanded smelting capacity included Australia, Chile, Mexico, and the Philippines. The PASAR smelter and refinery was commissioned in 1983 and subsequently expanded. To assure supplies to the Philippine Government-controlled (60%) operations, Philippine mines were ordered to ship a minimum of 30% of their concentrates to PASAR despite its high smelting and refining charges. In addition, newly industrialized countries such as the Republic of Korea have added capacity to meet their growing demand for refined copper. Similarly, Brazil became an exporter of brass mill products and major new brass mills were being constructed in the Republic of Korea, Philippines, and Taiwan.

In the 1950's, eight privately owned U.S. and Western European companies controlled three-fourths of world copper

TABLE 9

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)
	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	1,410	66	384	18	150	7	107	5	21	1	64	3	2,136
1987	1,494	68	395	18	132	6	88	4	22	1	66	3	2,197
1988[r]	1,592	72	332	15	133	6	66	3	22	1	66	3	2,211
1989	1,571	72	327	15	131	6	65	3	22	1	65	3	2,182

[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. Ordnance 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 uses.

production outside the U.S.S.R. By 1983, many mines in the less developed countries had been partially or totally nationalized so that more than 50% of the world's copper mine production was from Government-owned corporations. Most notable of the state-controlled mining companies that came into existence during the 1960's and 70's were the following: CODELCO-Chile, the world's largest copper producer; Zambia Consolidated Copper Mines Ltd. (ZCCM), which was formed in 1982 through the merger of state-owned Nchanga Consolidated Copper Mines Ltd. (NCCM) and Roan Consolidated Mines Ltd. (RCM), and was accountable for all of Zambia's mine production; La Générale des Carrières et des Mines du Zaire (Gécamines), which, in 1987, acquired Japanese and state-owned Société de Développement Industriel et Minière du Zaire (Sodimiza) to account for all of Zaire's production; and Empresa Minera del Centro del Perú (Centromín Perú), Empresa-Minera del Perú (Minero Perú), and Empresa Minera Especial Tintaya S.A. (Tintaya), which combined accounted for about one-third of Peru's mine capacity.

Since 1983, state control of copper production has declined slightly to about 50% of world capacity owing to contraction of some state-controlled operations and capacity growth in the private sector. All of the greenfield copper projects that came on-stream since 1983 or were slated to come on-stream over the next several years were privately owned.

Following the supply-demand imbalance in 1982, which led to accumulation of massive world refined copper inventories, copper prices were severely depressed. The fall-off in copper revenues resulted in

sustained economic losses by some copper producers and mine closures. In some countries, such as Chile and the Philippines, price support mechanisms were instituted to aide the private mining sector.

Significant restructuring by both state-controlled and privately held copper producers occurred in efforts to rationalize production and reduce operating costs. In Zaire, Gécamines, which operated about 1 dozen mines in three geographic regions along the Copperbelt of Central Africa, launched a 5-year, $870 million rehabilitation project in 1985, including plans for a new refinery. In Zambia, ZCCM began a 5-year plan in 1986 to streamline and rationalize production to stem the decline in annual output. The decline was ascribed to low equipment availability owing to a shortage of spare parts, insufficient skilled labor, an exodus of engineering staff, unreliable transportation to African ports, and a shortage of sulfuric acid for expanded leach operations. As part of the revitalization, the Chambishi Mine was closed, new reserves at Mufulira were developed, the worker training budget was increased 16-fold, and various national economic policies were adopted to ensure capital.

In the Philippines, most of seven mining companies continued to sustain losses, even after the recovery of copper prices in 1987. Atlas Consolidated Mining Development Corp., the largest Philippine producer, closed several open pit operations but was expanding high-grade underground operations and developing a new open pit to replenish reserves.

In Mexico, the two State-controlled mining companies, Mexicana de Cobra S.A., which operated the La Caridad Mine, and Cia Minera de Cananea S.A., which operated the Cananea Mine, together accounting for about 98% of production in Mexico, were offered for sale in 1988 in an effort to reduce Federal debt by selling nonstrategic assets. Cananea remained unsold through 1989.

In Chile, capital investments in excess of $2 billion and devaluation of currency helped to halve operating costs at CODELCO-Chile's four divisions over the decade ending in 1985, to make it one of the world's lowest cost copper producers. CODELCO-Chile, which operated the world's largest open pit (Chuquicamata) and underground (El Teniente) mines, continued to invest heavily to maintain and expand production in light of rapidly declining ore grades. In 1988, CODELCO-Chile announced a $1.25 billion, 5-year investment program that was projected to boost production by 200,000 tons to 1.38 million tons. Despite these investments, production by CODELCO-Chile remained nearly constant between 1986 and 1988, with most of Chilean production increases over that period coming from the private sector. However, production in Chile rose significantly in 1989, owing to capacity increases at Chuquicamata.

In the United States, major rationalization and ownership changes, restructuring, labor concessions, and major capital investments revitalized the copper industry and reduced average production costs from more than 80 cents per pound in 1982 to less than 60 cents per pound in 1989. Production rose from 1.04 million tons in 1983 to 1.5 million in 1989, just slightly short of the record production level set in 1973. Foremost in technology changes were expansion of lower cost SX-EW technology, in-pit crushing and conveying systems, and flash smelting technology. By 1989, with the sale of Kennecott to RTZ, oil companies, which in the late 1970's had seen domestic copper companies as attractive acquisitions, had divested their domestic copper holdings.

Though about 20 different companies operated a total of more than 60 copper-producing mines in the United States, 4 companies, Phelps Dodge Corp., Cyprus Minerals, Asarco, and Magma accounted for 90% of domestic capacity. Major industry ownership changes occurred as companies sought to raise capital for production increases and become more self-sufficient through vertical integration of mines, smelters, refineries, and rod mills.

Several companies, including Inspiration Resources, Noranda, and AMAX, totally divested their U.S. copper holdings. In 1986, Kennecott, the largest domestic producer (then owned by BP Minerals), in exchange for labor concessions, agreed to reopen its shuttered Bingham Canyon Mine and invest $400 million in modernization of its Utah operations. To raise capital, it sold its Chino and Ray Mines. Phelps Dodge emerged as the largest and lowest cost domestic copper producer following the purchase of Chino, restructuring of its labor force, major investments in electrowinning capacity, and investment in in-pit crushing and conveying technology.

Magma invested $200 million in a new flash smelter and acid plant at San Manuel. The new smelter provided the sulfuric acid necessary to develop open pit and in situ copper oxide reserves and to lower overall production costs. Asarco acquired the Ray Mine, full control of the Mission Complex reserves and other properties, switching from a custom smelter to an integrated producer. Between 1986 and 1989, Cyprus Minerals also acquired several properties from other companies.

The U.S. primary smelting industry underwent significant contraction with the coincidence of depressed copper prices and a yearend 1987 compliance deadline with the clean air regulations. Between 1983 and 1986, 7 of 13 primary smelters, most of which were noncompliance reverberatory smelters operating under interim compliance orders, were permanently closed. Insufficient smelting capacity for processing its concentrates prompted the acquisition of the Inspiration smelter and Lakeshore roast-leach plant by Cyprus Minerals and Chino smelter by Phelps Dodge. With the recovery of copper mine production, the United States became a significant exporter of concentrates.

The erosion of U.S. ownership of world copper production, which has been the case since the nationalizations of the 1960's, took on a new dimension in the 1980's, with foreign companies investing in domestic mines. In addition to foreign ownership of Kennecott, first by BP and later by RTZ, and Japanese investment in the Chino and Morenci Mines, Copper Range sold its mine, smelter, and refinery in White Pine, MI, in 1989 to a Canadian subsidiary of Metallgesellschaft AG. of Germany. Mitsubishi Metals of Japan planned to construct a copper smelter in Texas.

While companies tended to integrate their unwrought copper production facilities, the 25-year-old trend away from the strong ties between downstream processors and mine producers continued. In 1986, Anaconda sold its American Brass divisions. Ownership of Chase Brass, which had been reorganized in 1986 into separate operating divisions along product lines, remained partially with BP Minerals America when RTZ purchased Kennecott. Phelps Dodge sold or closed much of its wire production facilities. Where the brass industry was dominated by a few full-line mills, it evolved into four distinct industries with mills having single or limited product lines: Strip, sheet, and plate; plumbing and commercial tube; alloy wire and rod; and unalloyed copper wire rod for electrical wire production. Only the copper wire rod mills retained their association with the primary producers. Low processing margins

and increased import competition during the period of low copper prices hastened the trend toward sell-off or closure of unprofitable operations and specialization of product line.[24] Imports of semifabricated products doubled over a 10-year period, reaching their peak in 1984 of more than 260,000 tons. Though still high by historic standards, import penetration has declined slightly owing to successful antidumping suits filed by the domestic industry, restructuring of the domestic industry, and a weakened U.S. dollar.

Production and consumption of brass and bronze ingot in the United States declined markedly between the late 1960's and early 1980's owing to the substitution of plastics and aluminum for brass and bronze castings, increased import penetration, and more stringent environmental regulation being applied to ingot makers and foundries. Over that time period, domestic production of alloy ingot fell by 40%, and more than one-half of the approximately 40 ingot makers were closed. The foundry industry underwent a similar contraction, with alloy ingot consumption falling by a commensurate amount. However, since about 1985, domestic production and consumption of alloy ingot stabilized at about 180,000 tons per year.

Geology—Resources

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 percentage of total world capacity, the predominant type mined was that of the porphyry copper and associated deposits (59%), followed by stratiform sedimentary replacement and metasedimentary deposits (23%), 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 contained a wider variety of other mineral coproducts. In the United States, porphyry copper deposits made up 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 $(CuFe)_{12}Sb_4S_{13}$). 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.

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 had the largest share (22%) 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 had 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 (USGS) estimated total world land-based copper resources, comprised of the reserve base and a larger body of less well characterized resource, was about 1.6 billion tons.

Copper reserves reported at operating or developing properties were sufficient to meet a projected cumulative demand of nearly 130 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 23% and production by only 17%, while consumption grew by an impressive 36%. Since the late 1970's, the preoccupation with gold exploration and general neglect of base-metal exploration led to a significant decline of reserves in Canada, Peru, the Philippines, and other countries. Unless substantial new discoveries occur immediately, some countries' output will decline by the late 1990's. According to a recent Canadian analysis, to maintain 1988 Canadian production, each mine approaching exhaustion must be replaced by a new operation, based on a discovery some 6 years earlier.[25] Canadian copper production is forecast to fall off sharply by 1994 because mine reserves would be exhausted. The large reserves of copper in Canada were discovered during the period of high base-metal exploration that existed through the late 1950's to the early 1970's.

Technology

Exploration.—Exploration for copper deposits in the United States generally takes

TABLE 10

COPPER RESERVES AND RESERVE-BASE

(Million metric tons, contained copper)

Area and country	Reserves	Reserve base
North and Central America:		
Canada	13	24
Mexico	14	20
United States	55	90
Other	—	15
Total	82	149
South America:		
Chile	85	120
Peru	8	31
Other	1	21
Total	94	172
Europe:		
Poland	10	15
U.S.S.R.	37	54
Other	13	13
Total	60	82
Africa:		
Zaire	26	30
Zambia	16	34
Other	4	4
Total	46	68
Asia:		
Indonesia	3	5
Philippines	10	16
Other	17	28
Total	30	49
Oceania:		
Australia	17	41
Papua New Guinea	7	13
Total	24	54
Grand total	336	574
Of which:		
Market economy countries	281	492
Centrally planned economies	55	82

place in potential areas within which the anticipated copper deposit is masked by postore cover in the form of alluvium and volcanic or sedimentary rock. Following discovery of a potential deposit by geophysical and chemical 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. Copper exploration was seriously lacking through most of the 1970's and 1980's, but has received renewed vigor since the high prices of the late 1980's. In the United States, recent exploration and development has focused on oxide ores suitable for processing by low-cost, leaching SX-EW technology and on the stratiform ores of Montana.

Studies of the geologic environments of identified deposits may lead to a basis for predictive metallogeny of other parts of the same area. For example, the USGS considered the Midcontinent rift area of the United States as a particularly important geologic environment for certain types of mineral deposits. The rift structure extends for 2,000 kilometers from Kansas, northeast through the Lake Superior region, and bends southeast into Michigan. A new USGS project was designed to characterize the rift and provide metallogenetic analysis of types of minerals deposits that may be expected. Identified occurrences included the copper-nickel sulfides of the Duluth complex, stratiform deposits of the Keweenaw Peninsula, MI, and copper-molybdenum bearing breccia pipes of Ontario.[26]

Mining and Beneficiation.—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 waste-to-ore stripping 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 geophysical 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.[27] Following extraction, run-of-the-mine ore is milled (successively 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 modern smelting.

Faced with higher energy costs, deeper mines with longer haul distances, high labor rates, and lower ore grades, the domestic industry has fought to maintain and subsequently 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 strategies 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; increased equipment scale, including trucks and flotation cells; computer-controlled truck dispatch systems; and improved on-line sampling and automated reagent control in the mill.

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 through solvent extraction to concentrate the copper in solution. Copper is recovered from the concentrated solution by electrowinning where copper is plated directly from solution onto a starter cathode. The resultant electrolytically pure copper 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 processing oxidized ores, mines have realized tremendous cost savings by leaching existing waste and ore dumps and by adjusting cutoff grades to the concentrator upward, with lower grade material being processed by SX-EW.

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 358,000 tons of copper in 1989. Similarly, SX-EW capacity for the world, which was estimated to be 910,000 tons of copper per year in 1989, was expected to exceed 1.3 million tons by 1995.

Smelting.—Most copper concentrates are processed through three-stage smelting to produce anode suitable for electrolytic refining. Concentrate is processed in the primary smelting reactor to produce a

copper and iron sulfide matte containing up to 60% copper. The matte is oxidized in a converter, forming iron oxides that are removed in the slag and blister copper containing in excess of 98% copper. Sulfur is removed as sulfur dioxide in the gas streams. Blister copper is fire refined in an anode furnace to remove oxygen and other impurities. The anodes 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. The resulting cathode is 99.9% pure and suitable for most electrical applications of copper. Valuable impurities, including the precious metal values, collect as sludge in the bottom of the electrolytic cell.

In 1970, environmental constraints and energy costs became a prime concern of the domestic smelting industry. Through the late 1970's and mid-1980's, domestic smelters were able to use interim methods such as tall stacks and intermittent operation to meet sulfur dioxide emissions standards. However, by the 1987 compliance date, most remaining smelters had abandoned traditional reverberatory smelting and had adopted one of the various oxygen enriched smelting furnaces (Outokumpu flash, Noranda, Inco flash, Mitsubishi continuous). These furnaces generally required lower energy input and provided a more concentrated sulfur dioxide gas stream, which allowed for sulfuric acid production as a means of sulfur dioxide capture. The byproduct sulfuric acid has provided a readily available, inexpensive source of acid for expansion of the SX-EW capacity.

Flash smelting involves the blowing of concentrate, flux, and oxygen into a hot furnace. The sulfur and iron in the concentrate react rapidly (flash) with the oxygen, and release a tremendous amount of heat. Flash processes using oxygen or oxygen-enriched air are generally autogenous, requiring no external fuel input. In 1988, Magma commissioned the world's largest single furnace Outokumpu flash smelter. The majority of new smelters constructed worldwide since 1970 were Outokumpu flash smelters. However, in the United States, two new Inco furnaces, at Hayden, AZ, and Hurley, NM, were 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 produce a higher grade copper matte.[28] Cyprus operated the only domestic electric furnace, the Copper Hill smelter, having shutdown in 1987. Though electric furnaces require a large electrical energy input, they produce a low-copper slag suitable for direct disposal and can process a variety of materials.

Asarco, which operated one of the two remaining reverberatory smelters at its El Paso smelter, announced plans to install a Contop (Continuous Top-Blowing process) flash smelter. In this newly developed, autogenous process, concentrate is continuously melted in a cyclone furnace located 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. Also, because of its relatively low capital requirement and compact size, it was reportedly well-suited for retrofit installation.[29]

The rapid advancement in continuous cast technology for rod and sheet since the middle 1970's and the increasing dominance of the electrical end-use market has promoted the need for high-purity forms of copper. 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, which does not require further refining. The increase in continuous cast wire rod capacity has rendered the wire bar, an intermediate cast shape, almost obsolete and has effectively shifted intermediary casting from the refinery to the mill. Though it has not replaced deep-well casting of intermediate, cake slab, and billet, continuous casting technology also has been developed for the sheet and tube sectors.

Recycling.—The Institute of Scrap Recycling Industries Inc. (ISRI), recognized more than 50 classes of copper and copper alloy scrap. Although there were several grades of scrap within each, the major unalloyed scrap categories were No. 1 copper, which contained greater than 99% copper and often could be simply remelted, and No. 2 copper, which contained between 94.5% to 99% copper and usually had to be rerefined. In recent years, about 1.6 million tons of copper-base scrap, containing an estimated 1.3 million tons of copper, was consumed annually in the United States. The largest scrap categories were as follows: No.1 copper, 26%; No. 2 copper, 25%; yellow brass, 21%; cartridge cases, 9%; automobile radiators, 7%; low-grade ashes and residues, 4%; red brass, 3%; and refinery brass, 2%. A wide variety of alloys made up the remaining 3%. Brass and copper tube mills consumed 65% of No. 1 copper and most of the cartridge cases and yellow brass, while the secondary smelters and ingot makers consumed 85% 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 scrap directly. One U.S. wire rod producing company constructed a continuous-process scrap refining and wire rod casting plant in which it processed No. 1 return scrap from making wire in its own plants.

Scrap was classified into two general categories called old scrap and new scrap, depending on its origins. New scrap, or manufacturing scrap, was generated during the fabrication of copper products and was returned to the mill for reprocessing (return scrap) or sold; it was not considered a new source of copper supply by the Bureau of Mines. New scrap was termed "run-a-round" or home scrap when it was generated internally at the plant consuming it.

Old scrap was generated from wornout, discarded, or obsolete copper products and was considered to be a reservoir of recoverable copper, and thus, was a 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% and 33% of U.S. apparent demand and, on average, provided about 18% of world copper demand. It was estimated that the world copper reservoir of items in use or abandoned in place from which old scrap can be recovered exceeded 173 million tons. The U.S. old scrap reservoir was estimated to exceed 66 million tons or 38% of the world's total.

The rate of old scrap recovery was 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%-60% in the 1940's to about 40% in the 1980's. The decline in the old scrap component, relative to new scrap consumed, could be correlated not only to an increasing manufacturing base from which

to generate new scrap, but to a changing demand pattern in which electrical uses became more dominant. Essential electrical uses, which now form greater than 70% of the market, were less likely to be scrapped. 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 depression years of the 1930's.

In the United States, about 44% of total annual copper consumption was from copper in old and purchased new scrap. A similar percentage, 36%, was consumed in the EC, which collectively comprised one of the largest sources of copper scrap in the world. The intensity of scrap consumption varied in different parts of the copper industry. For example, scrap made up nearly all of the copper raw material for ingot makers, who made specialty alloy ingot for use in foundries. The same was true for mills producing yellow and leaded-yellow brass rod and for many copper tube mills. In both Europe and the United States, many of the smelters and refiners used scrap as feed, a trend that had been increasing. In recent years, about 40% of refined copper produced in Western Europe and about 24% of refined copper in the United States was derived from copper scrap. Copper scrap provided an average of about 19% of the world's refined copper annually. Direct melt copper and copper alloy scrap, used mostly by brass mills and foundries, was more than double that used to make refined copper.

Economic Factors

Prices.—Each copper product, including scrap, from mine through refinery has a distinct pricing mechanism linked, for the most part, to its copper content and the market price for refined copper. For example, copper concentrates, which contain between 20% and 30% copper, were purchased on the basis of recoverable copper content and anticipated smelter and refinery charges for processing.

Copper concentrates were sold 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 materials. Without such contracts, new mines would find development financing difficult. Contracts provided for two types of charges. A treatment charge was assessed for every ton of concentrate by the smelter, and a refining charge was assessed for every pound of recoverable copper contained. There was generally a provision for the smelter to participate in copper price rises. There also were penalties for undesirable impurities, such as antimony, arsenic, and bismuth, and credits or additional payment for precious metals in the concentrates. Anticipated material losses were figured into credit terms.

Refined copper prices varied according to its 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. In 1989, wirebar comprised less than 1% of refined copper trade. Copper wire rod prices were based on the refined copper cathode price plus a processing premium. In the case of scrap, the spread between the purchase price of scrap and refined copper must be sufficient to allow for processing costs.

Refined prices not only reflect 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 London Metal Exchange (LME) or COMEX. Trading in copper began on the LME January 1, 1877, and on the COMEX May 15, 1929. Futures contracts changed gradually over the years to correspond to the most active markets. The LME dropped its wirebar 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 periodic 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 when inventories accumulated on the exchanges and the COMEX price became more influential and have adopted 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 can prove to be less than satisfactory for the consumer. The conventional producer pricing system tended to provide less volatility in 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 increasingly used futures contracts and the newly introduced copper options to hedge their sales and purchases and protect themselves against fluctuations in the market.

Table 11 gives average U.S. producers' copper price by decade in both constant 1987 dollars and current dollars. Based on constant dollars, one must look to the depression era of the 1930's to find prices as low as those occurring in the 1979-88 decade. Since that time, current dollar prices have approached the long-term 1901-89 constant dollar average of $1.32 per pound.

TABLE 11

AVERAGE COPPER PRICES, BY DECADE[1]

(Cents per pound)

Period	Average annual price	Based on constant 1987 dollars
1870-79	22.88	330.64
1880-89	15.42	210.86
1890-99	12.25	169.33
1901-09	15.05	213.10
1910-19	18.87	217.56
1920-29	14.63	114.10
1930-39	9.67	87.52
1940-49	14.87	97.96
1950-59	29.66	131.00
1960-69	35.51	121.71
1970-79	65.69	133.22
1979-88	82.99	92.03
Averages:		
1870-1988	27.59	160.40
1901-88	31.37	133.75

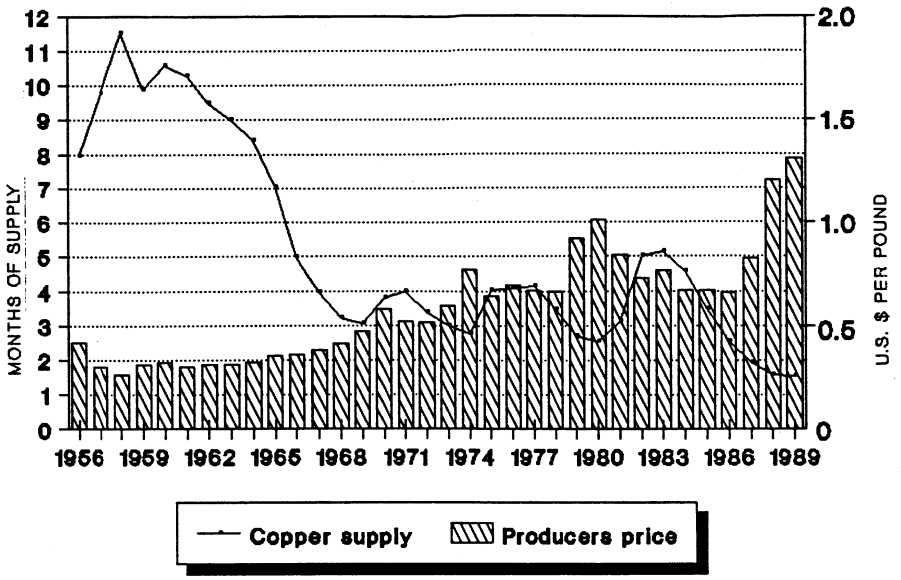
[1]Bureau of Mines. Nonferrous Metal Prices in the United States through 1988. Special publication, 1989, p. 33.

Copper prices not only responded to changes in the world economy but also to large copper inventory accumulation, copper cartel actions to restrict production, which were most effective before World War II, and from time to time to speculative influences on the commodity exchanges. The relationship of copper prices to U.S. supply levels are shown in figure 3. Significant events affecting copper supply and demand, prices, and inventory levels have been described in a recent paper by the Bureau of Mines.[30]

Surplus refined copper inventories not only have accumulated in response to periods of economic recession, but also as a result of U.S. Government purchases for, and release from, the National Defense Stockpile. High commercial inventory levels had a depressing effect on prices when these surplus supplies were released onto the market to compete with newly mined copper. In addition, whenever commercial refined copper stocks, for whatever reason, fell below 1 month's supply at prevailing consumption rates, prices took a sharp upward climb. Trends in U.S. copper inventories since 1955 are shown in table 12.

FIGURE 3

GRAPH DEPICTING SUPPLY LEVELS VS. PRICES



Source: Bureau of Mines; Aug. 1990.

Governmental Monetary, Trade, and Other Policies.—Government policies to control prices, levy tariffs, impose import quotas and export controls, provide price supports, lend monies for expansion and exploration, guarantee production purchases, levy taxes, and expand or contract the money supply all have had significant impact on copper supply and demand. In the United States, nearly all of these mechanisms were applied at one time or another. For example, prices were controlled at the end of World War I, during and after World War II, during the Korean war (1950-53), and near the end of the Vietnam war (1971-74).

U.S. export controls on copper and copper scrap were implemented during World War II and off and on through much of the 1950's and 1960's owing to recurring supply shortages during this period. On November 17, 1965, the U.S. Government announced a four-point program to reduce inflationary pressures on the price of copper that might impair the defense effort in Vietnam. The program called for release of material from the National Defense Stockpile, control of exports of copper and copper scrap for an indefinite period, legislation to suspend the 1.7% per pound import duty on copper, and the imposition of higher margin requirements on copper trading by COMEX to lessen speculation in the metal. Export controls on copper products were terminated finally in September 1970 as a result of the dramatic reversal in supply balance that year from shortage to surplus.

Many other countries also have had export controls on copper products. The EC imposed export controls on scrap from 1971 to yearend 1989. Some countries, such as Taiwan, used import or export licensing mechanisms to enforce trade restrictions. Because of pollution problems at the Tafa Industrial District, imports of pollution-prone materials such as insulated electric wire or cable have been banned by Taiwan's Environmental Protection Administration since October 1989. Sweden maintained export restrictions on copper waste and scrap. Japan has maintained restrictions on copper waste and scrap since 1965. After June 1986, scrap export from Japan was possible only through a license granted by the Agency for National Resources and Energy. Australia also maintained an export prohibition on copper and copper alloy scrap. New Zealand maintained export restrictions on copper ores, concentrates, matte, unwrought copper, and copper waste. In addition, New Zealand had discretionary import licensing on copper bars and rods.

Most developed countries had most-favored-nation (MFN) duties on copper and copper products. Although copper ores and concentrates were frequently MFN duty free, duties often increased with various stages of processing. Most countries applied tariffs on wrought copper products and copper chemicals. All developed countries also granted duty-free or preferential rates under the 1974 Trade Act, Generalized System of Preferences (GSP) schemes for developing countries.

The U.S. GSP was started on January 1, 1976, and provided for duty-free treatment for up to 10 years on a wide range of articles, including copper, imported directly from any developing country designated as a beneficiary developing country. There were program limitations to GSP status based on the value of the imported article. The EC scheme for GSP granted duty-free access to imports of copper semimanufactures and manufactures from 89 developing and 38 least developed countries. The EC also granted duty free treatment to members of the Lome Convention and Mediterranean countries,

TABLE 12

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	564
1985	20	100	5	66	109	300	20	320
1986	14	66	5	r35	84	205	20	r224
1987	15	28	r3	29	17	93	20	r112
1988	17	29	4	16	12	78	20	98
1989	12	32	9	18	15	84	20	106

rRevised.

[1]Semifabricated forms such as rod, sheet, etc., at consumers are not included. Data source was various issues of Bureau of Mines Mineral Industry Surveys and unpublished Bureau worksheets for the years 1955-70. Data for 1955-86 have been published in the Minerals Yearbook, 1986, copper chapter.

[2]Stocks held by ingot-makers, 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.

including Yugoslavia. Imported copper ores and concentrates enjoyed duty-free MFN status in Japan and accounted for about 70% of total Japanese imports. MFN rates for matte and copper scrap were also zero. Other unwrought copper was subject to MFN rates ranging from 3.2% to 7.3% on the value. Imports of copper manufactures were subject to even higher rates.

In recent years, some countries sought to promote copper production through temporary guaranteed price-support systems, as in Brazil, Chile (small- and medium-size mining sector), and the Philippines. Some countries used protective tariffs to aid domestic copper industries, as in Japan and the Republic of Korea; import restrictions, as in Brazil; and direct financial aid through loan guarantees and assumptions of company debt, as in the Philippines. In addition to drastic devaluations of currencies, these policies were effective in maintaining production in the face of falling dollar-denominated prices.

U.S. monetary policies have had a significant effect on the "real" price of copper, as well as on the general economic well-being and international competitiveness of the U.S. copper industry. The stable gold price following the Gold Reserve Act of 1934 had a general stabilizing effect on most industrial metal prices. Beginning with the monetary arrangements of the Bretton Woods Agreement of July 1945, which established the World Bank and the International Monetary Fund, a number of events had significant effect on the value of copper. One of the reasons for the extreme variability and inflation in copper prices since the 1960's was the destabilization of monetary arrangements that followed the U.S. Coinage Act of 1965, the cessation of silver certificates in 1967, the elimination of the gold reserve requirement in 1968, and the abandonment of fixed exchange rates in 1973. International debt reached record heights as a result of the Vietnam war and extensive borrowing done by the less developed countries in pursuit of economic expansion during the 1960's and early 1970's. These debts were compounded by the Organization of Petroleum Exporting Countries cartel action to increase the price of petroleum in 1974 and again in 1978. Oil shortages, inflationary prices, and economic downturns began to adversely affect world markets. Many of the developing countries adopted austerity measures because of heavy debt burdens, including devaluation of currencies by as much as 600% against the U.S. dollar. When inflationary pressures built up in the United States, the Federal Reserve Board restrained the money supply and increased interest rates.

The sustained strength of the U.S. dollar through the mid-1970's and 1980's and the series of devaluations by other countries to improve their balance of payments severely impacted the competitiveness of the U.S. copper industry. The effects of a strong dollar, high interest rates, and of high energy, labor, and environmental compliance

costs combined with the effect of copper surpluses and a depressed world market proved to be insurmountable for some mines. In response, the U.S. industry implemented innovative technology and productivity measures to cut costs. Considerable financial restructuring that often involved ownership changes also was necessary to gain sufficient capital to carry out the changes.

Operating Factors

Costs—Production.—In recent years all domestic and most world producers endeavored to cut production costs in an effort to remain competitive through periods of prolonged depressed prices, such as that experienced during the mid-1980's. Domestic producers adjusted mine plans, reduced stripping ratios, and raised cutoff grades. Large capital investments were made in new in-pit crushing and conveying systems and on mill and concentrator expansions or replacements. Lower cost SX-EW capacity was expanded to process both oxidized ores and the higher grade waste dumps resulting from increased cutoff grades. Consolidation of assets through ownership changes improved operating efficiencies. Overall labor costs were reduced through improved employee productivity and wage and work-rule concessions by union and nonunion miners. Productivity at mines, in terms of worker hours per ton of copper produced, declined from more than 40 hours in 1980 to 28 hours in 1983 to an average 18 hours in the 1985-90 period. Similar cost savings were realized through smelter renovations and renegotiation of smelter contracts.

Byproduct values and the combined affects of inflation, Governmental monetary policy, and exchange rates also affected operating costs. A study prepared by the Minerals Availability Field Office, Bureau of Mines, Denver, CO, compared operating cost factors for 89 mines operating in both 1981 and 1987. Table 13 shows the impact that technical factors, byproduct values, and the combined affects of inflation and exchange rate (I/ER) had on production costs. In the United States, technological improvements overcame a competitive disadvantage from shifting byproduct credits and I/ER. Conversely, devaluation of the kwacha and improved byproduct prices allowed Zambia to remain competitive despite deteriorating technical factors.[31]

TABLE 13

FACTORS AFFECTING COPPER PRODUCTION COSTS FOR MAJOR MEC COPPER PRODUCERS[1]

(U.S. dollars per pound of copper)

	Production costs at common mines, 1981	Cost changes, 1981-87			Production costs at common mines, 1987
		Byproduct credit[2]	Inflation-exchange rate[3]	Technical factors[4]	
Canada	0.48	0.06	0.24	-0.35	0.45
Chile	.46	.05	-.21	.00	.30
Mexico	.61	.06	-.19	.01	.49
Peru	.63	.00	.16	-.24	.55
Philippines	.63	-.09	-.05	-.02	.47
United States	.84	.04	.33	-.68	.53
Zaire	.48	.02	-.39	.34	.45
Zambia	.71	-.04	-.43	.19	.43

[1]Porter, K. E. and P. R. Thomas. International Competitiveness of U.S. Copper Production, 1981-87. Bureau of Mines, Mineral Issues 1989, Table 2—3, p. 14.

[2]A decrease in byproduct prices between 1981 and 1987 results in an increase in production costs.

[3]Represents the combined effect of changes in inflation and exchange rates. A negative value reflects an over devaluation of local currency in relation to local inflation.

[4]Included are the impacts of changes in stripping ratios, feed grades, smelting and refining charges, labor force and wage rates, technology, and other changes that were implemented to reduce costs and improve competitive positions. It was not possible to disaggregate this category into individual factors.

Capital.—An analysis of total development costs for 60 new mine projects in Australia, Brazil, Botswana, Burma, Canada, Chile, Indonesia, Pakistan, Panama, Papua New Guinea, Peru, the Philippines, Portugal, Turkey, and the United States indicated an average of $8,100 per ton of copper capacity must be invested to bring a new mine on-stream. Mine expansions at established mines, on the other hand, averaged $3,200 per ton of copper capacity. A new SX-EW plant cost an average of $2,400 per ton and a new smelter an average of $1,800 per ton of copper to construct. New mine costs varied widely with location, size, and type of mine; for example, the 300,000-ton-per-year Escondida open pit mine in Chile was estimated to cost about $3,200 per ton of copper, whereas the proposed Geddes underground mine in British Columbia and Olympic Dam Mine in Australia were around $10,000 per ton, according to published estimates.

Total project financing also varied with location, size, and type of mine. Financing required for expansion at an existing mine ranged from $48 million for the Morenci, AZ, expansion to $500 million for the Chuquicamata, Chile, expansion. Of the total 60 projects analyzed, the average new mine would cost $300 million to develop. Of 11 new mine projects in Peru, the average cost was about $400 million. Some individual projects, such as the Escondida Mine were to cost more than $1 billion to bring into production. The average of 19 SX-EW projects was $63 million, including expansions at existing plants.

Environmental Requirements.—The many environmental protection laws and regulations that have been promulgated in the United States since the late 1960's have impacted the copper industry in many ways. Most of the cost of compliance with environmental regulation was incurred at the smelter level. Although some regulations have resulted in offsetting costs through production of an additional salable product, such as sulfuric acid and reduced operating costs in modernized smelters, the net effect has been to increase total operating costs.

Laws and regulations in force that affect U.S. copper operations include those promulgated under the Federal Clean Water Act, the Clean Air Act of 1970, the National Environmental Policy Act of 1969, the Solid Waste Disposal Act (RCRA) of 1976, the Federal Surface Mining Control and Reclamation Act, the Toxic Substances Control Act, CERCLA, and numerous State laws concerned with mining techniques, reclamation of mined lands, air and water pollution, and solid waste disposal. Transportation of mineral and hazardous substances is also regulated. Ground water

regulations in Arizona were being developed and could have a greater impact on the copper industry than surface water quality. The new Arizona Aquifer Protection Permit program was expected to have important impact by 1990. Arizona already had a Groundwater Protection Permit Program.[32]

Under the 1980 Bevill Amendment to RCRA, solid wastes from the extraction, beneficiation, and processing of ores and minerals were temporarily exempted from regulation as hazardous wastes under subtitle C, pending a comprehensive study to determine potential hazard and feasibility of treatment. EPA published an interim interpretation that placed wastes from exploration, mining, milling, smelting, and refining within the exclusion pending completion of a report to Congress. Acting under a court-ordered deadline, in 1986 EPA issued its regulatory determination in which it concluded that subtitle C regulation was not warranted at that time for mining and beneficiation wastes.

However, EPA's determination of the scope of the Bevill exclusion was challenged in court, and in October 1988, the court found that the intent of the Bevill exclusion was to include only those wastes from processing ores that met a special waste criteria of high volume and low hazard. In compliance with the court, on October 20, 1988, (see 53 FR 41288) EPA published a proposal to define the scope of the exclusion and listed 15 wastes it believed met the necessary criteria. On April 17, 1989, (see 54 FR 15316) the agency published a revised list containing 6 wastes that it believed met all the necessary criteria, and an additional 33 wastes that they proposed to conditionally retain pending further study. EPA felt that these 33 wastes met the high-volume criteria but that they had insufficient data to determine if they met a low-hazard criterion, established, for the first time, in the April proposal.

On September 1, 1989, (see 54 FR 36592) EPA published a Final Rule for Bevill exclusion criteria and proposed a final list of 5 wastes to be temporarily retained within Bevill, including slag from primary copper processing, as well as a reduced list of only 20 mineral processing wastes for conditional retention. Four wastes, including acid plant and scrubber blowdown from primary copper processing, were permanently removed from the Bevill exclusion. Two other copper associated wastes, bleed electrolyte from primary copper refining and wastewater from primary selenium production, were omitted for further consideration of exclusion. This final rule contained a modified definition of "processing of ores and minerals" that incorporated leaching operations and roast leaching operations and a modified definition of "large volume." On September 25 (see FR 39298), EPA narrowed the list of conditionally retained wastes to only 13.

On January 23, 1990, EPA issued a final rule that retained 15 wastes, in addition to the 5 retained in the September 1 notice, within the exclusion pending preparation of a final report to Congress and subsequent Regulatory Determination. In addition to copper slag, the copper processing wastes retained were calcium sulfate wastewater treatment plant sludge from primary copper processing and slag tailings from primary copper processing.[33]

The major thrust to the Clean Water Act (an amalgam of numerous acts and amendments, including the Federal Water Pollution Control Act of 1972 and Clean Water Act of 1977 and some 23 amendments) and its legal interpretations is through its elimination of pollutant discharge into navigable waterways through the National Pollutant Discharge Elimination System (NPDES), which provides for a permitting system to cleanup discharge of process wastewater, mine drainage water, stormwater runoff, and nonpoint sources. At U.S. copper mills, processing plants, and semifabricating plants most process water was reclaimed and reused, particularly in the southwest where there is a chronic water deficit. Mine water discharge problems usually occur when a mine and mill shuts down, largely because there is no place, such as a mill, to use the continuously discharging mine water.[34]

Energy Requirements.—Open pit mining may extend to as much as 1,500 feet below the rim, and the energy required for hauling rock from such depths becomes an important cost factor. Hauling by truck was estimated to consume as much as 54% of total processes in the pit, including drilling, blasting, loading, hauling, and ancillary processes. Grinding and concentration consume about 45% of the energy used in the milling. The lower the ore grade, the more ore that must be processed and the finer the grinding required and thus, more energy consumed.

Major improvements in energy use in mining and milling have been made in recent years through improved strategies in grinding, concentration, and ore transportation. The use of larger flotation cells has improved process efficiency and also lessened energy usage. Hydrometallurgical processes for copper recovery, such as the SX-EW recovery of copper, required more energy than pyrometallurgical processes. Electrowinning consumes 21 to 24 million British Thermal Units (Btu) per ton of cathode, or almost 20% of the total required from mine to refining stages. The in situ extraction of copper was the least energy consuming process, despite the low (50%) recovery. Energy consumption in dump leaching was higher owing to pumping requirements for leachate circulation and cementation. The combined total energy required for dump leaching, cementation, and refining is about 94 million Btu per ton of cathode copper.[35]

Flash furnace technology and the Noranda and Mitsubishi continuous smelting technologies have resulted in energy savings. Energy consumption in millions of Btu per ton of refined copper recovered were reported as follows: Outokumpu flash smelting (18.92 million Btu), Inco flash smelting (21.25 million Btu), Noranda continuous smelting (24 million Btu), Mitsubishi continuous smelting (19.16 million Btu), and Oxy Fuel Reverberatory smelting (26.62 million Btu).[36]

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[1]All quantities in this chapter are given in metric tons unless otherwise specified.

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[3]Montana Standard. County Stands to Gain From Ore Tax Change. Butte, MT, Apr. 1, 1989, p. 2.

[4]The Wall Street Journal. Labor of Love, How Cyprus Mine in Arizona Wooed Most Workers Away From Their Union Loyalties. Aug. 8, 1989, p. A6.

[5]American Metal Market. Copper Firms Lag on Incentive Plans. V. 97, No. 119, June 20, 1989, pp. 1, 20.

[6]Southwestern Pay Dirt. Cyprus Miami Workers Receive Bonus. Jan. 1990, p. 9A.

[7]ASARCO Incorporated. 1989 Company Annual Report, pp. 21-22.

[8]Cyprus Minerals Co. 1989 Company Annual Report, pp. 5, 9, 27.

[9]Southwestern Pay Dirt. SRP Adds Extra Charge for Electricity to Cyprus Miami. Aug. 1989, p. 5A.

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[13]The Wallace Miner. Seepage From Tailings Pond Draws Concern. Wallace, ID, Mar. 30, 1989, p. 2.

[14]Southwestern Pay Dirt. New Mexico Agency Weighs Comment on Cyprus Deming Mill. Nov. 1989, p. 20A.

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[16]Pages 27-28 of work cited in footnote 8.

[17]Southwestern Pay Dirt. Pinos Altos Joint Venture Pact Near Completion. Sept. 1989, p. 6A.

[18]Southwestern Pay Dirt. Magma Still Smelting for Cyprus; Arbitration Seen for Fuss. Aug. 1989, p. 3A.

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[34]Work cited in footnote 31.

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[36]Work cited in footnote 35.

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TABLE 14

MINE PRODUCTION OF RECOVERABLE COPPER IN THE UNITED STATES, BY MONTH AND BY STATE

(Metric tons)

	1985	1986	1987[r]	1988[r]	1989
Month:					
January	92,696	98,725	101,563	110,863	127,188
February	87,087	86,953	92,154	102,507	121,491
March	100,168	96,343	105,904	120,936	134,205
April	93,639	93,840	98,040	111,851	125,521
May	96,832	97,117	104,404	120,981	127,860
June	90,223	95,879	102,007	115,826	121,759
July	90,711	94,777	104,000	116,131	122,518
August	87,444	94,418	107,004	128,163	127,516
September	81,896	97,201	105,180	120,031	122,490
October	94,218	99,969	104,586	123,646	125,174
November	91,384	92,253	108,324	121,308	118,169
December	98,525	96,738	110,430	124,685	123,567
Total	1,104,823	1,144,213	1,243,596	1,416,928	1,497,458
State:					
Arizona	795,622	786,111	751,031	842,728	898,315
New Mexico	W	W	246,532	258,660	259,432
Michigan, Montana, Utah	W	78,950	222,432	295,489	314,313
Other States[1]	309,201	279,152	23,601	20,051	25,398
Total	1,104,823	1,144,213	1,243,596	1,416,928	1,497,458

[r]Revised. W Withheld to avoid disclosing company proprietary data, included in "Other States."

[1]Includes California, Colorado, Idaho, Illinois, Missouri, and Tennessee. 1985 includes Michigan, Montana, New Mexico, and Utah; 1986 includes New Mexico; 1987 includes Washington.

TABLE 15

TWENTY-FIVE LEADING COPPER-PRODUCING MINES IN THE UNITED STATES IN 1989, 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	305
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	160
4	Chino	do.	Phelps Dodge Corp.	Copper-molybdenum ore, concentrated and leached	150
5	San Manuel	Pinal, AZ	Magma Copper Co.	do.	130
6	Ray	do.	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.	97
9	Pinto Valley	Gila, AZ	Pinto Valley Copper Corp.	do.	92
10	Inspiration	do.	Cyprus Miami Mining Corp.	Copper ore, leached	65
11	Mission Complex	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	70
12	White Pine	Ontonagon, MI	Copper Range Co.	do.	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	San Xavier	Pima, AZ	do.	Copper ore, concentrated	15
16	Casteel	Iron, MO	The Doe Run Co.	Lead-copper ore, concentrated	NA
17	Twin Buttes	Pima, AZ	Cyprus Sierrita Corp.	Copper ore, leached	20
18	Miami	Gila, AZ	Pinto Valley Copper Corp.	do.	6
19	Silver Bell	Pima, AZ	ASARCO Incorporated	do.	5
20	Pinos Altos	Grant, NM	Cyprus Pinos Altos Corp.	Copper ore, concentrated	8
21	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore, concentrated	NA
22	Lakeshore	Pinal, AZ	Cyprus Casa Grande Corp.	Copper ore, leached	5
23	Magmont	Iron, MO	Cominco American Incorporated	Lead-zinc ore, concentrated	NA
24	Viburnum No. 28	do.	The Doe Run Co.	Lead-copper ore, concentrated	NA
25	Fletcher	Reynolds, MO	do.	Lead-zinc ore, concentrated	NA

NA Not available.

TABLE 16

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	1985		1986		1987		1988		1989	
	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper[r]	Gross weight	Recoverable copper
Mined copper ore:										
Concentrated	164,029,000	905,537	170,020,000	906,072	201,434,000	991,857	[r]222,268,000	1,113,287	230,526,000	1,126,382
Leached[1]	1,161,000	98,453	2,456,000	135,448	1,198,000	[r]162,324	1,308,000	[1]227,992	6,736,000	[1]311,885
Total	165,190,000	1,003,990	172,476,000	1,041,520	202,632,000	[r]1,154,181	[r]223,576,000	1,341,279	237,262,000	1,438,267
Copper precipitates shipped; leached from tailings, dump, and in-place material	118,096	82,948	111,050	79,031	110,511	70,136	[r]69,683	49,299	47,388	34,485
Miscellaneous:										
Silver ore	1,004,000	3,745	552,000	2,599	275,000	1,194	464,000	2,098	538,000	2,355
Lead ore	6,433,000	13,410	3,336,000	7,405	W	4,463	5,357,000	8,176	—	—
Other copper-bearing ores[2]	4,867,000	729	2,513,000	13,659	5,766,000	13,622	4,864,000	16,077	14,653,000	22,352
Grand total[3]	XX	1,104,823	XX	1,144,213	XX	[r]1,243,596	XX	1,416,928	XX	1,497,458

[r]Revised. W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[1]Includes electrowon from concentrates roast-leached.

[2]Includes copper-lead ore, gold ore, gold-silver ore, lead-zinc ore, molybdenum ore, tungsten ore, zinc ore, fluorspar, flux ores, cleanup, ore shipped directly to smelters, and tailings.

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

TABLE 17

RECOVERABLE COPPER, GOLD, AND SILVER CONTENT OF CONCENTRATED COPPER ORE IN 1989

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	141,808	667,911	0.47	44,959	5,311,926	$0.32
Other[1]	88,718	480,769	.54	W	11,582,676	W
Total or average	230,526	1,148,680	.50	W	16,894,602	W

W Withheld to avoid disclosing company proprietary data.
[1]Includes Idaho, Michigan, Montana, Nevada, New Mexico, and Utah.

TABLE 18

BLISTER AND ANODE COPPER PRODUCED IN THE UNITED STATES, BY SOURCE OF MATERIAL

(Metric tons)

Source	1985	1986	1987	1988	1989
Ores and concentrates:					
Domestic	939,257	[1]908,087	[1]972,141	[1]1,042,954	[1]1,120,445
Foreign	1,424	W	W	W	W
Secondary materials	250,138	287,841	276,640	320,201	359,066
Total	1,190,819	1,195,928	1,248,781	1,363,155	1,479,511

W Withheld to avoid disclosing company proprietary data; included with "Domestic."
[1]Includes production from foreign ores and concentrates.

TABLE 19

REFINERY PRODUCTION IN THE UNITED STATES

(Metric tons)

	1985	1986[r]	1987	1988[r]	1989
PRIMARY					
Electrolytic[1]	966,778	948,623	965,621	1,178,028	1,164,948
Electrowon	90,463	125,357	161,287	227,992	311,885
Fire refined	W	W	W	W	W
Total[2]	1,057,241	1,073,981	1,126,908	1,406,020	1,476,833
SECONDARY					
Electrolytic	264,834	292,686	311,312	347,442	376,595
Fire refined	106,953	113,258	103,426	98,985	100,323
Total[2]	371,787	405,944	414,738	446,427	476,918
Grand total[2]	1,429,028	1,479,925	1,541,646	1,852,447	1,953,751
Primary domestic materials[3]	1,003,713	[4]1,073,981	[4]1,126,908	[4]1,406,020	1,351,748
Primary foreign materials[3]	53,528	W	W	W	125,085
Secondary materials	371,787	405,944	414,738	446,427	476,918
Total[2]	1,429,028	1,479,925	1,541,646	1,852,447	1,953,751

[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 20

APPARENT CONSUMPTION OF COPPER POWDER AND FLAKES IN THE UNITED STATES

Year	Production (metric tons)	Imports		Exports		Apparent consumption[1] (metric tons)
		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	
1978	16,992	1,153	$4,300	1,713	$4,597	16,432
1979	17,411	1,062	4,832	1,781	6,453	16,692
1980	13,203	896	4,675	1,766	6,397	12,333
1981	13,594	1,239	5,635	1,129	4,441	13,704
1982	9,686	1,064	4,521	959	3,834	9,791
1983	11,455	1,400	5,300	786	2,799	12,069
1984	12,783	1,490	5,341	893	3,419	13,380
1985	9,776	1,143	4,601	1,141	4,074	9,778
1986	7,898	1,277	5,198	1,367	5,353	7,808
1987	8,440	1,154	5,843	2,240	11,239	7,354
1988	9,370	1,430	9,180	2,664	11,074	8,136
1989	9,389	1,369	9,730	2,452	9,842	8,306

[1]Production plus imports minus exports.

Sources: Bureau of Mines and U.S. Department of Commerce, Bureau of the Census.

TABLE 21

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				
1985	32,740	8,265	31,952	4,353	2,958	NA
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

NA Not available.

[1]Includes consumption by producing companies.

TABLE 22

BYPRODUCT SULFURIC ACID (100% BASIS) PRODUCED IN THE UNITED STATES[1]

(Metric tons)

Plant type	1985	1986	1987	1988	1989
Copper[2]	2,230,257	2,308,804	2,542,602	2,892,655	3,075,859
Lead[3]	267,159	122,228	116,311	133,672	155,899
Zinc[4]	430,946	379,803	410,460	416,617	409,564
Total	2,928,362	2,810,835	3,069,373	3,442,944	3,641,322

[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 23

COPPER RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1985	1986	1987	1988[r]	1989[r]
KIND OF SCRAP					
New scrap:					
Copper-base	621,984	635,495	689,999	764,490	731,629
Aluminum-base	13,330	22,891	25,871	24,104	23,761
Nickel-base	328	221	240	118	47
Zinc-base	35	27	12	—	—
Total	635,677	658,634	716,122	788,712	755,437
Old scrap:					
Copper-base	487,199	461,490	481,460	498,797	526,534
Aluminum-base	15,459	15,859	16,401	19,271	16,957
Nickel-base	689	84	70	86	78
Zinc-base	60	36	6	25	27
Total	503,407	477,469	497,937	518,179	543,596
Grand total	1,139,084	1,136,103	1,214,059	1,306,891	1,299,033
FORM OF RECOVERY					
As unalloyed copper:					
At electrolytic plants	264,835	292,686	311,312	347,442	376,595
At other plants	122,834	121,760	112,445	109,036	110,385
Total	387,669	414,446	423,757	456,478	486,980
In brass and bronze	716,833	671,184	736,725	800,221	767,951
In alloy iron and steel	2,498	1,366	973	763	546
In aluminum alloys	29,423	45,781	47,932	45,632	41,356
In other alloys	1,803	359	506	327	252
In chemical compounds	[1]858	2,967	4,166	3,470	1,948
Total	751,415	721,657	790,302	850,413	812,053
Grand total	1,139,084	1,136,103	1,214,059	1,306,891	1,299,033

[r]Revised.

[1]Data do not include copper sulfate.

TABLE 24

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	
	1988[r]	1989	1988[r]	1989	1988[r]	1989
Ingot makers	24,383	22,523	127,317	120,621	151,700	143,144
Refineries[1]	146,258	140,836	300,169	336,082	446,427	476,918
Brass and wire-rod mills	573,071	549,399	35,590	35,031	608,661	584,430
Foundries and manufacturers	20,403	18,542	32,626	33,181	53,029	51,723
Chemical plants	375	329	3,095	1,619	3,470	1,948
Total	764,490	731,629	498,797	526,534	1,263,287	1,258,163

[r]Revised.

[1]Electrolytically refined and fire-refined scrap based on source of material at smelter level.

TABLE 25

PRODUCTION OF SECONDARY COPPER AND COPPER-ALLOY PRODUCTS IN THE UNITED STATES, BY ITEM PRODUCED FROM SCRAP

(Metric tons)

Item produced from scrap	1988	1989
UNALLOYED COPPER PRODUCTS		
Electrolytically refined copper	347,442	376,595
Fire-refined copper	r98,985	100,323
Copper powder	9,370	9,389
Copper castings	681	673
Total	r456,478	486,980
ALLOYED COPPER PRODUCTS		
Brass and bronze ingots:		
Tin bronzes	24,952	18,984
Leaded red brass and semired brass	108,376	109,746
High-leaded tin bronze	8,022	8,137
Yellow brass	8,831	8,181
Manganese bronze	8,691	8,437
Aluminum bronze	8,804	7,274
Nickel silver	3,538	4,701
Silicon bronze and brass	5,437	5,702
Copper-base hardeners and master alloys	r7,080	10,771
Miscellaneous	r6,564	4,024
Total	r190,295	185,957
Brass mill and wire-rod mill products	750,096	713,363
Brass and bronze castings	r40,975	46,938
Brass powder	252	259
Copper in chemical products	3,470	1,948
Grand total[1]	r1,441,564	1,435,445

rRevised.

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

TABLE 26

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]							
1988r	152,173	6,156	10,957	20,623	351	35	190,295
1989	150,248	5,693	10,003	19,499	481	32	185,957
Secondary metal content of brass mill products:							
1988	[3]611,763	780	1,721	133,663	2,168	1	[3]750,096
1989	[3]582,692	585	2,180	125,059	2,848	1	[3]713,363
Secondary metal content of brass and bronze castings:							
1988r	37,064	863	1,249	1,705	39	55	40,975
1989	42,396	922	1,303	2,005	138	175	46,938

rRevised.

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

[2]About 96% from scrap and 4% from other than scrap in 1988 and in 1989.

[3]Includes copper recovered from scrap at wire mills to avoid disclosing company proprietary data.

TABLE 27

STOCKS AND CONSUMPTION OF PURCHASED COPPER SCRAP IN THE UNITED STATES IN 1989, BY CLASS OF CONSUMER AND TYPE OF SCRAP

(Metric tons, gross weight)

Class of consumer and type of scrap	Stocks, Jan. 1[1]	Net receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
SECONDARY SMELTERS/REFINERS						
No. 1 wire and heavy	1,598	131,664	87,370	34,810	122,180	11,082
No. 2 wire, mixed heavy and light	21,370	338,572	41,155	301,751	342,906	17,036
Composition or soft red brass	1,973	38,479	6,166	32,657	38,823	1,629
Railroad-car boxes	88	534	—	523	523	99
Yellow brass	2,434	64,938	38,098	27,252	65,350	2,022
Cartridge cases	13	526	—	508	508	31
Automobile radiators (unsweated)	3,806	92,238	—	94,444	94,444	1,600
Bronze	1,092	15,159	2,594	12,808	15,402	849
Nickel silver and cupronickel	578	3,837	837	3,304	4,141	274
Low brass	697	2,598	385	2,214	2,599	696
Aluminum bronze	34	226	17	194	211	49
Refinery brass	2,036	40,157	1,716	38,589	40,305	1,888
Low-grade scrap and residues	25,938	93,299	56,493	45,854	102,347	16,890
Total	61,657	822,227	234,831	594,908	829,739	54,145
BRASS AND WIRE-ROD MILLS[2]						
No. 1 wire and heavy	15,101	265,038	245,751	19,287	265,038	8,804
No. 2 wire, mixed heavy and light	2,229	46,316	35,584	10,732	46,316	1,916
Yellow brass	7,575	247,535	239,954	7,581	247,535	11,692
Cartridge cases and brass	15,960	125,669	125,235	434	125,669	10,843
Bronze	625	4,613	4,613	—	4,613	792
Nickel silver and cupronickel	2,079	19,199	18,927	272	19,199	1,955
Low brass	2,286	17,162	17,085	77	17,162	1,476
Aluminum bronze	—	9	9	—	9	—
Total	45,855	725,541	687,158	38,383	725,541	37,478
FOUNDRIES, CHEMICAL PLANTS, AND OTHER MANUFACTURERS						
No. 1 wire and heavy	2,197	28,262	8,748	19,220	27,968	2,491
No. 2 wire, mixed heavy and light	178	3,416	941	2,485	3,426	168
Composition or soft red brass	3,333	13,907	5,510	8,254	13,764	3,476
Railroad-car boxes	255	2,980	1	2,663	2,664	571
Yellow brass	378	5,626	1,718	3,786	5,504	500
Cartridge cases	—	46	—	46	46	—
Automobile radiators (unsweated)	175	1,902	629	1,322	1,951	126
Bronze	858	903	40	857	897	864
Nickel silver and cupronickel	59	222	94	127	221	60
Low brass	145	2,345	2,374	57	2,431	59
Aluminum bronze	767	2,476	1,393	1,083	2,476	767
Low-grade scrap and residues	7	144	64	67	131	20
Total[3]	8,352	62,229	21,512	39,967	61,479	9,102
GRAND TOTAL						
No. 1 wire and heavy	18,896	424,964	341,869	73,317	415,186	22,377
No. 2 wire, mixed heavy and light	23,777	388,304	77,680	314,968	392,648	19,120
Composition or soft red brass	5,306	52,386	11,676	40,911	52,587	5,105
Railroad-car boxes	343	3,514	1	3,186	3,187	670
Yellow brass	10,387	320,099	279,770	38,619	318,389	14,214

See footnotes at end of table.

TABLE 27—Continued

STOCKS AND CONSUMPTION OF PURCHASED COPPER SCRAP IN THE UNITED STATES IN 1989, BY CLASS OF CONSUMER AND TYPE OF SCRAP

(Metric tons, gross weight)

Class of consumer and type of scrap	Stocks, Jan. 1[1]	Net receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
Cartridge cases	15,973	126,241	125,235	988	126,223	10,874
Automobile radiators (unsweated)	3,981	94,140	629	95,766	96,395	1,726
Bronze	2,575	20,675	7,247	13,665	20,912	2,505
Nickel silver and cupronickel	2,716	23,258	19,858	3,703	23,561	2,289
Low brass	3,128	22,105	19,844	2,348	22,192	2,231
Aluminum bronze	801	2,711	1,419	1,277	2,696	816
Low-grade scrap and residues[4]	27,981	133,600	58,273	84,510	142,783	18,798
Total	115,864	1,611,997	943,501	673,258	1,616,759	100,725

[1]Revised from 1988 closing stocks.
[2]Brass and wire-rod mill stocks include home scrap; purchased scrap consumption is assumed equal to receipts, so lines in "BRASS AND WIRE-ROD MILLS" and "GRAND TOTAL" sections do not balance.
[3]Of the total shown, chemical plants reported the following: unalloyed copper scrap, 342 tons new and 1,687 tons old.
[4]Includes refinery brass.

TABLE 28

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	Total
1988:[r]					
Copper scrap	[1]757,042	W	64,320	784,479	1,605,841
Refined copper[2]	493,215	1,667,190	47,412	2,607	2,210,424
Hardners and master alloys	3,104	—	3,929	—	7,033
Brass ingots	—	—	151,169	—	151,169
Slab zinc	82,727	—	4,496	3,735	90,958
Miscellaneous	—	—	—	97	97
1989:					
Copper scrap	[1]725,541	W	61,479	829,739	1,616,759
Refined copper[2]	461,021	1,698,351	42,434	1,337	2,203,143
Hardners and master alloys	7,331	—	3,573	—	10,904
Brass ingots	—	—	136,421	—	136,421
Slab zinc	70,584	—	22,017	3,139	95,740
Miscellaneous	—	—	—	19	19

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with consumption of copper scrap at brass mills.
[1]Includes consumption of copper scrap at wire-rod mills to avoid disclosing company proprietary data.
[2]Detailed information on consumption of refined copper can be found in table 32.

TABLE 29

PRODUCTION, SHIPMENTS, AND STOCKS OF BRASS AND WIRE-ROD MILL SEMIFABRICATES

(Metric tons)

	Production	Shipments	Stocks, Dec. 31
BRASS MILLS			
1987	1,301,804	1,316,632	54,759
1988	1,342,595	1,337,432	72,443
1989	1,345,745	1,352,379	66,785
WIRE-ROD MILLS			
1987	1,422,450	1,505,776	96,746
1988	1,516,461	1,531,055	82,153
1989	1,523,794	1,513,107	90,831

TABLE 30

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
1985	1,057,241	503,407	339,788	-244,000	2,144,436
1986[r]	1,073,981	477,469	489,532	-96,000	2,136,982
1987	1,126,908	497,937	459,962	-112,000	2,196,807
1988[r]	1,406,020	518,179	273,346	-14,000	2,211,545
1989:					
January	118,077	43,065	26,537	1,000	186,679
February	112,632	47,036	20,002	4,000	175,670
March	123,953	51,044	12,837	2,000	185,834
April	114,684	45,519	7,378	-1,000	168,581
May	129,187	46,939	19,867	3,000	192,993
June	123,254	46,118	19,277	-3,000	191,649
July	118,886	39,325	2,021	5,000	155,232
August	126,367	46,707	8,585	-10,000	191,659
September	119,994	47,021	4,856	-7,000	178,871
October	126,112	48,090	16,757	6,000	184,959
November	131,359	41,678	26,026	4,000	195,063
December	132,328	41,054	5,777	4,000	175,159
Total	1,476,833	543,596	169,920	8,000	2,182,349

[r]Revised.

TABLE 31

FOUNDRIES AND MISCELLANEOUS MANUFACTURERS[2] 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	Total brass ingot	Hardeners and master alloys[3]	Refined copper consumed	Copper scrap consumed
1985	27,328	87,053	8,014	6,216	1,788	7,052	137,451	3,133	54,390	66,557
1986	33,651	81,288	9,702	5,735	2,336	5,506	138,218	3,146	43,416	63,323
1987	31,198	79,074	7,365	7,433	2,239	5,545	132,854	3,193	40,649	67,316
1988[r]	33,336	89,024	8,669	6,660	1,959	7,593	151,169	3,929	46,412	60,706
1989:										
Atlantic:										
Middle: New Jersey, New York, Pennsylvania	7,385	8,266	913	827	184	695	18,366	97	8,221	8,276
South: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	8,531	5,732	361	418	248	714	16,035	33	5,866	5,300
Central:										
East North: Illinois, Indiana, Michigan, Ohio, Wisconsin	10,915	41,085	3,882	2,701	769	2,261	64,526	2,911	13,661	27,512
South: Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	3,808	6,945	396	389	82	469	12,147	57	6,538	4,065
West North: Iowa, Kansas, Minnesota, Missouri, Nebraska, South Dakota	1,547	5,336	567	363	6	620	8,576	135	4,376	4,382
Mountain and Pacific:										
Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington	1,481	9,886	1,020	916	29	346	14,000	321	1,130	8,695
New England:										
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	408	819	603	236	335	354	2,771	19	1,705	1,220
Total	34,075	78,069	7,742	5,850	1,653	5,459	136,421	3,573	41,497	59,450

[r]Revised.
[1]Includes silicon bronze and brass.
[2]Includes copper nickel and nickel bronze and brass.
[3]Includes special alloys.

TABLE 32

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	Other	Total
1988:[r]							
Wire-rod mills	1,667,190	—	—	—	—	—	1,667,190
Brass mills	279,810	14,037	37,168	63,037	99,025	138	493,215
Chemical plants	W	—	—	—	—	1,002	1,002
Ingot makers	W	—	W	—	2,607	2,607	
Foundries	1,562	W	8,350	—	W	4,586	14,498
Miscellaneous[1]	18,878	W	8,703	W	W	4,331	31,912
Total	1,967,440	14,037	54,221	63,037	99,025	12,664	2,210,424
1989:							
Wire-rod mills	1,698,351	—	—	—	—	—	1,698,351
Brass mills	265,634	5,810	19,735	64,921	104,863	59	461,021
Chemical plants	W	314	—	—	—	623	937
Ingot makers	W	—	W	—	—	1,337	1,337
Foundries	3,437	W	6,913	W	W	4,531	14,882
Miscellaneous[1]	14,143	W	7,800	W	W	4,671	26,615
Total	1,981,565	6,124	34,448	64,921	104,863	11,221	2,203,143

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with "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 33

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
1985	146	66	100	20	25	109	320
1986	[r]136	[r]35	66	14	25	84	[r]224
1987	150	29	28	15	[r]23	17	[r]112
1988	[r]121	16	29	17	24	12	98
1989:							
January	127	17	30	14	25	13	99
February	129	18	29	16	24	16	103
March	120	13	24	16	25	27	105
April	115	15	28	16	25	20	104
May	119	17	29	14	24	23	107
June	103	13	29	16	25	21	104
July	106	16	32	16	26	19	109
August	110	14	25	21	25	14	99
September	128	15	23	19	25	10	92
October	143	16	31	16	26	9	98
November	129	19	32	17	26	8	102
December	132	18	32	12	29	15	106

[r]Revised.

[1]Includes copper in transit from smelters in the United States to refineries therein.

[2]Includes secondary smelters, chemical plants, foundries, and miscellaneous plants; includes 20,000 tons in the National Defense Stockpile.

TABLE 34

DEALERS' MONTHLY AVERAGE BUYING PRICE FOR COPPER SCRAP AND CONSUMERS' ALLOY-INGOT PRICES AT NEW YORK, BY TYPE

(Cents per pound)

Year and month	Scrap			Ingot	
	No. 1 heavy copper	No. 2 heavy copper	Red brass	No. 115 brass (85-5-5-5)	Yellow brass (405)
1988:[r]					
January	102.78	94.10	83.50	100.50	84.25
February	87.15	77.58	77.43	98.59	82.34
March	90.56	82.24	73.50	97.71	81.46
April	88.44	79.48	73.00	99.00	82.75
May	88.30	79.24	70.45	99.00	82.75
June	93.87	83.75	71.80	99.00	86.59
July	88.70	79.58	71.08	99.00	89.75
August	88.18	79.20	70.50	99.00	89.75
September	98.14	88.36	70.50	99.71	90.18
October	101.29	93.64	78.79	105.43	94.18
November	111.27	98.03	82.50	109.68	99.22
December	116.15	103.98	89.47	110.00	99.75
Average	96.24	86.60	76.04	101.39	88.58
1989:					
January	114.62	103.50	52.75	112.00	101.25
February	110.75	97.97	57.50	116.00	104.75
March	119.31	108.32	57.50	116.00	106.90
April	119.21	110.93	57.95	116.00	107.75
May	109.47	100.16	59.00	118.27	115.02
June	100.45	91.18	59.00	117.83	115.25
July	144.44	88.63	59.00	117.50	113.95
August	108.78	99.78	59.65	117.63	112.95
September	115.57	105.50	62.00	123.09	116.75
October	116.14	106.64	62.00	120.50	116.75
November	104.95	97.25	62.00	119.70	115.50
December	95.73	88.05	60.78	119.50	115.25
Average	113.29	99.83	59.09	117.84	111.84

[r]Revised.

Source: American Metal Market.

TABLE 35

AVERAGE MONTHLY PRICES FOR REFINED COPPER IN THE UNITED STATES AND ON THE LONDON METAL EXCHANGE

(Cents per pound)

Month	1988				1989			
	U.S. producers delivered cathode[2]	COMEX first position	LME cash[1]		U.S. producers delivered		COMEX first position[4]	LME cash Grade A[1 5]
			Standard	Grade A	Cathode[2]	Wirebar[3]		
January	132.50	123.22	115.93	120.66	157.77	164.18	154.92	153.88
February	107.52	99.73	102.30	105.62	140.21	146.33	136.45	140.37
March	109.72	103.92	103.51	106.96	148.49	154.89	144.39	147.99
April	103.64	97.50	100.00	103.64	143.49	150.26	140.46	141.36
May	104.37	99.27	100.77	110.84	127.15	132.72	123.07	124.20
June	114.28	108.97	104.95	115.15	115.90	110.34	112.41	115.44
July	104.85	98.78	96.77	100.35	113.49	119.27	109.58	113.57
August	101.45	96.21	96.18	99.78	127.43	133.87	124.68	125.23
September	116.12	111.24	105.13	110.38	138.44	143.60	134.94	130.80
October	138.05	133.48	127.65	133.24	131.66	137.61	127.59	129.79
November	152.32	147.08	143.82	149.81	118.11	123.68	113.96	117.50
December	161.27	155.81	153.94	158.62	109.22	115.60	106.96	109.67
Average	120.51	114.60	112.58	117.92	130.95	136.03	128.91	129.15

[1]Based on average monthly rates of exchange.
[2]Listed as "U.S. producer cathode."
[3]Listed as "Electrolytic wirebar (Warrenton Refining Co.)."
[4]Listed as "COMEX high grade first position."
[5]Quotations for "Standard" no longer available. Suspended Jan. 1, 1989.

Sources: Metals Week and American Metal Market.

TABLE 36

U.S. EXPORTS OF COPPER, BY COUNTRY

Country	Ore and concentrate (copper content)		Ash and residues[1] (copper content)		Refined		Unalloyed copper scrap		Blister and precipitates	
	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	211,147	$420,003	4,380	$10,276	58,325	$138,539	119,773	$164,933	33,337	$65,978
1989:										
Australia	194	254	34	49	12	20	—	—	—	—
Belgium	42	75	600	4,574	19	57	3,624	4,640	—	—
Brazil	16,632	34,117	—	—	17	72	809	1,529	—	—
Bulgaria	4,560	9,350	—	—	—	—	—	—	—	—
Canada	10,999	18,453	5,680	7,693	4,731	7,327	38,062	47,784	9	44
China	3,654	8,016	—	—	12,874	31,452	6,048	3,297	—	—
Dominican Republic	17	89	—	—	84	172	—	—	—	—
Finland	7,241	10,933	—	—	—	—	—	—	—	—
France	80	80	3	5	689	2,059	53	66	—	—
Germany, Federal Republic of	13,966	34,579	334	2,255	1,298	3,621	13,217	24,251	22	34
Hong Kong	3	3	—	—	583	2,084	1,126	893	—	—
India	31	18	49	70	—	—	1,092	1,658	—	—
Israel	5	5	—	—	70	139	1	9	—	—
Italy	—	—	—	—	591	1,365	254	355	—	—
Japan	163,998	330,566	132	458	47,538	120,506	20,331	45,476	504	994
Korea, Republic of	27,552	45,034	6	26	1,247	2,849	32,600	60,535	6,674	17,843
Mexico	8	8	—	—	7,345	20,880	7,837	18,616	828	1,282
Netherlands	—	—	7	14	663	2,040	3,428	6,605	—	—
Philippines	2,714	4,971	—	—	2	3	121	28	—	—

See footnotes at end of table.

TABLE 36—Continued

U.S. EXPORTS OF COPPER, BY COUNTRY

Country	Ore and concentrate (copper content)		Ash and residues[1] (copper content)		Refined		Unalloyed copper scrap		Blister and precipitates	
	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)
Singapore	8	$ 8	—	—	1,204	$3,067	121	$ 123	—	—
Spain	15	18	—	—	—	—	869	877	—	—
Switzerland	—	—	—	—	226	644	111	225	—	—
Taiwan	8,712	21,340	1	$2	47,755	96,069	23,136	$23,726	—	—
United Kingdom	503	521	2	3	1,086	2,511	1,229	2,198	—	—
Venezuela	—	—	—	—	1,296	3,732	18	13	—	—
Yugoslavia	5,634	20,668	—	—	—	—	—	—	—	—
Other	263	219	60	7	859	2,344	848	1,291	4	$ 12
Total	266,831	539,325	6,908	15,156	130,189	303,013	154,935	244,195	8,041	20,209

	Pipes and tubing		Plates and sheets		Wire and cable, bare		Wire and cable insulated		Other copper manufactures[2]	
	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	7,749	$28,623	863	$4,141	12,422	$53,449	118,636	$667,158	2,350	$7,861
1989:										
Australia	79	465	5	48	70	480	1,306	9,858	84	775
Bahamas	15	33	1	3	145	574	141	747	3	49
Belgium	133	239	—	—	25	222	230	2,552	118	356
Brazil	222	738	1	3	41	569	288	3,520	2,549	8,162
Canada	7,170	18,971	883	3,293	6,598	28,169	16,104	73,365	12,135	36,426
China	261	956	1	10	87	124	449	3,210	2,652	6,590
Dominican Republic	24	75	9	38	583	3,119	468	1,983	1,176	3,803
Ecuador	24	86	1	10	43	179	35	320	105	431
Egypt	170	1,259	70	322	(3)	4	972	4,147	1	11
France	58	184	34	227	100	1,313	853	8,783	279	1,873
Germany, Federal Republic of	44	554	131	796	274	2,778	3,190	20,464	101	1,850
Hong Kong	119	507	159	999	345	1,342	851	5,531	5	51
India	26	115	17	309	17	192	243	2,708	862	1,599
Israel	85	475	37	442	53	627	233	2,759	13	93
Italy	57	261	31	169	132	1,084	232	3,486	14	261
Jamaica	60	242	4	16	334	1,720	234	1,028	663	1,945
Japan	110	821	649	4,693	386	2,747	855	10,811	1,257	5,137
Korea, Republic of	98	1,280	22	437	214	1,849	462	5,004	204	672
Kuwait	479	2,093	—	—	13	112	16	219	—	—
Mexico	4,932	14,967	640	2,992	14,616	62,387	46,891	178,066	5,861	20,468
Netherlands	503	1,979	87	792	66	542	598	12,005	597	3,634
Philippines	748	2,741	8	53	168	728	374	2,072	8	34
Saudi Arabia	665	2,633	—	—	150	862	608	3,314	27	97
Singapore	162	694	29	160	86	1,013	769	6,585	348	922
Sweden	2	17	1	5	15	202	149	4,209	5	34
Switzerland	5	69	—	—	132	2,601	588	3,373	36	697
Taiwan	989	3,357	860	3,904	150	1,413	939	6,924	3,004	7,876
Trinidad and Tobago	5	30	13	4	99	398	53	440	316	981
United Kingdom	253	1,180	77	668	733	6,895	3,865	33,827	130	1,787
Venezuela	271	1,412	12	66	103	734	515	4,384	974	2,979
Yugoslavia	—	—	—	—	4	27	21	177	—	—
Other	3,271	12,485	108	750	1,698	9,730	6,724	39,611	1,891	6,168
Total	21,767	73,061	3,890	21,209	27,560	135,499	90,393	461,725	35,418	115,763

[1]Includes matte.
[2]Excludes copper wire cloth.
[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 37

U.S. EXPORTS OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap				Copper-alloy scrap			
	1988		1989		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	2,813	$4,057	3,621	$4,640	8,715	$8,870	5,866	$7,744
Brazil	594	936	809	1,529	589	907	1,797	2,425
Canada	29,174	32,357	38,062	47,784	23,607	38,567	30,464	48,588
Chile	—	—	127	244	—	—	2	8
China	427	496	6,048	3,297	1,040	838	8,996	7,331
France	48	51	53	66	699	797	831	1,503
Germany, Federal Republic of	9,751	13,596	13,217	24,251	20,986	33,248	39,877	55,734
Hong Kong	1,433	1,149	1,126	893	206	212	1,435	1,365
India	2,015	2,358	1,092	1,658	13,184	14,371	25,554	32,530
Indonesia	—	—	413	457	—	—	—	—
Italy	834	1,065	254	355	1,948	2,450	4,935	5,922
Japan	16,130	25,810	20,331	45,476	17,225	31,365	18,826	46,793
Korea, Republic of	19,541	39,041	32,600	60,535	44,044	70,221	29,230	47,194
Mexico	11,496	20,353	7,837	18,616	10,094	23,637	14,934	27,911
Netherlands	924	2,037	3,428	6,605	1,115	2,214	3,300	5,692
Norway	—	—	222	447	—	—	19	6
Philippines	—	—	121	28	—	—	84	182
Singapore	2,098	3,066	121	123	1,138	1,260	1,219	1,605
Spain	3,379	2,228	869	877	10,099	3,936	4,165	2,927
Sweden	15	40	—	—	1,614	3,866	2,106	3,764
Switzerland	15	3	111	225	53	63	10	24
Taiwan	16,292	12,185	23,136	23,726	39,596	36,697	14,592	19,052
Trinidad and Tobago	—	—	22	21	956	1,037	148	132
United Kingdom	2,311	3,103	1,229	2,198	2,698	5,181	5,564	7,765
Venezuela	305	607	18	13	150	416	102	190
Other	178	395	68	131	193	407	622	821
Total	119,773	164,933	154,935	244,195	199,949	280,560	214,678	327,208

Source: Bureau of the Census.

TABLE 38

U.S. IMPORTS FOR CONSUMPTION OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate		Matte		Blister and anode		Refined		Unalloyed scrap		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)
1988	2,776	$7,917	5,462	$10,399	98,453	$197,621	331,671	$810,495	37,152	$87,124	475,512	$1,113,556
1989:												
Australia	343	985	—	—	(1)	181	—	—	—	—	343	1,166
Brazil	—	—	—	—	—	—	18,220	50,691	—	—	18,220	50,691
Canada	731	454	—	—	188	1,116	180,814	508,425	19,368	58,200	201,101	568,195
Cape Verde	—	—	—	—	745	1,655	—	—	—	—	745	1,655
Chile	3,566	8,164	—	—	33,713	93,133	75,436	215,088	4,805	15,495	117,520	331,880
China	—	—	—	—	—	—	65	223	—	—	65	223
Costa Rica	—	—	—	—	—	—	—	—	539	1,212	539	1,212
Dominican Republic	—	—	—	—	—	—	—	—	467	1,377	467	1,377
Germany, Federal Republic of	—	—	—	—	(1)	9	281	1,065	295	273	576	1,347
Guatemala	—	—	—	—	—	—	—	—	243	425	243	425
Jamaica	—	—	—	—	—	—	—	—	188	333	188	333
Japan	—	—	—	—	22,298	79,301	3	120	—	—	22,301	79,421
Mexico	40,974	38,781	2,238	5,192	6,645	24,902	165	441	3,568	5,048	53,590	74,364
Netherlands	—	—	—	—	(1)	3	2,431	8,432	276	1,090	2,707	9,525
Niger	—	—	—	—	—	—	828	2,536	—	—	828	2,536
Norway	—	—	—	—	—	—	55	154	—	—	55	154
Panama	—	—	—	—	—	—	—	—	638	1,305	638	1,305
Peru	232	661	—	—	2,952	8,258	9,240	24,865	—	—	12,424	33,784
South Africa, Republic of	—	—	—	—	—	—	1,083	3,657	—	—	1,083	3,657
Sweden	600	1,534	—	—	(1)	6	—	—	—	—	600	1,540
Tanzania	—	—	—	—	987	2,877	—	—	—	—	987	2,877
Trinidad and Tobago	—	—	—	—	—	—	—	—	305	642	305	642
United Kingdom	—	—	3	19	(1)	10	19	98	1	2	23	129
Venezuela	—	—	—	—	—	—	—	—	588	1,292	588	1,292
Zaire	—	—	—	—	9,689	24,672	11,437	30,618	—	—	21,126	55,290
Other	69	165	11	21	(1)	6	33	196	297	559	410	947
Total	46,515	50,744	2,252	5,232	77,217	236,129	300,110	846,609	31,578	87,253	457,672	1,225,967

[1]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 39

U.S. IMPORTS FOR CONSUMPTION OF COPPER MANUFACTURES, BY COUNTRY

Country	Pipes and tubing		Plates and sheets		Wire and cable, bare		Oxides and hydroxides		Other copper manufactures[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988	62,633	$255,551	26,049	$88,228	7,843	$20,846	5,089	$10,436	9,698	$29,610
1989:										
Argentina	—	—	211	602	—	—	—	—	72	141
Australia	—	—	541	1,987	—	—	2,249	5,745	—	—
Austria	116	588	17	64	7	99	—	—	—	—
Belgium	—	—	147	839	—	—	—	—	1	9
Brazil	27	101	893	2,959	20	99	—	—	409	1,113
Canada	4,313	17,898	6,046	23,158	219	814	61	91	6,433	22,877
Chile	913	3,309	1,780	6,033	—	—	75	173	7,622	22,955
China	—	—	28	101	—	—	—	—	8	36
Finland	76	549	3,444	13,066	219	1,230	—	—	894	3,788
France	842	3,450	9	110	46	612	4	4	6	32
Germany, Federal Republic of	549	3,685	2,071	8,455	424	4,184	1	17	1,435	5,669
Israel	—	—	—	—	83	503	—	—	—	—
Italy	2,213	8,929	68	209	74	951	—	—	16	69
Japan	16,467	76,463	3,245	17,398	650	4,410	28	157	468	2,174
Korea, Republic of	5	23	26	94	31	135	—	—	1	16
Luxembourg	—	—	278	3,025	—	—	—	—	—	—
Mexico	7,157	26,849	80	376	1,446	7,367	594	1,347	—	—
Netherlands	(2)	7	215	916	17	90	—	—	(2)	2
Norway	—	—	—	—	—	—	109	305	—	—
Peru	—	—	—	—	9,457	25,341	—	—	300	992
Poland	—	—	—	—	76	224	—	—	17	38
Singapore	—	—	—	—	127	780	—	—	—	—
Sweden	73	344	12,638	49,418	2	14	—	—	19	89
Switzerland	5	15	3	30	13	87	—	—	25	170
Taiwan	11	95	118	861	169	730	15	17	—	—
Turkey	—	—	—	—	379	1,773	—	—	—	—
United Kingdom	179	1,767	411	4,443	53	682	60	138	40	316
Venezuela	67	207	—	—	—	—	—	—	18	39
Yugoslavia	31	89	273	829	10	36	—	—	16	29
Other	21	68	33	122	29	151	20	53	47	161
Total	33,065	144,436	32,575	135,095	13,551	50,312	3,216	8,047	17,847	60,715

[1]Excludes copper wire cloth.
[2]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 40

U.S. IMPORTS FOR CONSUMPTION OF COPPER SCRAP, BY COUNTRY

Country	Unalloyed copper scrap		Copper-alloy scrap		
	Quantity (metric tons)	Value (thousands)	Gross weight (metric tons)	Copper content[1] (metric tons)	Value (thousands)
1988	37,152	$87,124	49,526	35,848	$75,768
1989:					
Bahamas	15	19	61	—	53
Barbados	51	90	32	—	23
Belgium	—	—	1,431	—	972
Canada	19,368	58,200	38,755	—	78,684
Chile	4,805	15,495	3,347	—	8,470
China	—	—	136	—	235
Costa Rica	539	1,212	133	—	224
Dominican Republic	—	—	1,067	—	2,130
France	467	1,377	187	—	1,005
Germany, Federal Republic of	295	273	212	—	893
Guatemala	243	425	315	—	352
Haiti	44	93	108	—	170
Honduras	34	92	62	—	22
Hong Kong	—	—	92	—	176
Jamaica	188	333	320	—	230
Japan	—	—	305	—	287
Mexico	3,568	5,048	20,707	—	33,098
Netherlands	276	1,090	—	—	—
Netherlands Antilles	28	62	309	—	429
Panama	638	1,305	848	—	1,342
Singapore	—	—	178	—	364
Sweden	—	—	19	—	42
Switzerland	—	—	43	—	156
Taiwan	—	—	3,479	—	5,917
Trinidad and Tobago	305	642	301	—	414
United Kingdom	1	2	274	—	747
Venezuela	588	1,292	6,144	—	11,015
Other	125	203	459	—	1,225
Total	31,578	87,253	79,324	e57,000	148,675

eEstimated.

[1]Under the Harmonized Tariff System that was implemented January 1989, copper content is no longer available. Total content for 1989 is estimated to be 72% of gross weight.

TABLE 41

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Albania[e]	16.2	17.6	17.8	15.0	16.0
Argentina	.4	.3	.4	.5	.6
Australia	259.8	248.4	232.7	238.3	[2]289.2
Bolivia	1.7	.3	([3])	.2	[2].3
Botswana[4]	21.7	[r]21.3	18.9	24.4	[2]22.6
Brazil	41.0	40.2	37.8	44.4	45.8
Bulgaria[e]	80.0	80.0	80.0	80.0	80.0
Burma	16.7	11.4	17.3	13.8	5.0
Canada:					
By concentration or leaching[5]	738.6	[r]697.9	790.2	753.5	716.9
Leaching (electrowon)	—	.7	3.9	5.0	5.0
Chile[6]	1,359.8	1,399.4	1,412.9	1,472.0	[2]1,645.0
China[e]	185.0	185.0	250.0	[r]375.0	375.0
Congo	.5	.7	1.3	[e]1.0	1.0
Cuba	3.1	3.3	3.5	3.0	3.0
Cyprus[7]	1.1	.6	.1	.3	[2].3
Czechoslovakia[e 8]	[r]6.3	[r]5.3	[r]5.3	[r]5.0	5.0
Ecuador[e]	.1	.1	.1	.1	.1
Finland	[r]27.9	[r]26.0	20.4	20.2	14.5
France	.2	.3	.3	.3	.3
German Democratic Republic[e]	12.0	[r]11.0	[r]11.0	[r]10.0	9.0
Germany, Federal Republic of[8]	.9	.8	1.5	.7	.1
Honduras	5.1	[e]5.0	.6	.6	.6
India	45.9	48.1	56.5	55.7	57.4
Indonesia[8]	88.7	95.8	102.1	121.5	[2]144.0
Iran[e]	[r]40.0	[r]50.0	[r]40.0	[r]51.0	60.0
Italy	.1	—	—	—	—
Japan	43.2	34.9	23.8	16.7	[2]14.7
Korea, North[e]	15.0	15.0	15.0	15.0	15.0
Korea, Republic of	.3	.2	.2	([3])	([3])
Malaysia	30.5	28.3	29.9	22.0	[2]25.4
Mexico:					
By concentration or leaching	169.1	181.1	244.0	268.8	250.0
Leaching (electrowon)	8.0	8.0	9.7	11.4	10.0
Mongolia[e]	128.0	136.0	140.0	160.0	160.0
Morocco	22.0	20.2	16.6	14.5	13.3
Mozambique[e]	.1	[r].1	.2	[r].1	.1
Namibia	48.0	49.6	37.6	40.9	[2]26.9
Nepal	([3])	([3])	([3])	([3])	([2 3])
Norway	19.0	21.9	22.0	15.9	16.5
Oman	[r]17.7	[r]18.2	18.1	17.1	16.6
Papua New Guinea	175.0	178.2	217.7	218.6	[2]204.0
Peru:[6]					
By concentration or leaching	[r]389.3	[r]370.9	391.1	301.7	[2]353.1
Leaching (electrowon)	[r]30.9	[r]29.0	26.5	21.1	[2]19.7
Philippines	222.2	222.6	216.1	218.1	[2]189.5
Poland	431.3	434.0	438.0	437.0	436.0
Portugal[6]	.3	.2	1.1	5.2	103.7
Romania[e 8]	26.0	27.0	26.0	26.0	25.0
Saudi Arabia[e]	—	—	—	.3	.6

See footnotes at end of table.

TABLE 41—Continued

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
South Africa, Republic of[8]	195.4	184.2	188.1	168.5	[2]196.6
Spain	61.1	53.5	16.3	18.1	27.4
Sweden	91.8	87.4	85.0	74.4	71.0
Turkey[9]	[r]26.8	[e]23.8	25.8	[r e]31.2	35.9
U.S.S.R.[e 8]	600.0	620.0	630.0	640.0	640.0
United Kingdom	.6	.6	.8	.7	.6
United States:[8]					
By concentration or leaching	1,012.2	1,018.8	1,082.5	1,191.7	[2]1,185.6
Leaching (electrowon)	90.4	125.4	161.1	228.0	[2 10]311.9
Yugoslavia[9]	142.5	138.5	130.5	103.5	105.0
Zaire:					
By concentration or leaching	244.0	212.5	[e]217.5	[e]250.0	225.0
Leaching (electrowon)	313.9	319.2	307.5	[e]280.0	250.0
Zambia:[11]					
By concentration or leaching (smelted)	354.7	322.6	318.7	284.1	295.0
Leaching (electrowon)	103.9	[r]139.8	144.5	147.7	150.0
Zimbabwe[e]	21.6	21.4	19.8	16.9	16.4
Total	[r]7,987.6	[r]7,992.6	8,306.3	8,536.7	8,887.2

[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 27, 1990.

[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.

[8]Recoverable content.

[9]Copper content by analysis of ore mined.

[10]Includes electrowon from concentrates roast-leached.

[11]Data are for fiscal years beginning Apr. 1 of year stated. Zambian-mined copper reported recovered during smelting and electrowinning.

TABLE 42

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1985	1986	1987	1988[p]	1989[e]
Albania, primary[e]	12.6	13.7	14.0	14.5	14.5
Australia:					
Primary	167.7	169.6	172.9	177.8	[3]203.0
Secondary	7.7	9.2	[e]8.5	[e]9.0	[3]10.0
Total	175.4	178.8	[e]181.4	[re]186.8	[3]213.0
Austria, secondary	25.9	25.5	29.1	34.5	33.7
Belgium:[e]					
Primary	.9	[r].9	[r].1	[r].2	.2
Secondary	114.2	[r]105.0	[r]92.1	[r]93.2	93.4
Total	115.1	[r]105.9	[r]92.2	[r]93.4	93.6
Brazil, primary	93.9	116.0	147.0	147.9	150.0
Bulgaria:[e]					
Primary	87.0	87.0	87.0	87.0	87.0
Secondary	3.0	3.0	4.0	5.0	5.0
Total	90.0	90.0	91.0	92.0	92.0

See footnotes at end of table.

TABLE 42—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1985	1986	1987	1988[p]	1989[e]
Canada:					
Primary	493.3	472.7	499.4	537.0	510.0
Secondary[e]	17.0	12.0	14.0	14.0	16.0
Total[e]	510.3	484.7	513.4	r551.0	526.0
Chile, primary[4]	1,088.4	1,123.9	1,107.0	1,189.4	1,250.0
China, primary[e]	225.0	225.0	300.0	r400.0	450.0
Czechoslovakia:[e]					
Primary	r6.3	r5.3	r5.3	r5.0	5.0
Secondary	r20.2	r20.9	r21.9	r22.1	22.0
Total	r26.5	r26.2	r27.2	r27.1	27.0
Finland:					
Primary	68.9	84.5	77.4	79.0	79.5
Secondary[e]	12.0	12.0	12.0	12.0	12.0
Total[e]	r80.9	96.5	89.4	r91.0	91.5
France, secondary	7.0	6.1	7.0	8.5	8.4
German Democratic Republic, primary[e]	14.0	15.0	r17.0	r25.0	24.0
Germany, Federal Republic of:					
Primary	152.4	161.9	165.0	171.5	171.5
Secondary	94.6	76.7	42.7	50.0	50.5
Total	247.0	238.6	207.7	221.5	222.0
Hungary, secondary[e]	.1	.1	.1	.1	.1
India, primary	32.5	39.1	32.9	44.8	3 42.7
Iran, primary[e]	r40.0	r50.0	r40.0	r52.0	80.1
Japan:					
Primary	802.3	827.7	871.0	854.6	3 882.3
Secondary	130.3	134.4	109.0	139.4	3 123.2
Total	932.6	962.1	980.0	994.0	3 1,005.5
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	r112.7	r123.2	143.8	123.5	3 123.6
Mexico, primary	68.2	74.7	127.6	151.8	175.0
Namibia, primary	43.3	45.7	35.5	42.2	3 38.0
Norway, primary	38.2	35.2	29.7	31.7	35.0
Oman, primary	14.2	14.7	15.7	16.8	15.3
Peru, primary	r320.1	r327.2	323.0	246.9	241.4
Philippines, primary	133.8	124.3	124.7	e159.2	3 105.0
Poland:[e]					
Primary	370.0	375.0	385.0	385.0	385.0
Secondary	20.0	25.0	25.0	25.0	25.0
Total	390.0	400.0	410.0	410.0	410.0
Portugal:[e]					
Primary	2.6	3.0	2.0	2.5	.7
Secondary	2.0	3.0	2.0	2.0	2.0
Total	4.6	6.0	4.0	4.5	2.7
Romania:[e]					
Primary	32.0	32.0	30.0	28.0	42.0
Secondary	6.0	7.0	8.0	8.0	8.0
Total	38.0	39.0	38.0	36.0	50.0

See footnotes at end of table.

TABLE 42—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2] and metal origin	1985	1986	1987	1988[p]	1989[e]
South Africa, Republic of, primary[e]	[3]191.7	192.0	192.0	180.0	190.0
Spain:					
Primary	88.0	100.0	95.0	95.6	[3]120.0
Secondary	[r]32.5	35.2	47.6	50.0	[3]32.3
Total	[r]120.5	135.2	142.6	145.6	[3]152.3
Sweden:					
Primary	74.7	83.4	92.9	90.4	95.0
Secondary	26.0	19.1	12.7	25.5	25.0
Total	100.7	102.5	105.6	115.9	120.0
Taiwan, primary	46.7	50.4	47.0	43.3	[3]43.2
Turkey:					
Primary	33.5	35.2	[e]19.3	[e]12.8	20.9
Secondary	.4	.3	[e].1	[e].1	.2
Total	33.9	35.5	[e]19.4	12.9	[3]21.1
U.S.S.R.:[e]					
Primary	750.0	770.0	780.0	800.0	800.0
Secondary	143.0	145.0	147.0	150.0	150.0
Total	893.0	915.0	927.0	950.0	950.0
United States:					
Primary[5]	940.7	908.1	972.1	1,043.0	[3]1,120.4
Secondary	250.1	287.8	276.6	320.2	[3]359.1
Total	1,190.8	1,195.9	1,248.7	1,363.2	[3]1,479.5
Yugoslavia:					
Primary	137.0	196.4	103.4	106.5	110.0
Secondary	52.2	31.5	62.4	65.5	65.0
Total	189.2	227.9	165.8	172.0	175.0
Zaire, primary:					
Electrowon	313.9	319.2	307.5	306.8	275.0
Other	172.9	178.9	179.9	[e]160.0	150.0
Total	486.8	498.1	487.4	[r e]466.8	425.0
Zambia, primary:[6]					
Electrowon	[r]70.7	[r]88.7	74.8	95.9	100.0
Other	[r]387.0	[r]349.5	347.9	308.9	325.0
Total	[r]457.7	[r]438.2	422.7	404.8	425.0
Zimbabwe, primary[7]	20.4	20.4	18.8	16.1	[3]15.7
Grand total[8]	[r]8,629.6	[r]8,816.2	8,923.3	9,284.6	9,534.9
Of which:					
Primary:					
Electrowon	[r]384.6	[r]407.9	382.3	402.7	375.0
Other	[r]7,277.8	[r]7,446.4	7,616.3	7,844.8	8,116.0
Secondary	[r]967.2	[r]961.9	924.8	1,037.1	1,043.9

[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 27, 1990.

[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 metric tons per year that is fire refined and cast into wirebars; detailed data are not available.

[5]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: 1985—90,938; 1986—89,122; 1987—71,173; 1988—49,356; and 1989—34,485.

[6]For fiscal years beginning Apr.1 of year stated. Electrowon is based on total primary production and represents metal that is further refined; also includes a small amount of leach material from the Chanobie Mine. Smelter production also includes toll material processed for Zaire.

[7]Refined figure; unrefined data not available. Includes production from low-grade electrowon cathodes produced in nickel processing.

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

TABLE 43

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Albania, primary[e]	11.5	11.7	12.0	13.0	13.0
Australia:					
Primary	163.8	164.0	178.9	191.2	[2]230.0
Secondary	30.5	21.1	28.8	26.7	[2]25.0
Total[3]	194.3	185.1	207.8	217.9	[2]255.0
Austria:					
Primary	8.2	7.1	3.9	3.6	4.0
Secondary	35.0	32.6	32.9	38.4	40.0
Total[3]	43.2	39.6	36.8	41.9	44.0
Belgium:					
Primary	340.5	337.8	345.9	364.3	365.0
Secondary	115.0	120.0	130.0	140.0	145.0
Total	455.5	457.8	475.9	504.3	510.0
Brazil:					
Primary	93.9	116.0	147.0	147.9	150.0
Secondary	49.0	50.0	52.2	38.1	40.0
Total[3]	142.9	166.0	199.2	185.9	190.0
Bulgaria:[e]					
Primary	73.0	75.0	75.0	75.0	70.0
Secondary	20.0	20.0	20.0	20.0	20.0
Total	93.0	95.0	95.0	[r]95.0	90.0
Canada:					
Primary	[r]414.6	[r]469.4	461.2	490.7	472.2
Secondary[e]	[r]25.0	[r]24.0	[r]30.0	[r]38.0	39.0
Total[e]	[r]439.6	[r]493.4	[r]491.2	[r]528.7	511.2
Chile, primary	884.3	942.3	970.3	1,012.7	1,071.0
China, primary and secondary[e]	400.0	400.0	400.0	[r]510.0	550.0
Czechoslovakia:					
Primary[e]	6.3	5.3	5.3	5.0	5.0
Secondary	20.1	20.9	21.9	22.1	22.0
Total[e]	[r]26.4	[r]26.2	[r]27.2	[r]27.1	27.0
Egypt, secondary[e]	2.6	2.7	2.5	2.5	2.6
Finland:					
Primary	53.5	59.2	54.5	47.9	[2]49.7
Secondary[e]	[r]5.0	[r]5.0	[r]5.0	[r]6.0	6.0
Total[e]	58.5	64.2	59.5	[r]53.9	55.7
France:					
Primary[e]	[r]14.7	[r]17.9	[r]11.3	[r]7.2	16.3
Secondary[e]	[r]29.0	[r]24.0	[r]28.0	[r]36.0	33.0
Total	43.7	41.9	39.3	43.2	49.3
German Democratic Republic:[e]					
Primary	15.0	13.0	13.0	18.0	13.0
Secondary	60.0	60.0	61.0	62.0	62.0
Total	75.0	73.0	[r]74.0	80.0	75.0
Germany, Federal Republic of:					
Primary	209.9	238.1	195.2	192.2	257.3
Secondary	204.3	183.9	204.7	[e]234.2	218.0
Total	414.2	422.0	399.9	426.4	475.3

See footnotes at end of table.

TABLE 43—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Hungary, primary and secondary[e]	12.8	12.8	12.5	[2]19.2	19.0
India, primary:					
Electrolytic	28.0	37.9	29.8	39.6	[2]42.0
Fire refined	[e]1.0	[e]1.0	0.8	5.2	[2]0.7
Total	[e]29.0	[e]38.9	30.6	44.8	[2]42.7
Iran, primary[e] [4]	12.0	12.0	[r]30.0	[r]32.0	40.0
Italy:					
Primary[e]	13.3	4.4	5.0	4.0	3.3
Secondary	[r]51.0	[r]61.0	60.0	71.4	80.0
Total	64.3	65.4	65.0	75.4	83.3
Japan:					
Primary	802.3	827.7	871.0	854.6	[2]882.3
Secondary	133.6	115.4	109.4	100.5	[2]107.3
Total[3]	936.0	943.0	980.3	955.1	[2]989.6
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	140.1	157.8	154.6	168.3	171.9
Secondary	[e]11.5	[e]7.2	3.3	0.7	8.0
Total	[e]151.6	[e]165.0	157.9	169.0	[2]179.9
Mexico:					
Primary:					
Electrowon	8.0	8.0	9.7	11.4	10.0
Other[e]	96.1	67.8	100.2	98.9	112.0
Secondary[e]	19.4	13.7	20.2	[r]19.9	22.0
Total[3]	123.6	89.5	130.0	130.2	144.0
Norway, primary[4]	31.1	30.5	29.4	31.7	[2]35.0
Oman, primary	14.0	14.5	15.5	16.5	[2]15.1
Peru, primary:					
Electrowon	[r]30.9	[r]29.0	26.5	21.1	[2]19.7
Other	[r]230.5	[r]226.7	225.9	179.6	[2]220.0
Total[3]	[r]261.4	[r]255.7	252.4	200.7	239.6
Philippines, primary	130.2	134.5	132.1	132.2	[2]132.2
Poland, primary[4]	387.0	388.0	390.0	401.0	400.0
Portugal, primary[4]	4.5	5.3	[e]5.3	[e]6.0	6.8
Romania:[e]					
Primary	33.0	32.0	30.0	30.0	33.0
Secondary	12.0	11.0	12.0	12.0	12.0
Total	45.0	43.0	42.0	42.0	45.0
South Africa, Republic of, primary[4]	164.3	158.6	152.7	139.4	145.7
Spain:					
Primary	101.7	130.6	100.4	108.8	115.7
Secondary	50.0	24.5	51.0	50.0	50.0
Total	151.7	155.1	151.4	158.8	165.7

See footnotes at end of table.

TABLE 43—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Sweden:					
Primary	58.5	[r]72.8	79.9	68.3	69.7
Secondary	[r]26.0	[r]19.1	12.0	22.0	25.0
Total	84.5	[r]91.9	91.9	90.3	94.7
Taiwan:					
Primary	46.7	50.4	47.0	43.3	[2]43.2
Secondary[e]	8.0	8.0	10.0	10.0	10.0
Total[e]	54.7	58.4	57.0	53.3	53.2
Turkey, primary	60.6	75.1	75.6	68.4	68.4
U.S.S.R.:[e]					
Primary	810.0	830.0	840.0	850.0	850.0
Secondary	143.0	145.0	147.0	[r]150.0	150.0
Total	953.0	975.0	987.0	[r]1,000.0	1,000.0
United Kingdom:					
Primary	63.9	62.4	54.0	49.3	50.0
Secondary	61.6	63.2	68.3	74.7	75.0
Total[3]	125.4	125.6	122.3	124.0	125.0
United States:					
Primary:					
Electrowon	90.5	125.4	161.3	228.0	[2]311.9
Other	966.8	948.6	965.6	1,178.0	[2]1,164.9
Secondary	371.8	405.9	414.7	446.0	[2]476.9
Total[3]	1,429.0	1,479.9	1,541.6	1,852.0	[2]1,953.8
Yugoslavia:					
Primary	101.7	99.2	98.8	105.6	110.0
Secondary	33.8	0.8	40.1	39.8	41.0
Total[3]	135.4	[r]100.0	138.9	145.4	[2]151.0
Zaire, primary	221.4	218.0	210.1	202.6	[2]181.9
Zambia, primary:[5 6]					
Electrowon	33.2	[r]51.1	69.6	51.8	50.0
Other	463.3	[r]446.5	426.6	397.7	400.0
Total[3]	496.5	497.6	496.3	449.6	450.0
Zimbabwe:[7]					
Primary	20.4	20.4	18.8	16.1	[2]15.7
Secondary[e]	2.1	4.9	4.2	11.4	8.3
Total[e]	22.5	25.3	23.0	27.5	24.0
Grand total[3]	[r]9,408.3	[r]9,601.5	9,833.4	10,331.7	10,726.6
Of which:					
Primary[3]	[r]7,472.2	[r]7,740.8	7,847.7	8,126.2	8,435.5
Secondary[3]	[r]1,523.2	[r]1,447.9	1,573.3	1,676.2	1,722.1
Primary and secondary, undifferentiated	[r]412.8	[r]412.8	412.5	529.2	569.0

[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 27, 1990.

[2]Reported figure.

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

[4]May include secondary.

[5]Data are for fiscal year beginning Apr. 1 of that stated.

[6]Electrowon covers only presumably high-grade cathodes reported as "finished product leach cathodes." Other, in addition to electro-refined cathodes, includes "finished product refined shapes" presumably cast from electro-refined cathodes, high grade electrowon cathodes or any blister/anodes and low-grade electrowon cathodes that were fire-refined.

[7]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 34 years of industry and 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 Giovanni Jacarepaqua, international data assistant.

U.S. sales of processed diatomite decreased slightly to 617,000 metric tons valued at $137 million. Seven companies processed diatomite at 11 plants in 5 States. California continued to be the leading State followed by Nevada, Washington, Oregon, 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.

CONSUMPTION AND USES

Apparent domestic consumption of processed diatomite decreased slightly to 481,000 metric tons. The major use of diatomite is in filtration to separate suspended solids in liquids. In 1989, domestic and export sales of filter-grade diatomite were 441,000 tons, slightly more than in 1988. Sales of diatomite as a filler, the second largest use, were 90,000 tons, about 15% less than in 1988.

PRICES AND FOREIGN TRADE

The average unit value of sales for processed diatomite was $222 per ton. This was slightly less than in 1988. U.S. exports of processed diatomite were 137,000 tons, about 7% less than in 1988. Average unit value was $302 per ton compared with $268 per ton in 1988. Diatomite was exported to 67 countries. The following four countries combined received 37% of the total exported: Japan, 16,600 tons; Australia, 12,600 tons; the Federal Republic of Germany, 11,100 tons; and the United Kingdom, 10,100 tons. U.S. exports represented 22% of domestic production. Imports of diatomite were 838 tons, of which 84% was supplied by Mexico.

WORLD REVIEW

World production was estimated to be 1.8 million tons in 1989. 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 edition.

Other Sources

Engineering and Mining Journal.
Industrial Minerals (London).
Mining Engineering.
Mining Journal (London).

TABLE 1

DIATOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
Domestic production (sales)	576	570	596	629	617
Total value of sales	$127,030	$128,362	$134,239	$143,774	$136,754

TABLE 2

DIATOMITE SOLD OR USED,[1] BY MAJOR USE

(Percent of U.S. production)

Use	1985	1986	1987	1988	1989
Fillers	21	17	16	17	15
Filtration	66	67	69	69	71
Insulation	1	3	2	2	3
Other[2]	12	13	13	12	11

[1]Includes exports.
[2]Includes absorbents, additives, and silicate admixtures.

TABLE 3

AVERAGE ANNUAL VALUE PER METRIC TON[1] OF DIATOMITE, BY MAJOR USE

Use	1987	1988	1989
Fillers	$249.71	$243.49	233.68
Filtration	239.86	244.34	237.61
Insulation	120.95	121.12	107.61
Other[2]	132.87	140.16	132.89
Weighted average	225.06	228.56	221.58

[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]
1986	119	32,180
1987	126	33,075
1988	147	39,374
1989	137	41,290

[1]U.S. Customs.

TABLE 5

DIATOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Algeria	3	4	[e]4	[e]4	4
Argentina	10	14	5	7	7
Australia	8	9	10	11	11
Brazil (marketable)	[r]18	[r]20	16	[r e]20	20
Canada[e]	4	4	4	4	4
Chile	2	3	3	3	3
Costa Rica	—	—	—	5	5
Denmark:[2]					
Diatomite[e]	6	6	6	6	6
Moler	72	73	[e]66	[e]66	66
France[e]	[3]270	260	250	250	250
Germany, Federal Republic of	48	49	47	[e]48	48
Iceland	29	23	[e]25	[e]25	25
Italy[e]	30	27	28	28	28
Kenya	3	1	1	1	1
Korea, Republic of	54	55	65	72	70
Mexico	46	36	35	35	35
Peru	15	[r]9	21	15	15
Portugal	2	2	[e]2	[e]2	2
Romania[e]	300	300	280	280	260
South Africa, Republic of	1	2	(4)	(4)	(4)
Spain	96	128	[e]100	[e]100	100
Thailand	(4)	(4)	(4)	(4)	(4)
Turkey[e]	3	3	3	[r]1	1
U.S.S.R.[e]	245	250	255	260	260
United Kingdom[e]	(4)	(4)	(4)	(4)	(4)
United States[5]	576	570	596	629	[3]617
Total	[r]1,841	[r]1,848	1,822	1,872	1,838

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through Apr. 9, 1990.

[2]Data represent sales.

[3]Reported figure.

[4]Less than 1/2 unit.

[5]Sold or used by producer.

FELDSPAR, NEPHELINE SYENITE, AND APLITE

By Michael J. Potter

Mr. Potter, a physical scientist with 23 years industry and 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 assistant.

Total U.S. feldspar production in 1989, including soda, potash, mixed feldspar, and feldspar-silica mixtures, was 720,000 short tons with a value of $28 million. Imports of nepheline syenite were an estimated 334,000 tons with a total value of $12.3 million.

FELDSPAR

Domestic Data Coverage

Domestic production data for feldspar are developed by the Bureau of Mines by means of a voluntary survey. Of the 14 active operations, 11, or 79%, responded, representing an estimated 83% of the total production data for feldspar shown in table 1. The remaining 17% was estimated from prior year data adjusted to current industry levels.

Legislation and Government Programs

According to provisions of the Tax Reform Act of 1969, which continued in force throughout 1989, 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 67% of the total. Twelve U.S. companies operating 14 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 12 companies, 3 produced potash feldspar, and the remainder produced soda or mixed feldspar or feldspathic sand mixtures. North Carolina had six plants, California had three, and Connecticut, Georgia, Idaho, Oklahoma, and South Dakota each had one. The grinding plant was located in South Carolina.

The Bureau of Mines uses a criterion of 8% minimum K_2O content in collecting data for potash feldspar.

California Silica Products Co. withdrew from glass sand supply at the end of 1988 and was to concentrate on the recreational and construction sectors. Beginning in January 1989, Corona Industrial Sand Co. (CISCO), Corona, CA, and Unimin Corp., Emmett, ID, were added as producers of feldspar silica sand.

Consumption and Uses

Of the total feldspar sold or used in the United States, 54% went into glassmaking, including container glass and glass fiber, and 45% was used in pottery. Fewer housing starts in 1989 resulted in decreased feldspar usage in plumbing fixtures and tile compared to 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 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

TABLE 1

SALIENT FELDSPAR AND NEPHELINE SYENITE STATISTICS

		1985	1986	1987	1988	1989
United States:						
Feldspar:						
Produced[1]	short tons	700,000	735,000	720,000	715,000	720,000
Value	thousands	$22,800	$26,100	$26,100	$26,400	$28,000
Exports	short tons	9,280	12,000	9,634	13,712	10,283
Value	thousands	$680	$1,024	$691	$769	$829
Imports for consumption	short tons	952	1,251	4,833	6,827	13,231
Value	thousands	$1,150	$542	$477	$659	$873
Nepheline syenite:						
Imports for consumption	short tons	332,604	298,806	308,685	309,844	334,000
Value	thousands	$11,435	$11,280	$11,401	$11,233	$12,273
Consumption, apparent[2] (feldspar plus nepheline syenite)	thousand short tons	1,024	1,023	1,024	1,018	1,057
World: Production (feldspar)	do.	r4,442	r4,430	4,769	p5,150	e5,155

e Estimated. p Preliminary. r Revised.

[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 short tons and thousand dollars)

Year	Hand-cobbed		Flotation concentrate		Feldspar-silica mixtures[2]		Total[3]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1985	14	W	487	16,781	197	W	700	22,800
1986	13	W	522	19,855	200	W	735	26,100
1987	10	W	492	17,800	219	W	720	26,100
1988	14	W	498	18,657	204	W	715	26,400
1989	12	W	468	16,915	241	W	720	28,000

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.

TABLE 3

PRODUCERS OF FELDSPAR AND FELDSPATHIC MATERIALS IN 1989

Company	Plant location	Product
APAC Arkansas Inc.	Muskogee, OK	Feldspar-silica mixture.
Calspar Div. of Steelhead Resources Inc.	Santa Fe Springs, CA	Soda feldspar.
CISCO	Corona, CA	Feldspar-silica mixture.
Cyprus Foote Mineral Co.	Kings Mountain, NC	Do.
The Feldspar Corp.	Middletown, CT	Soda feldspar.
Do.	Monticello, GA	Potash feldspar.
Do.	Spruce Pine, NC	Soda feldspar.
Do.	Montpelier, VA	Aplite.
Indusmin Inc.	Spruce Pine, NC	Soda 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 feldspar.
U.S. Silica Co.	Oceanside, CA	Feldspar-silica mixture.

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 raw materials most often substituted for feldspar in a number of end uses are aplite and nepheline syenite. Aplite, which contains plagioclase (lime-soda) feldspar, is mined in Virginia and used mostly in glassmaking. Nepheline syenite is a coarse crystalline rock resembling granite but consisting principally of feldspathoid minerals—sodium-potassium feldspars and nepheline—with little or no free quartz. All of the nepheline syenite consumed in the United States in the manufacture of glass and ceramics and in filler applications is imported from Ontario, Canada.

Other materials that can serve as substitutes for feldspar in the glass and ceramics industries include talc, pyrophyllite, electric-furnace slag, and Cornwall stone.

The quantity of potash feldspar sold or used in 1989 was 80,500 tons with a value of $6.4 million.

Prices

Industrial Minerals (London), listed the following prices for feldspar, per short ton, f.o.b. plant, bulk:

Producing States	1988	1989
Ceramic grade:		
Middleton, CT, minus 200 mesh	$53.25	$67.50
Monticello, GA, 200 mesh, high potash	73.50	82.50
Spruce Pine, NC, 170–250 mesh	44.00	50.00
Glass grade:		
Middleton, CT, 96% plus 200 mesh	39.00	45.00
Monticello, GA, 92% plus 200 mesh, high potash	54.00	64.75
Spruce Pine, NC, 97.8% plus 200 mesh	30.75	32.50

Source: Industrial Minerals (London), No. 267, Dec. 1989, p. 74.

World Review

Capacity.—The data in table 9 are rated capacity for mines and refineries 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. Because actual capacity data were not available, recent peak production during the past 5 years for the United States and foreign countries was considered to be equal to rated capacity.

Ethiopia.—A feasibility study and engineering design were being prepared for the production of 4,400 tons per year each of kaolin, feldspar, and quartz. These products would be used as raw materials for the Ceramics Manufacturing Complex to be established at Awassa. The kaolin and feldspar deposits were 267 miles from Addis Ababa. Laboratory tests on feldspar from the Kenticha deposit showed that the material was suitable for use in ceramics and glass. Development of the

TABLE 4

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

(Thousand short tons and thousand dollars)

Use	1988		1989	
	Quantity	Value	Quantity	Value
Hand-cobbed:				
Pottery	5	W	5	W
Other	7	W	5	W
Total[2]	12	W	9	W
Flotation concentrate:				
Glass	217	7,937	183	7,009
Pottery	287	15,591	288	15,717
Total[2]	503	23,528	470	22,726
Feldspar-silica mixtures:[3]				
Glass	181	7,569	202	10,716
Pottery	32	W	25	W
Total[2]	212	W	227	W
Total:[2]				
Glass[4]	397	15,506	384	17,725
Pottery	324	W	318	W
Other[5]	7	W	5	W
Total	730	33,300	710	35,900

W Withheld to avoid disclosing 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.

industrial minerals sector is the responsiblity of the Industrial Minerals Division of the Ethiopian Mineral Resources Development Corp.[1]

Turkey.—Laboratory research was performed on feldspar ore, from Simav in western Turkey, containing 98% feldspar and quartz, 1.5% micas and 0.5% accessory minerals such as garnet, tourmaline, magnetite, and hematite. The research, done at the Technical University of Istanbul, included geologic, petrographic, and mineral processing studies. The optimum mineral processing scheme included size reduction, classification, and flotation.[2]

NEPHELINE SYENITE

Nepheline syenite was produced by Indusmin Ltd., a division of Falconbridge Ltd., from two operations at Blue Mountain, and Nephton, Ontario, Canada. Output in 1988, the latest year for which information was available, was at least 660,000 tons. The largest market for the mineral has been the glass industry. Applications were being pursued in the adhesives, rubber, and plastics industries.[3]

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. Sales were largely to markets in Western Europe.[4]

Prices for Canadian nepheline syenite listed in Industrial Minerals (London), December 1989, were $22 to $28 per ton for glass grade, 30 mesh, bulk, carlots-trucklots, depending on iron content; $67 per ton for ceramic grade, 200 mesh, bagged, 10-ton lots; and $79 to $91 per ton for filler-extender grade, bagged.

In China, 14 nepheline syenite bodies with a total area of approximately 0.4 square miles have been found, mainly in southwestern China. Because of its high iron content, the nepheline syenite's application is limited. Another nepheline ore, apaneite ore, is found only in Sichuan province. This ore is characterized by high contents of K_2O plus Na_2O, Al_2O_3, and nepheline, and low iron content. The ore can be beneficiated by crushing, grinding, and magnetic separation, yielding a product that can be used in glass and ceramics.[5]

APLITE

Aplite is a feldspar mineral that has more than one geological definition. However, aplite from the one active U.S. operation contains primarily lime-soda feldspar. Aplite, usually unsuitable for use in ceramics, has been used in the manufacture of glass when it is sufficiently low in iron.

Aplite of glassmaking quality was produced in the United States by The Feldspar Corp. near Montpelier, Hanover County, VA.

Domestic output decreased compared with that of 1988. The data are company proprietary and cannot be released for publication. Aplite traditionally has a somewhat lower price than feldspar. Industrial Minerals (London), December 1989, 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 580,000 tons, 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.

OUTLOOK

The outlook for the near future is for feldspathic demand to remain generally at 1989 levels. Continued competition from imported nepheline syenite, as well as increased use of recycled glass (cullet) and lightweighting of glass containers, will reduce the demand for feldspathic materials in glass manufacturing.

If housing starts rebound moderately from 1989 levels, requirements for feldspathics in plumbing fixtures, tile and glass fiber for insulation will be maintained. This should offset the drop of feldspathic usage in glass demand.

TABLE 5

DESTINATION OF SHIPMENTS OF FELDSPAR[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Short tons)

State	1985	1986	1987	[2]1988	[3]1989
Alabama	W	20,100	W	W	W
California[e 4]	50,000	50,000	50,000	50,000	75,000
Florida	16,900	20,000	14,200	W	W
Georgia	95,300	91,600	86,500	93,100	82,200
Illinois	37,000	27,900	28,700	29,700	27,500
Indiana	W	W	W	30,100	28,000
Kentucky	16,200	16,900	W	17,000	16,200
Louisiana	12,200	14,100	14,900	13,900	12,000
Maryland	7,400	7,000	6,400	7,200	8,400
Mississippi	W	W	W	13,200	11,500
Missouri	4,700	6,100	5,200	4,900	W
North Carolina	17,000	20,700	40,500	23,700	19,900
Ohio	65,800	68,200	64,400	64,700	57,600
Pennsylvania	31,100	33,600	36,400	29,200	38,400
Texas	42,000	45,000	44,000	W	W
West Virginia	27,000	24,400	19,800	18,700	18,500
Other[5]	277,400	289,400	306,000	332,400	314,800
Total[6]	700,000	735,000	720,000	730,000	710,000

[e] Estimated. W Witheld to avoid disclosing company proprietary data; included with "Other destinations."
[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] Due to lack of actual data, an estimated 65% of State destination data were obtained by projections of previous years' data.
[4] Data are incomplete and estimates are very rough.
[5] Includes Arkansas, Colorado, Connecticut, Kansas, Massachusetts, Michigan, Minnesota, New Jersey, New York, Oklahoma, Rhode Island, South Carolina, Tennessee, Virginia, Wisconsin, 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

(Short tons)

Destination	1985	1986	1987	1988	1989
Illinois, Indiana, Wisconsin	5,800	5,500	W	W	W
Maryland, New York, West Virginia	28,000	25,600	W	W	W
Ohio	8,200	W	W	W	W
Pennsylvania	8,200	W	W	W	W
Texas	200	300	W	W	W
Canada	5,200	3,500	W	W	W
Other[2]	21,400	39,200	W	W	W
Total	77,000	74,100	W	94,500	80,500

W Witheld 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, Oklahoma, South Carolina, Tennessee, Virginia, States indicated by symbol W, and other unspecified States. May also include countries.

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 which occurs in the Spruce Pine district of North Carolina. The principal mineral ingredients of this ore are approximately: plagioclase, 45%; quartz, 25%; microcline, 20%; and muscovite mica, 10%. Minor amounts of other minerals are also present.[6] Beneficiated feldspar from alaskite comprises 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 else 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, 150 to 200 pounds of ground feldspar is used to produce 1 ton of container glass.

TABLE 7

U.S. EXPORTS OF FELDSPAR, BY COUNTRY

Country	1988		1989	
	Short tons	Value	Short tons	Value
Canada	1,454	$76,986	2,217	$146,955
Dominican Republic	294	17,754	323	22,433
Italy	1,274	66,216	979	74,680
Mexico	2,954	199,653	2,252	172,329
Panama	970	50,439	—	—
Taiwan	5,182	269,692	1,202	154,261
Venezuela	734	38,160	825	59,898
Other	850	50,197	2,485	198,440
Total	13,712	769,097	10,283	828,996

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF FELDSPAR, BY TYPE AND COUNTRY

Type and country	1988		1989	
	Short tons	Value[1]	Short tons	Value[1]
Crude:				
Canada	—	—	—	—
Germany, Federal Republic of	12	$3,507	—	—
Mexico	56	2,487	(2)	(2)
Netherlands	7	1,975	—	—
Ground, crushed, or pulverized:				
Canada	19	6,278	—	—
Germany, Federal Republic of	25	5,076	32	$8,241
Korea, Republic of	—	—	—	—
Mexico	6,708	639,643	13,199	864,407
United Kingdom	—	—	—	—
Total	6,827	658,966	13,231	872,648

[1] Customs value.
[2] Crude and ground combined.
Source: Bureau of the Census.

TABLE 9

WORLD FELDSPAR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand short tons)

	Rated capacity[1]
North America:	
Mexico	117
United States	735
Total	852
South America:	
Brazil	133
Venezuela	106
Other	123
Total	362
Europe:	
Finland	62
France	238
Germany, Federal Republic of	355
Italy	1,540
Norway	88
Poland	66
Romania[e]	95
Spain	178
Sweden	55
U.S.S.R.[e]	360
Yugoslavia	54
Other	68
Total	3,159
Africa:	
South Africa, Republic of	90
Other	30
Total	120
Asia and Oceania:	
India	57
Korea, Republic of	266
Thailand	330
Other	281
Total	934
World total[2]	5,430

[e] Estimated.
[1] Includes capacities of operating plants, as well as plants on standby basis.
[2] Data do not add to total shown because of independent rounding.

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.

Industry Structure

Among the largest U.S. feldspar producers in 1989 were The Feldspar Corp., with operations in Connecticut, Georgia, and North Carolina, and Indusmin Inc. and Unimin Corp. in North Carolina. Feldspar, aplite and imported nepheline syenite from Canada compete against each other, especially in the eastern United States. Shipping costs play a big role in determining the market radius of each of the three feldspathic products.

Feldspar was produced in more than

40 other countries in 1989. Italy has reportedly had the highest output of feldspathic materials in recent years; much of that country's production is believed to be aplite (lime-soda feldspar). Other significant feldspar producers in Western Europe included France and the Federal Republic of Germany. Norway is the only other producer of nepheline syenite in the Western World besides Canada. There has been considerable trade in feldspathic materials in Western Europe because of the close proximity of the countries involved. International trade in other parts of the world is somewhat limited.

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 located in Connecticut, North Carolina, Georgia, 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 Okla-

TABLE 10

FELDSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	30	r27	32	44	33
Australia	7	11	13	18	18
Austria	15	3	5	9	9
Brazil[3]	121	133	131	re132	132
Burma	3	3	2	3	3
Chile	3	3	1	5	5
Colombia	38	39	37	e39	39
Ecuador	4	3	2	re3	3
Egypt	21	21	18	7	7
Finland	58	52	57	e55	55
France	190	238	e231	e231	220
Germany, Federal Republic of	355	273	342	e330	350
Guatemala	6	6	8	e8	8
Hong Kong	120	39	25	12	11
India	51	51	55	56	57
Iran[e]	435	35	35	35	35
Italy	1,230	r1,258	1,310	1,508	1,540
Japan[5]	34	35	37	32	48
Kenya	1	—	(6)	(6)	—
Korea, Republic of	160	144	199	266	265
Mexico	e110	94	117	106	110
Morocco[e]	1	1	1	1	1
Mozambique[e]	(4 7)	(7)	(6)	(6)	—
Nigeria	e2	3	1	(8)	(7)
Norway[e 9]	488	88	88	88	88
Pakistan	6	13	7	10	10
Peru	—	21	71	re22	22
Philippines	6	7	e7	10	7
Poland	66	63	61	e55	55
Portugal	32	37	45	e41	42
Romania[e]	95	95	90	90	83
South Africa, Republic of	36	58	73	90	90
Spain[10]	150	149	178	154	154
Sri Lanka	11	8	8	7	7
Sweden[e]	446	44	44	44	44
Taiwan	12	29	31	21	21
Thailand	115	127	186	324	330
Turkey	e22	e22	33	62	66
U.S.S.R.[e]	r360	r360	r360	r360	360
United Kingdom (china stone)	7	8	6	7	8
United States	700	735	720	715	720
Uruguay[e]	41	1	1	1	1
Venezuela	r47	38	48	106	55

See footnotes at end of table.

TABLE 10—Continued

FELDSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Yugoslavia	54	53	50	39	39
Zambia	(7)	(7)	(7)	(7)	(7)
Zimbabwe	3	2	3	4	4
Total	[r]4,452	[r]4,430	4,769	5,150	5,155

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 18, 1990.

[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 thousand short tons: 1985—109; 1986—116; 1987—109; 1988—154; and 1989—150 (estimated).

[4] Reported figure.

[5] In addition, the following quantities of aplite concentrate were produced in thousand short tons: 1985—517; 1986—504 (revised); 1987—514 (revised); 1988—580; and 1989—625 (estimated).

[6] Revised to zero.

[7] Less than 1/2 unit.

[8] Revised to less than 1/2 unit.

[9] Excludes nepheline syenite.

[10] Includes pegmatite.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF NEPHELINE SYENITE

Year	Crude		Ground	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thoudsands)
1987	3,720	$142	304,965	$11,259
1988	2,882	111	306,962	11,122
1989[1]	—	—	334,000	12,273

[1] Crude and ground combined.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORT DUTIES

Tariff item	No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Feldspar:			
Crude	2529.10	Free	$ 0.50 per long ton.
Ground	2529.10	2.8% ad valorem.	30% ad valorem.

homa. 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 1989 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.

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[2] Capkinoglu, N., O. Aydan, and Y. Kaytaz. Mineral Processing of Pegmatites As Feldspar Ore. Paper from Second World Congress on Non-Metallic Minerals, Beijing, China, Oct. 17-21, 1989, pp. 669-674.

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FERROALLOYS

By Clark R. Neuharth

Mr. Neuharth, a physical scientist with 7 years 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 and Elizabeth Voyatzis, mineral data assistants, and Mr. Neuharth; the international data tables were prepared by Peter Roetzel, international data assistant.

Overall domestic demand for ferroalloys and related metals declined approximately 5% compared with that of 1988 owing to decreased production of iron and steel. Free market prices for most ferroalloys dropped throughout most of the year, stabilizing somewhat at yearend. World production was essentially unchanged.

LEGISLATION AND GOVERNMENT PROGRAMS

The South Carolina Research Authority, a public corporation created by the State's government to promote high-technology industries, received seed funding from the Defense Logistics Agency (DLA) to support a research project aimed at utilizing plasma arc smelting technology in the production of ferrochromium. Macalloy Corp., Arthur D. Little, Clemson University, and the Massachusetts Institute of Technology, are principals in the project. In the first stage of the project, Macalloy was to build a pilot scale (2,000-kilowatt) smelter that would produce about 1,000 pounds of ferrochromium per hour at the company's plant in Charleston, SC. Site preparation was nearly complete at yearend; assembly of the furnace was scheduled to be completed by April 1990.

STRATEGIC CONSIDERATIONS

Ferroalloys are essential in the production of iron and steel, making their continued availability a matter of strategic importance. Silicon metal is consumed in the aluminum industry as an alloying agent and in the chemical industry as a raw material in silicon-based chemicals. 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.

Security of Supply

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 78%, 100%, and 23%, respectively, in 1989. 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 National Defense Stockpile (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.

Stockpile

DLA renewed contracts for the upgrading of ferroalloy materials in the NDS. Macalloy was awarded a contract to convert 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. The contract included an option to convert a total of 264,791 short tons in 1992 and 1993. Elkem Metals Co. was awarded a contract to convert 132,861 short tons and 132,244 short tons of manganese ore to high-carbon ferromanganese in 1990 and 1991, respectively, at a total cost of approximately $82 million. The manganese contract also included a third and fourth year option in which an additional 264,791 short tons of manganese ore would be converted to high-carbon ferromanganese. Elkem also was awarded a contract for the conversion of low-carbon ferrochromium to vacuum melting-grade electrolytic chromium metal. The conversion will yield 1,150 short tons of chromium metal at a cost of $7.2 million.

TABLE 1

GOVERNMENT INVENTORY OF FERROALLOYS, DECEMBER 31, 1989

(Thousand short tons of alloy)

Alloy	Stockpile grade	Non-Stockpile grade	Total
Ferrochromium:			
High-carbon	640	1	641
Low-carbon	300	19	319
Ferrochromium-silicon	57	1	58
Ferrocolumbium (contained columbium)	.3	.2	.5
Ferromanganese:			
High-carbon	812	—	812
Medium-carbon	29	—	29
Ferrotungsten (contained tungsten)	.4	.6	1
Silicomanganese	24	—	24

ISSUES

The Office of the United States Trade Representative (USTR) denied the U.S. Ferroalloys Association's 1988 request to end the duty-free status under the Generalized System of Preferences (GSP) for imports of silicon metal (99.00% to 99.99% purity) coming from Argentina and

Yugoslavia. The duty on this product would be 5.3% ad valorem without GSP status. Both of these countries were considered by the U.S. industry to be longtime producers of silicon metal; however, individually, they did not meet the criterion for GSP removal, which is to account for more than 25% of total imports of a product. Imports of the 99.00%- to 99.99%-pure silicon metal from the two countries combined accounted for about 30% of all silicon metal imports into the United States over the past few years. The USTR did reject GSP status for import of ferrosilicon in the 55% to 80% silicon range (above and below 3% calcium) and ferrosilicon-manganese from Brazil.

As part of the United States-Canadian Free Trade Agreement, duties on imports of all forms of ferromanganese, silicomanganese, silicon-containing ferroalloys, and ferrochromium silicon from Canada were lifted effective January 1, 1989. For some other manganese materials and silicon metal of Canadian origin, scheduled stages of reduction were established in which some duties would be reduced to zero by January 1, 1993, and others by January 1, 1998.

PRODUCTION

Domestic production of ferroalloys and related metals overall decreased 2% compared with that of 1988. Shipments overall were unchanged from those of the previous year. Production of silicon-containing ferroalloys and silicon metal overall increased 2% compared with that of 1988, but near the end of the year, major producers were facing cutbacks because of oversupply, low prices, and much needed maintenance. SKW Alloys Inc. Elkem, and Globe Metallurgical Inc. were among the silicon producers that announced significant maintenance programs and/or production cutbacks. Elkem was the only producer of ferromanganese and silicomanganese. Elkem and Macalloy continued to produce high-carbon ferrochromium. Macalloy's ferrochromium smelter was shut down for a few weeks owing to erratic power supplies following Hurricane Hugo. Ferronickel was produced domestically for the first time in 3 years as Glenbrook Nickel Co. poured its first ingot on August 12.

Shieldalloy Metallurgical Corp. purchased Frankel Metal Co. (Detroit, MI), a titanium scrap processor. Shieldalloy officials said the acquisition would broaden its base as a supplier of titanium-bearing materials. Shieldalloy also concluded its purchase of Affiliated Metals and Minerals Inc.'s 20% interest in a joint-venture vanadium project to be situated in Pittsburgh, PA; Shieldalloy already owned the remaining 80% of the venture. The plant was scheduled to be operational by mid-1990. The process would involve the conversion of vanadium-bearing residues to an intermediate step for the eventual production of ferrovanadium.

Strategic Minerals Corp. (Stratcor), Danbury, CT, completed expansion and renovation of its Niagara Falls, NY, facility. The expansion included new furnace operations that were to increase the company's worldwide output of nitrogen-bearing vanadium ferroalloy, trade-named Nitrovan. In the past, Stratcor had produced Nitrovan only in the Republic of South Africa.

The Glenbrook Nickel operation, which was previously owned and operated by the M.A. Hanna Co., started production in August at Riddle, OR. Universal Consolidated Co. initiated the venture when they bought the property from M.A. Hanna in 1988. Universal Consolidated then sold the project to Cominco American Resources (a wholly owned subsidiary of Cominco Resources International Ltd.) and USA Investments in April of 1989. In June, the operation was supplied power by the Bonneville Power Administration after the installation of a new transformer at the power substation. The plant began producing ferrosilicon, which is consumed in the ferronickel process, and upgrading stockpiled nickel ore in July, and tapped the first ferronickel the following month. In November, USA Investments' interest in the project was sold to Cominco Resources International. Although stockpiled ore (6 million short tons containing 0.7% nickel) that had accumulated over 30 years while M.A. Hanna operated the smelter was being used for feed initially, the company was facing either reopening the Riddle Mine or importing ore as a means of lowering production costs. The company's goal of producing 1 million pounds of nickel contained in ferronickel per month was not met in 1989, but was expected to be reached sometime in 1990.

Globe Metallurgical Inc., Cleveland, OH, purchased Materials & Methods Ltd. (London) to broaden its European presence in the worldwide marketing of foundry processes and ferroalloys. Globe expected to double its current European revenue (5% of total sales) as a result of the deal. This was Globe's first major acquisition since its management buyout in 1987. In July, Globe terminated its 34-year-old relationship with Pickands Mather & Co., a subsidiary of Cleveland-Cliffs Inc., and formed an internal sales force in what company officials said was an attempt to increase the quality of service and technical support to its customers. In November, Cleveland-Cliffs announced that it was selling the metallurgical sales business it had acquired with the purchase of Pickands Mather in 1986.

American Alloys Inc. began producing silicon metal during the third quarter at its Graham, WV, facility (previously operated by Foote Mineral Co.).

In December, Boulder Gold NL (Australia) entered into an agreement with DCC Equities Ltd. (Canada), which includes as its shareholders Dynamic Capital Corp., Placer Dome Inc., Corona Corp., and the Canadian, Imperial Bank of Commerce, to finance a feasibility study of the planned Mountain View ferrochromium project near Columbus, MT. Chrome Corp. of America, Boulder Gold's U.S.-owned subsidiary, would manage the project during the feasibility stage. The project, if determined feasible, would utilize the Coal Ore Direct Iron Reduction 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; however, continued operation would require reopening of the Mouat chromite mine, which is estimated to have a life of about 20 years.

The Ferroalloys Association reported that its member companies consumed approximately the same amount of electricity in 1989 as in 1988, 5.3 billion kilowatt hours.

CONSUMPTION AND USES

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 demand for ferroalloys and related metals decreased about 5% compared with that of 1988 owing to

TABLE 2

U.S. FERROALLOY PRODUCTION[1] AND SHIPMENTS[2]

(Short tons, gross weight, unless otherwise specified)

	1988				1989			
	Net production	Net shipments		Stocks Dec. 31	Net production	Net shipments		Stocks Dec. 31
		Quantity	Value (thousands)			Quantity	Value (thousands)	
Ferrosilicon[3]	495,299	475,453	$298,822	77,504	523,879	481,973	$319,969	106,026
Silicon metal	164,348	162,283	218,934	7,243	150,500	146,573	175,888	9,666
Other[4]	316,857	296,355	408,322	43,508	292,241	287,510	430,705	37,755
Ferrophosphorus	66,381	50,963	9,583	r42,621	59,024	69,476	9,658	28,085
Total	1,042,885	985,054	935,661	r170,876	1,025,644	985,532	941,888	181,532

rRevised.

[1]Does not include alloys produced for consumption in the making of other ferroalloys.

[2]Gross sales (including exports) minus purchases.

[3]Includes all regular and specialty grades of ferrosilicon, excluding silvery pig iron.

[4]Includes ferroaluminum, ferroboron and other complex boron additive alloys, all chromium-containing ferroalloys and chromium metal, ferrocolumbium, all manganese-containing ferroalloys and manganese metal, ferromolybdenum, ferronickel, ferrotitanium, ferrovanadium, and silvery pig iron.

decreased production of iron and steel. The steel industry was very strong during the first half of the year; however, overall production of steel (i.e., raw steel production) dropped significantly during the second half, ending the year down 2%. Production of stainless grades decreased 5%, lessening the demand for nickel- and chromium-containing ferroalloys. Shipments of iron and steel castings from U.S. foundries decreased significantly. Compared with that of 1988 demand decreases for both chromium- and silicon-containing materials were 5%; demand for manganese-containing materials increased slightly.

Functions of the Elements

Manganese is required in virtually all steels and cast irons to counteract the harmful effects of sulfur. Manganese is also a mild deoxidizer, but is supplemented generally by stronger deoxidizers such as silicon and aluminum. Chromium provides corrosion resistance to stainless steels.

PRICES

Prices for most ferroalloys and related materials fell throughout 1989, owing to decreased demand by consuming industries. The price for imported ferromanganese containing 78% manganese was much more stable than that of most other alloys and actually ended the year up $25 per long ton of alloy at a range of $620 to $645. The yearly average, $620, was nearly 25% higher than that of 1988. The price for imported charge chrome (ferrochromium containing 50% to 55% chromium) on January 1 was quoted at a range of 88 to 93 cents per pound of contained chromium and fell to a low range of 52.0 to 55.5 cents by the end of the year. The yearly average was 75.7 cents per pound, about 10% lower than that of 1988. The silicon price swing was by far the most drastic. The price of imported 75% ferrosilicon was quoted at a range of 66 to 69 cents per pound of contained silicon on January 1 and fell to a 2-year low range of 34.0 to 35.5 cents per pound in November before rebounding slightly at the end of the year. The average yearly price was 49 cents, 12% lower than that of 1988. Prices for molybdenum-, nickel-, and vanadium-containing ferroalloys also fell during 1988.

FOREIGN TRADE

The trade deficit for ferroalloys and related metals overall was $977 million, a 7% increase over that of 1988. A trade deficit of $26 million was recorded for related metals, compared with a surplus of $52 million in 1988.

Exports of ferroalloys and related metals overall increased 19% compared with that of 1988; however, the associated value of those materials decreased 35% compared with that of the previous year. The rise in exports overall was fueled primarily by a 63% increase in the exports of alloys containing chromium, manganese, and silicon. Exports of other ferroalloys decreased 5% and those of ferroalloy metals decreased 44%.

Imports for consumption of ferroalloys and related metals overall were supplied by 44 countries and decreased 10% and 18%, respectively, compared with those of 1988. Geographic sources and their respective share of total U.S. imports of ferroalloys and related metals overall were Africa, 35%; Europe, 25%; the Western Hemisphere, 22%; Asia, 9%; Oceania, 6%; and the Mideast, 3%. The Republic of South Africa continued to be the main source of U.S. imports of those materials, accounting for 30% of the total. Of the imported chromium- and manganese-containing alloys, the Republic of South Africa supplied 40% and 36% of the respective totals. The second leading suppliers of those materials were Zimbabwe (17%) for chromium and France (20%) for manganese. Imports of ferrosilicon decreased 18% compared with those of 1988. The principal sources of ferrosilicon imports were Brazil, 25%; the U.S.S.R., 19%; Venezuela, 15%; and Canada, 15%. Imports of silicon metal overall decreased 23%. The principal sources of silicon metal were Brazil, 36%; Canada, 18%; China, 17%; and Argentina, 16%.

Tariffs

Tariff schedules for ferroalloys and related metals can be found in the respective individual commodity chapters of this yearbook.

TABLE 3

PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1989

Producer	Plant location	Products[1]	Type of furnace
FERROALLOYS (Except ferrophosphorus)			
Affiliated Metals and Minerals Inc.	New Castle, PA	FeMo, FeV	Metallothermic.
AMAX Inc., Climax Molybdenum Co. Div.	Langeloth, PA	FeMo	Metallothermic.
American Alloys, Inc.	New Haven, WV	FeSi, Si	Electric.
Applied Industrial Minerals Corp. (AIMCOR)	Bridgeport, AL Kimball, TN	FeSi, other[2] do.	Do. Do.
Cabot Corp.	Revere, PA	FeCb	Metallothermic.
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.
Globe Metallurgical Inc.	Beverly, OH Selma, AL	FeCr, FeSi, Si	Electric.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi, silvery pig iron	Do.
Kerr-McGee Chemical Corp.	Hamilton (Aberdeen), MS	Mn	Electrolytic.
Macalloy Corp.	Charleston, SC	FeCr	Electric.
Metallurg Inc., Shieldalloy Metallurgical Corp.	Cambridge, OH Newfield, NJ	Cr, FeAl, FeB, FeCb, FeTi, FeV, other[2]	Electric and metallothermic.
Reading Alloys Inc.	Robesonia, PA	FeCb, 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	FeCr, FeCrSi FeSi, Si	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	do.	Do.
Stauffer Chemical Co., Industrial Chemical Div.	Mount Pleasant, TN	do.	Do.

[1]Cr, chromium metal; FeAl, ferroaluminum; FeB, ferroboron; FeCb, ferrocolumbium; FeCr, ferrochromium; FeCrSi, ferrochromium-silicon; FeMn, ferromanganese; FeMo, ferromolybdenum; FeNi, ferronickel; FeP, ferrophosphorus; FeSi, ferrosilicon; FeTi, ferrotitanium; FeV, ferrovanadium; FeW, ferrotungsten; FeZr, ferrozirconium; Mn, manganese metal; Si, silicon metal; SiMn, silicomanganese.
[2]Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

TABLE 4

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ADDITIVES IN 1989, BY END USE[1]

(Short tons of alloys unless otherwise specified)

End use	FeMn	SiMn	FeSi	FeTi	FeP	FeB
Steel:						
Carbon	329,699	71,684	[2]57,907	([3])	7,271	414
Stainless and heat-resisting	[2]14,783	4,849	[2]85,534	2,918	([3])	23
Other alloy	[2]78,128	[2]23,075	[2]65,950	164	1,451	238
Tool	[2]392	([3])	[2]2,349	([3])	—	—
Unspecified	936	213	3,106	1,712	6	—
Total steel[4]	423,938	99,821	214,846	4,794	8,728	675
Cast irons	13,610	1,712	[5]205,559	W	2,175	W
Superalloys	5[1]70	—	[5]377	882	—	W
Alloys (excluding alloy steels and superalloys)	[5]19,643	W	[5]59,149	962	194	85
Miscellaneous and unspecified	5,988	2,815	144,949	52	—	33
Total[4]	463,349	104,348	624,880	6,690	11,097	793
Percent of 1988	94	88	100	112	92	77
Consumer stocks, Dec. 31	79,172	[6]10,393	21,700	718	1,469	215

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, ferrophosphorus; FeB ferroboron, including other boron materials.

[2]Part included with "Steel: Unspecified."

[3]Included with "Steel: Unspecified."

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

[5]Part included with "Miscellaneous and unspecified."

[6]Includes some producer stocks.

TABLE 5

REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ALLOYING ELEMENTS IN 1989, BY END USE[1]

(Short tons of contained elements unless otherwise specified)

End use	FeCr	FeMo	FeW	FeV	FeCb	FeNi
Steel:						
Carbon	[2]5,015	103	—	1,216	900	—
Stainless and heat-resisting	180,637	245	69	106	443	10,488
Other alloy	[2]29,405	1,428	W	2,340	912	232
Tool	[2]2,745	W	319	463	([3])	—
Unspecified	([4])	([4])	([4])	([4])	32	—
Total steel[5]	217,802	1776	388	4,123	2,287	10,720
Cast irons	[2]4,672	851	W	20	—	W
Superalloys	9,747	61	W	42	397	W
Alloys (excluding alloy steels and superalloys)	3,261	130	W	824	W	W
Miscellaneous and unspecified	739	283	99	106	364	483
Total[5]	236,221	3,102	487	5,117	3,047	11,203
Percent of 1988	88	99	92	96	88	87
Consumer stocks, Dec. 31	14,099	257	49	615	NA	NA

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

NA Not available.

[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 totals shown because of independent rounding.

TABLE 6

U.S. EXPORTS OF FERROALLOYS AND RELATED METALS IN 1989

Alloy	Gross weight (short tons)	Content (short tons)	Value (thousands)
Ferroalloys:			
Ferrochromium with greater than 4% carbon	5,114	3,053	$5,262
Ferrochromium with less than 4% carbon	2,625	1,556	2,988
Ferrochromium-silicon	2,694	1,616	2,788
Ferromanganese with greater than 2% carbon	1,746	1,378	1,424
Ferromanganese, other	7,270	5,392	5,886
Silicomanganese	5,859	3,807	4,068
Ferromolybdenum	83	50	615
Ferronickel	387	232	949
Ferrophosphorus	24,898	(1)	3,511
Ferrosilicon (greater than 55% silicon)	23,297	14,738	18,262
Ferrosilicon, other	30,760	15,380	22,580
Ferrovanadium	544	283	5,299
Ferrozirconium	512	(1)	530
Ferroalloys, n.e.c.	6,642	(1)	9,068
Total ferroalloys[2]	112,429	XX	83,230
Metals:			
Chromium	216	(1)	4,097
Manganese	5,665	(1)	10,632
Silicon			
(less than 99% silicon)	3,249	(1)	6,539
(99.00% to 99.99% silicon)	1,305	(1)	2,269
(greater than 99.99% silicon)	1,007	(1)	75,266
Total ferroalloy metals[2]	11,442	XX	98,802
Grand total[2]	123,871	XX	182,033

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

Source: Bureau of the Census.

WORLD REVIEW

The Chromium Association and the Chromium Centre announced the merger of their organizations into a single unit, the International Chromium Development Association, effective January 1, 1990. The new group was charged with promoting the use of chromium in both traditional and new markets. The Manganese Centre, which was formed in 1975 to promote the use of manganese and its alloys, changed its name to the International Manganese Institute. The organization's address will remain 17 ave. Hoche, 75008 Paris, France.

Capacity

The data in table 8 are rated capacities for major countries that produce ferroalloys containing chromium, manganese, and silicon, as well as silicon metal 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. 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

Status of the new ferrochromium smelter, which was to be located at the Elbasan steel and metallurgical complex, was uncertain. Initial plans called for the facility to produce 38,000 metric tons per year of HC material with startup scheduled for 1990; however, in recent years, the country had encountered difficulties with chromite and ferrochromium operations because of water and electrical power shortages.[1] Albania and Gesellschaft für Electrometallurgy (GfE) of the Federal Republic of Germany entered into a marketing agreement in which GfE would provide technical advice to Albania in setting up new ferrochromium smelting facilities in exchange for the right to market a predetermined amount of Albanian ferrochromium in the Federal Republic of Germany annually.[2]

Australia

Late in the year, Barrack Mines Ltd. started operation of its newly commissioned silicon metal production facility in Western Australia. The plant, utilizing two 18-megawatt electric furnaces, had a planned capacity of 24,000 metric tons per year, but it was expected that production could reach 30,000 metric tons per year once both furnaces were fully operational. Barrack had secured contracts to export material to Asia, Europe, and North America.[3]

Brazil

Overall ferroalloy production increased 6%, compared with that of 1988 to a new record high of slightly more than 1 million metric tons, despite significant increases, 12% to 18%, in electric power rates, according to Anuario da Industria Brasileira de Ferroligas (ABRAFE). The most significant production increases were those of ferrosilicon and silicon metal, 7% and 47%, respectively. Total production of silicon-containing materials was 436,793 metric tons. The production of manganese-containing ferroalloys also increased by 4% to 388,930 metric tons. Of the ferroalloy production overall, nearly one-half was exported.

The largest production increase, that of silicon metal, was attributed to five new furnaces; two were started in late 1988 by Camargo Correa Metais S/A, two by Rima Electrometalurgia S/A in 1989, and one by Cia. Ferroligas Minas Gerais in 1989.[4]

After several years of rapid expansion, many of Brazil's ferrosilicon and silicon producers canceled or postponed plans for

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF FERROALLOYS AND RELATED METALS IN 1989

Alloy	Gross weight (short tons)	Content (short tons)	Value (thousands)
Chromium alloys:			
Ferrochromium containing 4% or more carbon	303,852	176,380	$243,800
Ferrochromium containing less than 4% but greater than 3% carbon	34,064	22,172	35,858
Ferrochromium containing 3% or less carbon	40,984	27,858	50,769
Ferrochromium-silicon	7,499	3,038	4,565
Total chromium alloys[1]	386,398	229,448	334,992
Manganese alloys:			
Ferromanganese containing 4% or more carbon	391,513	300,980	170,816
Ferromanganese containing less than 4% but greater than 2% carbon	73	58	29
Ferromanganese containing less than 2% but greater than 1% carbon	67,303	54,441	53,307
Ferromanganese containing 1% or less carbon	17,175	15,004	22,388
Silicomanganese	255,390	166,484	151,241
Spiegeleisen	276	(2)	154
Total manganese alloys[1]	731,730	XX	397,936
Silicon alloys (ferrosilicon):			
Less than 55% silicon, containing more than 2% magnesium	7,333	3,082	5,970
Less than 55% silicon, n.e.c.	55,891	25,704	21,166
55% to 80% silicon, containing more than 3% calcium	22,510	13,929	28,607
55% to 80% silicon, n.e.c.	107,341	80,557	72,912
80% to 90% silicon	25	21	35
Greater than 90% silicon	2,996	2,766	2,941
Total silicon alloys[1]	196,096	126,059	131,631
Other ferroalloys:			
Ferrocerium and other cerium alloys	267	(2)	1,688
Ferromolybdenum	1,554	851	9,062
Ferronickel	37,356	12,650	117,630
Ferroniobium (columbium)	4,089	(2)	28,657
Ferrophosphorus	156	(2)	413
Ferrotitanium and ferrosilicon-titanium	2,213	(2)	11,115
Ferrotungsten and ferrosilicon-tungsten	609	396	1,987
Ferrovanadium	712	536	13,493
Ferrozirconium	489	(2)	596
Ferroalloys, n.e.c.	2,302	(2)	7,583
Total other ferroalloys[1]	49,747	(2)	192,223
Total ferroalloys[1]	1,363,971	XX	1,056,782
Related metals:			
Chromium	4,630	(2)	27,590
Manganese	12,174	(2)	16,497
Silicon, greater than 99% silicon	9,775	9,560	8,798
Silicon, 99.00 to 99.99% silicon	36,874	36,553	36,438
Silicon, greater than 99.99% silicon	965	(2)	35,152
Total metals[1]	64,419	XX	124,474
Grand total[1]	1,428,390	XX	1,181,256

XX Not applicable.
[1]Data may not add to totals shown because of independent rounding.
[2]Not recorded.
Source: Bureau of the Census.

TABLE 8

WORLD PRODUCTION CAPACITY FOR BULK FERROALLOYS,[1] DECEMBER 31, 1989

(Thousand short tons, gross weight)

Country	Capacity
Albania	50
Argentina	144
Australia	260
Belgium	105
Brazil	1,171
Bulgaria	[2]35
Canada	295
Chile	(3)
China	1,950
Colombia	[2]10
Czechoslovakia	[2]138
Egypt	75
Finland	176
France	718
German Democratic Republic	[2]102
Germany, Federal Republic of	335
Greece	33
Hungary	(3)
Iceland	72
India	545
Italy	358
Japan	1,551
Korea, North	[2]85
Korea, Republic of	96
Mexico	319
Norway	1,400
Peru	(3)
Philippines	152
Poland	[2]235
Portugal	100
Romania	[2]195
South Africa, Republic of	2,251
Spain	429
Sweden	407
Switzerland	(3)
Taiwan	108
Turkey	136
U.S.S.R.	3,819
United Kingdom	97
United States	1,504
Uruguay	(3)
Venezuela	107
Yugoslavia	407
Zimbabwe	285
Other[4]	395
Total	20,600

[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]Includes silicon-containing ferroalloys and silicon metal.

further growth as world silicon prices dropped to preboom levels, and that country was struck with power shortages and increased power rates. One company, Cia. di Ferro Ligas da Bahia, also considered switching ferrosilicon capacity to that of silicomanganese. However, one ferrosilicon expansion project that had not been delayed at yearend was Eletrovale SA Industria e Comercio, a Brazilian-Japanese joint venture that began construction of a 31-megavolt·ampere (MV·A) furnace at the Nova Era Works, Minas Gerais State. The expansion was expected to double the output of 75% ferrosilicon from 24,000 to 50,000 metric tons per year.[5]

Cia. Ferroligas do Amapá continued construction of a 20,000 metric-ton-per-year ferrochromium smelter at Porto de Santana, with completion scheduled for 1990.[6]

Finland

Chromium producer Outokumpu Oy continued the expansion of its chromium operations. Expansion of its concentrator facility and construction of a new sintering plant were complete by yearend. Future plans included an increase in annual ferrochromium capacity from 60,000 metric tons to 250,000 metric tons sometime in 1990.[7]

France

Chromeurope S.A., a subsidiary of Ferroaleaciones Espanolas S.A. of Spain, started its second high-carbon ferrochromium furnace, a 16-MV·A unit. The company began production at its new Dunkirk facility with a 12-MV·A unit in 1988. The combined planned output of the two furnaces was to be 36,000 metric tons per year.[8]

India

Major developments were occurring in the ferroalloy industry. New ferrochromium and ferrosilicon smelters and electrical-power generating plants were being planned, constructed, and put into operation. Potential for significantly increased ferrochromium production capacity existed as the Government issued letters of intent (i.e., license agreements) to 11 domestic companies to produce at least 15,000 metric tons per year of ferrochromium each.[9] This amount of expansion, along with a number of smaller new operations that would not require licensing, would nearly double the country's ferrochromium production capacity over the next several years.[10] Ferrosilicon producer Nav Bharat Ferro Alloys announced plans to increase ferrosilicon production capacity from 30,000 metric tons per year to 40,000 metric tons per year with the addition of a new furnace. The company also planned to build a new plant and install two 16.5-MV·A furnaces to produce 40,000 metric tons per year of silicomanganese.[11]

Indonesia

Ispat Alloys Ltd. (India) planned to build a new bulk ferroalloy production facility to be operated as PT Ispat Alloys. Construction was expected to begin in 1990, and overall planned capacity was to be approximately 50,000 metric tons per year.

Italy

Italcromo planned to build a 100,000-metric-ton-per-year high-carbon ferrochromium plant at the site of a closed steel mill in Termoli. The company, a member of the Schlax group, received approval for initial financing through GEPI, a state-owned financing company.[12]

Japan

Steelmaker NKK Corp. divested its interest in ferrosilicon producer Yakushima Denko Co. Ltd. The sale was based on a decision by NKK to rely on imports from Brazilian ferroalloy producer Ferro Ligas Assofon SA, of which NKK held a 27% portion of ownership. Yakushima Denko said it would continue production at the same level and sell to other outside customers.[13]

Norway

BHP-Utah Minerals International, a subsidiary of Broken Hill Pty. Co. Ltd. (BHP, Australia) and Elkem A/S, announced plans to form a 50-50 joint venture involving the Bell Bay ferroalloy smelter of Tasmanian Electro Metallurgical Co. Pty. Ltd. in Tasmania and the Beauharnois, Quebec, plant of Elkem Metals Canada Inc. Details of the agreement were expected to be worked out sometime in 1990. The two companies have been doing business involving Elkem technology and BHP raw materials since the mid-1970's.

Norway's first ferrochromium project started production in September. Norsk Ferrokrom, a joint venture involving Norsk Jern Holding, the FESIL group, and Macalloy Corp. (United States), consists of two furnaces with a total capacity of 100,000 metric tons per year in Mo I Rana, Norway Only one of the furnaces had been operated at yearend, but company officials said the other could be started with very short notice. Macalloy will be responsible for North American marketing, while FESIL will control sales for the rest of the world. Another ferroalloy joint venture between Norsk Jern and FESIL was started at Mo I Rana. This project involved the conversion of two electric furnaces to produce 70,000 metric tons per year of ferrosilicon.

Late in the year, Elkem announced that it would cut ferrosilicon production 8% to 10% worldwide in 1990. During the period of reduced production, some extensive overhauls and maintenance would take place in Norway and North America. FESIL also planned cutbacks in production. The cuts were considered by industry representatives as "timely," in that prices were not favorable and demand had softened, helping to bring balance to the market.

Elkem and Tinfos Jernverk A/S were granted an extension of their Government's approval to continue importing manganese ore from the Republic of South Africa until 1991, as the country's two manganese ferroalloy producers were unable to secure other sources of manganese ore.[14]

Philippines

Integrated Chrome Corp. started production of ferrochromium with its newly converted 20-MV·A furnace. The furnace, which could produce 30,000 metric tons per year ferrochromium, previously had been used to produce silicon by Electro Alloys Corp. Integrated Chrome is a joint venture, between Nippon Denko Co. Ltd., a Japanese ferrochromium producer, and Kaschrome, a Philippine chromium ore producer.[15]

Ferro Chemicals Inc. completed the conversion of one of its ferrochromium furnaces to silicomanganese production. As a result of the conversion, Ferro Chemicals' ferrochromium production was expected to decrease by 50%.[16]

Maria Cristina Chemicals Industries (MCCI), along with Korean interests, Sangyong Co. Ltd., Pohang Iron and Steel Co. (Posco), and Dongil Chungong Co. Ltd., planned the construction of a 13,000-metric ton per year ferrosilicon production facility. MCCI would have a 60% interest in the venture, which was scheduled for startup in 1990.[17]

Portugal

After 2 years without ferroalloy production, the Brazilian Italmagnesio group planned to restart idled Portuguese ferrosilicon, ferromanganese, and silicomanganese capacity through its new subsidiary, Novos Fornas de Beira Alta Lda. (Forbel). The plan involved eight electric furnaces, previously owned by Cia Portuguesa de Fornos Eletricos S.A.R.L., with combined capacity of 30,000 metric tons per year 75% ferrosilicon, 20,000 metric tons per year manganese alloys, and 24,000 metric tons per year calcium carbide. Italmagnesio, which had previously experienced antidumping problems in the European Community, hoped the new subsidiary would give the company a better sales position in the European market;[18] however, only one of the furnaces had been started at yearend and was reported to be producing either 75% ferrosilicon or inoculants.[19]

South Africa, Republic of

Several ferrochromium expansion projects included ChromeCorp Technology's startup of a 30-MV·A furnace;[20] construction of a 32.5-MV·A furnace at CMI's facility in the Transvaal province;[21] 16-MV·A to 40-MV·A transformer capacity expansion on a direct current transferred arc plasma furnace at Middelburg Steel and Alloys (Pty.) Ltd., potentially increasing output from 20,000 metric tons per year to 50,000 metric tons per year; and Purity Minerals' development of a new 120,000-metric tons per year ferrochromium smelter near Rustenburg, Transvaal Province. Tubatse Ferrochrome (Pty.) Ltd., a subsidiary of Samancor, started production from its fourth furnace. The new furnace had an annual production capacity of 60,000 metric tons, bringing Tubatse's production capacity from 180,000 metric tons to 240,000 metric tons. Tubatse also started construction on a fifth furnace, which was to be completed in 1990.[22]

Turkey

Etibank General Management started a third high-carbon ferrochromium furnace at its Elazig plant and was scheduling startup of a fourth sometime in early 1990. The existing electric furnaces at the Elazig facility, two 17- MV·A units, were capable of producing 50,000 metric tons per year; the addition of the third and fourth furnaces, 30 MV·A each, was expected to raise total production capacity to 150,000 metric tons per year.[23]

Venezuela

The State development body, Corporacion Venezolana de Guayana (CVG), was involved with a number of joint-venture ferroalloy projects. These projects were being developed primarily to take advantage of Venezuela's abundant electricity available from CVG's Guri Dam near Puerto Ordaz. Joint ventures included Rima Electrometallurgical SA (Brazil), Italmagnesio (Brazil), C.V.G. Ferrosilicio de Venezuela CA, Central de Ferroaleacines de Venezuela CA, and Venezuelan PT Investment Alloy.[24]

Zimbabwe

Zimbabwe Mining and Smelting Company (ZIMASCO) completed construction of its 3-MV·A remelting furnace for ferrochromium fines generated from its crushing operations. ZIMASCO planned to process 15,000 metric tons per year with the new furnace, increasing its total ferrochromium capacity to 190,000 metric tons per year.[25]

OUTLOOK

Production

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, the Republic of South Africa, Turkey and Zimbabwe). Some of the projects came on-line in 1989, increasing world ferrochromium capacity by more than 10%. 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 manganese 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.

Trends in Usage

In most cases, consumption of chromium, columbium, manganese, nickel, silicon, vanadium, and the rareearths 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 chapters.

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 is essential to the production of virtually all steels and is also important to the production of cast iron. Manganese is used to neutralize the harmful effect of sulfur and as an alloying element. Silicon is used primarily for deoxidation in steel and as an alloying element in cast iron. Boron, chromium, 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 chapter 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 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 master alloys containing little iron, employed to introduce reactive elements to nickel- and cobalt-base aluminum and titanium-base, and other alloy systems.

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), but further subclassifications exist in the high- and low-carbon categories. 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 or "addition agents" used in the

TABLE 9

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
Albania: Electric furnace, ferrochromium[e]	47	51	51	51	52
Argentina: Electric furnace:					
Ferromanganese	26	22	24	22	[4]28
Silicomanganese	8	14	13	13	[4]19
Ferrosilicon	21	25	26	34	[4]31
Other	5	6	7	7	[4]8
Total	60	67	70	75	[4]86
Australia: Electric furnace:[5]					
Ferromanganese	78	67	56	64	66
Silicomanganese	28	25	47	49	50
Ferrosilicon	21	21	20	[e]20	22
Total[6]	127	[r]114	123	[r e]132	138
Austria: Electric furnace, undistributed	13	13	13	13	13
Belgium: Electric furnace, ferromanganese[e]	99	96	99	105	105
Brazil: Electric furnace:					
Ferromanganese	149	181	171	199	[4]199
Silicomanganese	199	196	207	213	[4]230
Ferrosilicon	200	240	255	295	[4]316
Silicon metal	32	41	44	87	[4]129
Ferrochromium	140	121	116	143	[4]125
Ferrochromium-silicon	10	10	9	10	[4]10
Ferronickel	37	38	39	37	[4]39
Other	68	68	67	87	[4]90
Total[6]	835	894	908	1,073	[4]1,137
Bulgaria: Electric furnace:					
Ferromanganese[e 7]	33	35	34	34	34
Ferrosilicon[e]	[r]11	17	[r]11	18	18
Other[e]	1	1	1	1	1
Total[6]	[r]45	53	[r]46	53	53
Canada: Electric furnace:[e]					
Ferromanganese[7]	130	139	141	143	143
Ferrosilicon	93	97	99	99	99
Silicon metal	28	29	33	33	33
Total[6]	250	265	273	275	275
Chile: Electric furnace:					
Ferromanganese	7	7	7	7	7
Silicomanganese	1	2	1	1	1
Ferrosilicon	5	4	5	6	6
Other	1	2	2	4	3
Total[6]	14	[r]15	16	18	17
China: Furnace type unspecified:[e 8]					
Ferromanganese[7]	[r]610	[r]690	[r]740	[r]740	740
Ferrosilicon	[r]415	[r]500	[r]660	[r]850	850
Silicon metal	[r]28	[r]55	[r]80	[r]110	110
Ferrochromium[9]	[r]135	[r]165	[r]190	[r]190	190
Other	80	[r]110	[r]165	[r]165	165
Total[6]	[r]1,268	[r]1,520	[r]1,835	[r]2,055	2,055

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
Colombia: Electric furnace:[e]					
Ferrosilicon	(10)	(10)	(10)	(10)	—
Ferronickel	33	51	57	4/46	47
Total	r33	r51	r57	4/46	47 e
Czechoslovakia: Electric furnace:					
Ferromanganese[e 7]	103	101	101	101	101
Ferrosilicon[e]	33	33	33	33	33
Silicon metal[e]	5	6	6	6	6
Ferrochromium[e]	28	28	28	28	28
Other[e 11]	10	9	r10	r11	9
Total[6]	177	176	177	179	176
Dominican Republic: Electric furnace, ferronickel	71	62	90	81	86
Egypt: Electric furnace, ferrosilicon	e8	8	8	9	9
Finland: Electric furnace, ferrochromium	147	147	158	172	176
France:					
Blast furnace:					
Ferromanganese	367	r301	323	353	353
Electric furnace:					
Ferromanganese	—	24	26	20	20
Silicomanganese[12]	26	r30	34	65	65
Ferrosilicon	217	216	e216	e216	220
Silicon metal[e]	77	77	77	77	77
Ferrochromium[e 9]	41	1	1	20	20
Other[13]	107	85	e85	e85	85
Total[6]	r796	r734	762	836	840
German Democratic Republic: Electric furnace:					
Ferromanganese[e 7]	69	75	75	76	75
Ferrosilicon[e]	25	29	29	29	29
Silicon metal[e]	4	4	4	4	4
Ferrochromium[e]	21	24	24	25	24
Other[e 11]	17	17	17	18	17
Total[6]	137	149	149	152	149
Germany, Federal Republic of:					
Blast furnace:					
Ferromanganese[e]	179	206	r172	r230	237
Ferrosilicon[e]	47	76	r44	72	72
Electric furnace:					
Ferromanganese[e 7]	28	39	r28	r39	42
Ferrosilicon[e]	44	55	44	r55	55
Ferrochromium[e]	55	66	r55	r66	66
Other[e 11]	62	67	r63	68	68
Total[6]	414	509	r406	r530	540
Greece: Electric furnace:					
Ferrochromium	r38	42	46	49	50
Ferronickel[e]	r59	r38	r34	r48	59
Total[e 6]	r97	r80	r80	r97	109

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
Hungary: Electric furnace:[e]					
Ferrosilicon	10	10	10	11	10
Silicon metal	2	2	2	2	2
Other	2	2	2	1	1
Total	14	14	14	14	13
Iceland: Electric furnace, ferrosilicon	67	74	77	77	[4]79
India: Electric furnace:					
Ferromanganese	180	197	191	152	154
Silicomanganese[e]	1	1	[4]41	[4]50	52
Ferrosilicon	44	55	58	46	50
Silicon metal[e]	3	3	[4]2	[r]2	2
Ferrochromium	73	93	139	136	138
Ferrochromium-silicon	14	[e]11	14	3	3
Other[e]	1	1	[4]1	1	1
Total[6]	316	362	444	390	399
Indonesia: Electric furnace, ferronickel	26	25	9	30	29
Italy: Electric furnace:					
Ferromanganese	19	13	[r e]17	[r e]17	18
Silicomanganese	71	73	[r e]72	[r e]72	73
Ferrosilicon	83	69	[r e]69	[r e]68	69
Silicon metal	20	21	[r e]21	[r e]20	21
Ferrochromium	64	62	[r e]62	[r e]61	62
Other[14]	17	15	[r e]16	[r e]16	17
Total[6]	[r]274	[r]253	[r e]256	[r e]253	259
Japan: Electric furnace:					
Ferromanganese	487	396	366	417	[4]434
Silicomanganese	239	164	101	118	[4]135
Ferrosilicon	166	118	81	81	[4]83
Ferrochromium[9]	375	309	291	326	[4]358
Ferronickel	250	221	224	267	[4]304
Other[15]	14	11	9	11	[4]12
Total[6]	1,531	1,218	1,073	1,220	[4]1,325
Korea, North: Furnace type unspecified:[e 8]					
Ferromanganese[7]	77	77	77	77	77
Ferrosilicon	33	33	33	33	33
Other[11]	22	22	22	22	22
Total	132	132	132	132	132
Korea, Republic of: Electric furnace:					
Ferromanganese	68	59	64	84	[4]94
Ferrosilicon	38	34	14	10	[4]5
Other	60	73	100	99	[4]112
Total[6]	167	167	178	193	[4]211
Mexico: Electric furnace:					
Ferromanganese	169	172	178	182	[4]185
Silicomanganese	43	67	88	88	[4]109
Ferrosilicon	30	19	20	18	[4]10
Ferrochromium	7	3	7	10	[4]3
Other	3	2	1	1	([4 16])
Total[6]	253	263	294	300	[4]308

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
New Caledonia: Electric furnace, ferronickel[e]	155	144	127	[4]161	155
Norway: Electric furnace:					
Ferromanganese	237	226	212	398	[4]243
Silicomanganese	267	271	262	256	[4]298
Ferrosilicon	425	389	371	420	[4]440
Silicon metal[e]	112	110	110	110	110
Other[e 13]	3	3	3	3	3
Total[6]	1,045	998	957	[re]1,188	1,094
Peru: Electric furnace:					
Ferromanganese	([10])	([16])	2	1	1
Ferrosilicon	([10])	([16])	([16])	1	1
Total[6]	([10])	1	3	2	2
Phillippines: Electric furnace:					
Ferrosilicon[e]	22	22	—	10	10
Ferrochromium[e]	[4]56	61	63	84	77
Total[e]	78	83	63	94	87
Poland:					
Blast furnace:					
Spiegeleisen[e]	[4]3	3	4	4	4
Ferromanganese	88	94	[e]94	[e]94	94
Electric furnace:[e]					
Ferromanganese[7]	54	54	54	53	53
Ferrosilicon	57	56	55	55	55
Silicon metal	12	12	11	11	11
Ferrochromium	54	54	53	50	50
Other[11]	18	18	18	18	18
Total[e 6]	[4]287	291	289	285	285
Portugal: Electric furnace:					
Ferromanganese[e 17]	46	22	([10])	[r]1	1
Silicomanganese[e 17]	28	11	([10])	([10])	—
Ferrosilicon[e]	10	6	([10])	([10])	—
Silicon metal[e]	12	8	([10])	([10])	—
Other	([16])	([16])	([10])	([10])	—
Total[6]	96	46	([10])	1	1
Romania: Electric furnace:[e]					
Ferromanganese	88	90	89	88	88
Silicomanganese	43	44	43	44	44
Ferrosilicon	55	56	55	55	55
Silicon metal	5	5	5	5	5
Ferrochromium	49	49	46	46	46
Total[6]	240	244	239	238	238
South Africa, Republic of: Furnace type unspecified:[8]					
Ferromanganese	365	372	347	493	386
Silicomanganese	287	334	346	325	309
Ferrosilicon	83	92	91	[e]93	88
Silicon metal	39	39	37	[e]37	39
Ferrochromium	939	959	1,048	[e]1,100	1,160
Ferrochromium-silicon	6	6	30	[e]23	22
Other[e 18]	([16])	1	1	1	1
Total[e 6]	1,720	1,802	1,900	[r]2,075	2,005

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
Spain: Electric furnace:[e]					
Ferromanganese	95	95	99	99	99
Silicomanganese	77	77	77	77	77
Ferrosilicon	67	67	66	66	66
Silicon metal	68	68	77	77	77
Ferrochromium	19	19	22	22	22
Other	4	4	6	6	6
Total[6 11]	[4]331	331	347	347	347
Sweden: Electric furnace:					
Ferrosilicon	31	22	22	22	21
Silicon metal[e]	22	22	22	[4]22	—
Ferrochromium	149	139	123	[e]125	127
Ferrochromium-silicon	29	19	([10])	([10])	—
Other	([16])	([10])	([10])	([10])	—
Total[11]	232	[r e]202	167	[r e]169	148
Switzerland: Electric furnace:[e]					
Ferrosilicon	3	3	3	3	3
Silicon metal	2	2	2	2	2
Total	5	5	5	5	5
Taiwan: Electric furnace:					
Ferromanganese	20	22	19	28	[4]34
Silicomanganese	25	23	21	34	[4]29
Ferrosilicon	19	15	4	22	[4]21
Total[6]	64	61	44	84	[4]84
Turkey: Electric furnace:					
Ferrosilicon[e]	8	8	[4]5	[4]6	6
Ferrochromium	[e]55	[e]55	58	60	66
Total	[e]63	[e]63	63	65	72
U.S.S.R.:					
Blast furnace:					
Spiegeleisen	21	22	21	[e]21	21
Ferromanganese	633	662	654	[e]660	660
Ferrophosphorus	29	29	28	[e]28	28
Electric furnace:[e 19]					
Ferromanganese	744	772	772	772	772
Silicomanganese	209	220	220	220	220
Ferrosilicon	827	882	937	937	937
Silicon metal	66	72	72	72	72
Ferrochromium	463	468	474	496	496
Ferrochromium-silicon	13	14	15	15	15
Ferronickel	99	99	99	99	99
Other[13]	[r]155	[r]166	[r]166	[r]177	177
Total[6]	3,259	3,406	3,458	[e]3,497	3,497
United Kingdom					
Blast furnace, ferromanganese	85	110	102	118	110
Electric furnace, undistributed[e]	11	11	11	11	11
Total[6]	96	[r e]121	[r e]113	[r e]129	121

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
United States: Electric furnace: [20]					
Ferromanganese[21]	154	117	113	W	W
Ferrosilicon	442	339	356	495	[4]524
Silicon metal	121	124	147	164	[4]150
Ferrochromium[22]	110	105	118	W	W
Other[23]	151	130	84	383	[4]352
Total[6]	977	816	818	1,043	[4]1,026
Uruguay: Electric furnace, ferrosilicon	(16)	(16)	(16)	([e] 16)	(16)
Venezuela: Electric furnace:					
Ferromanganese	(10)	(10)	(10)	(10)	—
Silicomanganese	[r]27	[r]31	31	37	33
Ferrosilicon	67	56	58	57	61
Total[6]	[r]93	[r]87	88	94	94
Yugoslavia: Electric furnace:					
Ferromanganese	39	44	42	50	50
Silicomanganese	48	46	47	52	51
Ferrosilicon	101	110	109	133	110
Silicon metal	36	35	35	28	28
Ferrochromium	81	76	62	103	99
Ferrochromium-silicon	8	8	7	4	4
Ferronickel	10	10	11	17	11
Calcium-silicon	(16)	(16)	1	1	1
Other	[r]6	[r]7	8	12	11
Total[6]	[r]330	[r]335	321	399	364
Zimbabwe: Electric furnace:					
Ferromanganese	2	[e]2	—	(11)	[4]—
Ferrochromium	172	[e]171	234	247	[4]191
Ferrochromium-silicon	59	[e]55	32	32	[4]28
Total[6]	233	[e]228	266	279	[4]218
Grand total[6] [r]	16,722	[r]16,776	17,066	18,716	18,660
of which:					
Blast furnace:					
Spiegeleisen[24]	[r]24	[r]25	25	25	25
Ferromanganese[24] [25]	[r]1,351	[r]1,373	1,344	1,455	1,454
Ferrosilicon	47	76	44	72	72
Ferrophosphorus	29	29	28	28	28
Total blast furnace[6]	[r]1,451	[r]1,503	1,441	1,580	1,579
Electric furnace:[8]					
Ferromanganese[26]	[r]3,125	[r]3,068	2,979	[27]3,152	[27]3,048
Silicomanganese[26]	[r]1,629	[r]1,630	1,652	1,715	1,793
Ferrosilicon	[r]3,781	[r]3,781	3,902	4,383	4,426
Calcium-silicon	(16)	(16)	1	1	1
Silicon metal	[r]695	[r]733	788	871	877
Ferrochromium[28]	[r]3,278	[r]3,267	3,470	[27]3,608	[27]3,624
Ferrochromium-silicon	[r]138	[r]124	106	[27]88	[27]83
Ferronickel	[r]741	[r]687	690	786	828

TABLE 9—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Thousand short tons)

Country, furnace type,[2] and alloy type[3]	1985	1986	1987	1988[p]	1989[e]
Electric furnance[8]—Continued					
Other[29]	[r]809	[r]822	854	1,197	1,180
Undistributed	24	24	24	24	24
Total electric furnace[6] [r]	14,220	[r]14,136	14,466	15,825	15,884
Furnace type unspecified:					
Ferromanganese[8]	[r]1,052	[r]1,139	1,164	1,310	1,203

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1]Table includes data available through June 20, 1990.

[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 1985 and 1986; calendar years thereafter.

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

[7]Includes silicomanganese.

[8]Although furnace type has not been specified for any ferroalloy production for China, North Korea, and the Republic of South Africa, all output of these countries has been included under "Electric furnace" (and metallothermic) output except for their production of ferromanganese, which is reported separately.

[9]Includes ferrochromium-silicon, if any was produced.

[10]Revised to zero.

[11]Includes ferrochromium-silicon and ferronickel, if any was produced.

[12]Includes silicospiegeleisen.

[13]Includes ferronickel, if any was produced.

[14]Series excludes calcium silicide.

[15]Includes calcium-silicon, ferrotungsten, ferromolybdenum, ferrovanadium, ferrocolumbium, and other ferroalloys.

[16]Less than 1/2 unit.

[17]Estimated figures based on reported exports and an allowance for domestic use.

[18]Ferrovanadium only; other minor ferroalloys may be produced, but no basis is available for estimation.

[19]U.S.S.R. production of electric furnace ferroalloys is not reported; estimates provided are based on crude source material production and availability for consumption (including estimates) and upon reported ferroalloy trade, including data from trading partner countries.

[20]U.S. production of ferronickel cannot be reported separately to conceal corporate proprietary information.

[21]U.S. output of ferromanganese includes silicomanganese and manganese metal.

[22]U.S. output of ferrochromium includes ferrochromium-silicon, chromium briquets, exothermic chromium additives, other miscellaneous chromium alloys, and chromium metal.

[23]Includes ferronickel.

[24]Spiegeleisen for the Federal Republic of Germany is included with "Blast furnace ferromanganese."

[25]Includes silicospiegeleisen for France.

[26]Ferromanganese includes silicomanganese and manganese metal for U.S. and silicomanganese (if any was produced) for countries carrying footnote 7 on "Ferromanganese" data line.

[27]U.S. production under "Other."

[28]Ferrochromium includes material listed in footnote 22 for the United States and ferrochromium-silicon (if any was produced) for countries carrying footnote 9 on "Ferrochromium" data line.

[29]Includes ferronickel production for France, Norway, and the United States.

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, with or without 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 is 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. World production of the ferroalloys and silicon metal was estimated to be 18.66 million short tons in 1989. U.S. ferroalloy shipments in 1989 were 985,000 short tons valued at $928 million. Domestically, 28 companies produced ferroalloys and/or silicon metal, although 5 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 are either vertically integrated and produce alloys such as ferromolybdenum or ferronickel using ores from their own mines, or produce relatively low-tonnage but high-unit-value ferroalloys such as ferrovanadium or ferrocolumbium from purchased raw materials.

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 the United States, has been in a state of decline in more recent years because of high power costs. The Japanese ceased silicon metal production at the end of 1982 and have cut back the production of some other ferroalloys.

Resources

The reader is referred to the respective commodity chapters 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 molybdenum 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 manganese, silicon, and chromium 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 MV·A, 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 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.

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, 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 about 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 assured 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.

Operating Factors

Environmental Requirements.—Air pollution is the principal environmental problem in the production of ferroalloys. Most ferroalloy furnaces in the United States use baghouses to control air pollution. Wet scrubbers and electrostatic precipitators are also in use.

Most developed countries, particularly Japan and the countries of Western Europe, have stringent environmental controls. In other countries, such as Brazil, environmental controls are not always required by the Governments; but ferroalloy producers are generally 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 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 of 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 interruptable contracts, power can be cut off during power shortages.

[1]Metal Bulletin (London). No. 7359, Feb. 13, 1989, p. 11.
[2]_____. No. 7433, Nov. 13, 1989, p. 31.
[3]Metals Week. V. 61, No. 5, Jan. 29, 1990, p. 2.
[4]Metal Bulletin Monthly (London). No. 227, Nov. 1989, pp. 12-15.
[5]American Metal Market. V. 97, No. 237, Dec. 7, 1989, p. 5.
[6]Metal Bulletin (London). No. 7411, Aug. 24, 1989, p. 13.
[7]The TEX Report. V. 21, No. 4996, Sept. 4, 1989, p. 1.
[8]Metal Bulletin (London). No. 7437, Nov. 27, 1989, p. 13.
[9]Metals Week. V. 60, No. 51, Dec. 18, 1989, p. 2.
[10]Metal Bulletin (London). No. 7438, Nov. 30, 1989, p. 15.
[11]_____. No. 7433, Nov. 13, 1989, p. 31.
[12]Metals Price Report (London), No. 35, Nov. 28, 1989, p. 2.
[13]Metals Week. V. 60, No. 33, Aug. 14, 1989, p. 8.
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[16]Metal Bulletin (London). No. 7373, Apr. 6, 1989, p. 13.
[17]Metals Week. V. 60, No. 49, Dec. 4, 1989, p. 6.
[18]Metal Bulletin (London). No. 7361, Feb. 20, 1989, p. 15.
[19]Personal Communication with Jorne De Linde, RSI, Exton, PA.
[20]The TEX Report. V. 21, No. 4970, July 27, 1989, p. 15.
[21]Metal Bulletin (London). No. 7432, Nov. 9, 1989, p. 15.
[22]_____. No. 7372, Apr. 3, 1989, p. 15.
[23]The TEX Report. V. 21, No. 5055, Nov. 30, 1989, p. 13.
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[25]The TEX Report. V. 21, No. 4909, Apr. 27, 1989, p. 2.

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FLUORSPAR

By M. Michael Miller

Mr. Miller, a physical scientist with 12 years of minerals 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 Gio Jacarepaqua, international data assistant.

In 1960, an International System of Units was adopted by the 11th General Conference of Weights and Measures. This system is called the MKS system or metric system, and most countries of the world have adopted it as their official system of measurement. The Bureau of Mines, in an effort to provide statistical data on fluorspar in units most consistent with international usage, will henceforth report fluorspar data in metric tons (mt) unless otherwise noted.

In the United States, fluorspar was shipped by one major producer and by one small producer that supplied less than 10% of the Nation's requirements. Supplementing fluorspar as a domestic source of fluorine was byproduct fluosilicic acid production from some phosphoric acid and hydrofluoric acid (HF) producers. Imports of fluorspar, which continued to supply most of the United States requirements, decreased nearly 5% from 1988. HF imports were nearly 4% lower than reported in the previous year.

The fluorspar industry witnessed some important events in 1989. In July, the first phase of cutbacks in chlorofluorocarbon (CFC) production, mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol), went into effect, freezing CFC production at 1986 levels. Pennwalt Chemical Corp., parent of domestic fluorspar producer Ozark-Mahoning Co., was purchased by the French chemicals giant, Société Nationale Elf Aquitaine. An international meeting was held in Monterrey, Mexico, in April to discuss fluorspar production and markets and to assess how developments are shaping the industry.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for fluorspar were developed by the 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 four fluorspar mining operations to which a survey request was sent, 100% responded. Production statistics in table 1 are withheld to protect company proprietary data. Of the seven fluosilicic acid producers surveyed, 100% responded, representing 100% of the quantity reported. The consumption survey was sent to approximately 88 operations quarterly and to 39 additional operations annually. Of the operations surveyed quarterly, 70% re-

TABLE 1

SALIENT FLUORSPAR STATISTICS[1]

		1985	1986	1987	1988	1989
United States:						
Production:						
Finished (shipments)[e]	metric tons	59,900	70,800	63,500	63,500	66,000
Value f.o.b. mine	thousands	W	W	W	W	W
Exports	metric tons	8,773	14,710	2,595	3,136	5,134
Value	thousands	$964	$1,634	$308	$346	$694
Imports for consumption	metric tons	501,636	501,478	531,530	689,139	655,590
Value[2]	thousands	$45,032	$41,436	$43,935	$62,748	$79,875
Consumption (reported)	metric tons	514,939	525,112	542,830	551,055	641,882
Consumption (apparent)[3]	do.	619,576	518,264	r643,659	723,804	738,825
Stocks, Dec. 31:						
Domestic mines:						
Finished	do.	W	W	W	W	W
Consumer	do.	42,266	81,531	30,310	56,012	79,347
World: Production	do.	r4,979,045	r4,854,054	4,843,483	5,292,418	5,731,340

[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.

sponded. Of the operations surveyed on an annual basis, 36% responded. Together, quarterly and annual responses represented 87% of the apparent consumption data shown in table 1.

LEGISLATION AND GOVERNMENT PROGRAMS

At yearend, the National Defense Stockpile fluorspar inventory was unchanged from yearend 1988 and remained well below the stockpile goals of 1.4 million short dry tons (about 1.27 million mt) for acid grade and 1.7 million short dry tons (about 1.54 million mt) for metallurgical grade. Revised goals were authorized in 1989 of 900,000 short tons (about 816,000 mt) for acid grade and 310,000 short tons (about 281,000 mt) for metallurgical grade. The revised goals had not been implemented by the end of the year. Depletion allowances against Federal taxes of 22% and 14%, respectively, remained in effect for domestic and foreign production by U.S.companies.

In September 1987, the United States and 22 other nations signed the Montreal Protocol. The protocol, under the auspices of the United Nations Environmental Program, mandated a freeze in CFC production at the 1986 level by July 1989, followed by a 20% reduction by mid-1993 and an additional 30% reduction by mid-1998. The United States complied with the July 1989 date for reduction of CFC production to 1986 levels. In December 1989, an excise tax was levied on the production of CFC's that are subject to the Montreal Protocol. The tax was included as part of a deficit reduction bill, which set a base tax rate for CFC-11 of $1.37 per pound in 1990 and 1991. The rate increases to $1.67 in 1992, $2.65 in 1993 and 1994, and an additional 45 cents per pound per year thereafter. Tax rates for CFC-12, CFC-113, CFC-114, CFC-115, and halon-1201, halon-1301, and halon-2402 will be calculated based on their ozone layer depletion potential relative to CFC-11.[1]

ISSUES

The total phaseout of CFC's by the end of the century is likely to generate large costs. About one-half of CFC consumption consists of foam production, solvents, and firefighting applications. Non-CFC replacements for foam production and solvents can be developed without significant costs. Although there are no replacements for the halons used as firefighting agents, emissions can be greatly reduced by the strict control of operating practices. Large costs will occur in replacing the CFC's used for refrigeration and air-conditioning. Replacement costs for new equipment in net present value may range from $6.4 billion to as much as $12.5 billion by early next century. If CFC's were to become unavailable in 10 years, the costs of premature obsolescence of equipment could be as high as $13 to $23 billion in net present value. Automobile air conditioners would account for 75% of these costs. Additional costs would ensue from a slight decline in energy efficiency of equipment that formerly used CFC's.[2] These cost projections were made before passage of the excise tax on CFC production and do not take into account impacts of the tax.

PRODUCTION

Illinois remained the leading producing State, accounting for over 98% 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 now 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. J. Irving Crowell, Jr., & Son produced and shipped a small amount of metallurgical-grade fluorspar from its Crowell-Daisy Mine in Nye County, NV.

Ozark-Mahoning reopened the former Inverness Mining Co. Minerva #1 Mine, acquired from Seaforth, in December 1988. Ozark completed the rehabilitation of the mine in late December 1989 and planned to start production in January 1990.

Eleven plants processing phosphate rock for the production of phosphoric acid and one plant producing HF sold or used 46,565 mt of byproduct fluosilicic acid, which was equivalent to 90,700 mt of fluorspar.

TABLE 2

U.S. FLUOSILICIC ACID PRODUCERS

Company	Number of plants
Agrico Chemical Co.	3
Conserv Inc.	1
Farmland Industries Inc.	1
Gardinier Inc.	1
IMC Fertilizer Inc.	3
Occidental Chemical Agricultural Products Inc.	1
Seminole Fertilizer Corp.	1
Texasgulf Inc.	1
U.S. Agrichemicals Corp.	1
Weaver Fertilizer Co. Inc.	1

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 less than 3%; consumption by the steel industry remained essentially unchanged. According to the American Iron and Steel Institute (AISI), domestic production of raw steel decreased slightly from 90.1 million mt in 1988 to 88.4 million mt in 1989. A comparison of the AISI data with fluorspar consumption data collected by the Bureau of Mines from the U.S.steel industry shows that aver-

age fluorspar consumption per ton of raw steel has remained relatively constant during 1986–89. The industry average for all furnace types is shown below:

Fluorspar consumption (kilograms per metric ton)			
1986	1987	1988	1989
1.37	1.34	1.34	1.39

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 over 177,148 mt for 1989, compared with the 1988 quantity of 195,777 mt.

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 data from the U.S. International Trade Commission, production of trichlorofluoromethane (CFC-11) decreased over 13% to 87,657 mt; dichlorodifluoromethane (CFC-12) increased slightly to 177,604 mt, and chlorodifluoromethane (HCFC-22) remained essentially unchanged at 148,413 mt, compared with 1988 figures.

As a consequence of the adoption of the terms of the Montreal Protocol, CFC-11 and CFC-12 production will probably decrease continuously for the next 10 years and may be phased out completely when adequate substitutes are developed and tested. Because HCFC-22 is not a fully halogenated CFC and is broken down in the lower atmosphere, it was not included in the list of ozone-depleting substances covered by the Montreal Protocol.

The chemical industry is pursuing research into replacement compounds for the CFC's that are to be phased out. 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 over 90% of CFC consumption. Other substitutes are called hydrofluorocarbons (HFC's), which have no ozone-depletion potential, since they contain no chlorine atoms. So far, 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. Only HCFC-22 is currently in commercial use, although several companies have announced plans to build commercial-scale plants to manufacture the other compounds. These plans are not without risk, since the compounds have to pass inhalation and toxicity tests before commercial sales are allowed.[3]

The manufacture of synthetic cryolite and aluminum fluoride for use in aluminum reduction cells was a major use of HF. An estimated 40 to 60 pounds of fluorine was consumed for each ton of aluminum produced. Aluminum fluoride was used by the ceramic industry for some body and glaze mixtures and in the production of specialty refractory products. It was used in the manufacture of aluminum silicates and in the glass industry as a filler.

HF was consumed in the manufacture of uranium tetrafluoride that was used in the process of concentrating uranium isotope 235 for use as nuclear fuel and in fission explosives. It was also used in stainless steel pickling, petroleum alkylation, glass etching, oil and gas well treatment, as a cleaner and etcher in the electronics industry, and 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 water fluoridation, either directly or after processing to sodium silicofluoride, and to make aluminum fluoride for the aluminum industry.

TABLE 3

U.S. CONSUMPTION (REPORTED) OF FLUORSPAR, BY END USE

(Metric tons)

End use or product	Containing more than 97% calcium fluoride (CaF_2)		Containing not more than 97% calcium fluoride (CaF_2)		Total	
	1988	1989	1988	1989	1988	1989
Hydrofluoric acid (HF)	407,752	397,423	—	—	407,752	397,423
Iron and steel (foundries)	W	—	4,733	4,534	4,733	4,534
Open-hearth furnaces	—	W	20,578	24,528	20,578	24,528
Basic oxygen furnaces	—	—	80,714	74,356	80,714	74,356
Electric furnaces	1,542	1,635	29,909	32,778	31,451	34,413
Other[1]	W	W	W	W	105,827	106,628
Total	411,339	W	135,934	W	651,055	641,882
Stocks, Dec. 31 (consumer)	24,368	47,703	31,644	8,309	56,012	79,347

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

[1] Includes glass and fiberglass, enamel, welding rod coatings, primary aluminum, primary magnesium, other chemical products, other ceramic products, and other primary metals.

STOCKS

Fluorspar consumer stocks increased substantially for the second straight year. Consumer stocks were 79,347 mt, up 42% from the level reported in 1988. This approached the level reported in 1986. Government stockpiles of fluorspar remained unchanged and contained 891,957 short dry tons (809,171 mt) of acid grade and 294,045 short dry tons (266,753 mt) of metallurgical grade.

TRANSPORTATION

Fluorspar products are transported to customers by truck, train, barge, and ship. Most acid-grade fluorspar is shipped in the form of damp filter cake containing 7% to 10% moisture to facilitate handling and reduce dust. Types of transportation available to producers influence the economic viability of an operation to a certain extent. The Republic of South Africa must transport its products over long distances from the mines in the Transvaal area to the port of Durban. Fortunately, the Republic of South Africa has an extensive rail network that serves a large number of mineral producers in the Transvaal area. The port at Durban is highly mechanized and can load and unload ships faster and more efficiently than most ports in the world, allowing shipments to be cost competitive with other less distant producers.

In contrast, Mexico has a less efficient rail and highway network, and the port facilities at Tampico are older; these are disadvantages that are overcome by short rail and water transport distances to major markets along the U.S. gulf coast. However, the cost competitiveness becomes strained for more distant consumers.

In the United States, after the products have cleared the port, they are transported to consumers by barge, rail, or truck. Truck and rail costs are much higher than barging costs, and many consumers are located near ports or along major rivers in order to take advantage of the lower costs that are provided by proximity to water transportation.[4]

PRICES

According to prices published by Industrial Minerals (Metal Bulletin PLC), the price of domestic acid-grade fluorspar was unchanged. Foreign producer prices at yearend had increased by about $15 per metric ton compared with 1988 prices.

Yearend price quotations from the Chemical Marketing Reporter (CMR) were unchanged at $0.6875 per pound for anhydrous HF and up $3.00 at $52.00 per 100 pounds for aqueous HF, 70%, in tanks. These quotations were equivalent to about $1.52 per kilogram (kg) for anhydrous HF and $114.64 per 100 kg for aqueous HF, 70%, in tanks. The CMR yearend price quotation for fluosilicic acid, 100% basis, in tanks, was up at $340 per short ton (about $375 per metric ton), and for cryolite was unchanged at $550 per short ton (about $606 per metric ton).

The impact of the Montreal Protocol was evident in the price increases reported for CFC compounds. The CMR yearend price quotations increased from $0.64 to $0.90 per pound for CFC-11, from $0.74 to $1.04 per pound for CFC-12, from $0.935 to $1.22 per pound for CFC-113, and from $1.08 to $1.41 per pound for CFC-114.

FOREIGN TRADE

According to the Bureau of the Census, U.S. exports of fluorspar increased by 64% and had an average value of $135 per metric ton. Synthetic cryolite exports decreased to 6,103 mt representing 7,360 mt of 92% equivalent fluorspar, valued at $3.2 million. In descending order of the quantity exported, the most important importers of U.S. produced synthetic cryolite were Canada, Turkey, and Japan. Ac-

TABLE 4

PRICES OF DOMESTIC AND IMPORTED FLUORSPAR

(Dollars per metric ton)

	1988	1989
Domestic, f.o.b., Illinois district, bulk, acid-grade	185–191	185–191
Mexican, f.o.b., Tampico:		
Acid-grade, filtercake	115–120	130–135
Metallurgical-grade	70– 77	90
South African, f.o.b., Durban, acid-grade, dry basis	115–120	130–140

Source: Industrial Minerals (Metal Bulletin PLC), No. 237, Jan. 1989, p. 60 and No. 238, Jan 1990, p. 66.

TABLE 5

U.S. EXPORTS OF FLUORSPAR, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	55	$6,073	208	$22,961
Canada	2,131	240,690	4,317	546,944
Dominican Republic	733	95,771	190	34,886
Ghana	59	13,559	57	14,670
Gibraltar	22	9,612	—	—
India	—	—	28	37,600
Indonesia	18	2,032	43	4,706
Mexico	91	10,835	261	28,695
Taiwan	27	3,000	—	—
Venezuela	—	—	30	3,900
Total	3,136	381,572	5,134	694,362

Source: Bureau of the Census.

cording to the reported data, the average export value for synthetic cryolite was $522 per metric ton.

Imports for consumption of fluorspar decreased by nearly 5% 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 Spain. The average unit value, in dollars per metric ton, was $127 for acid grade and $93 for subacid grade. U.S. import duties remained in effect for all grades of fluorspar. The duty was $1.875 per short ton for acid grade ($2.07 per metric ton) and 13.5% ad valorem for ceramic- and metallurgical-grade material.

Imports for consumption of HF decreased nearly 4% to a quantity equivalent to approximately 172,000 mt of fluorspar. Imports of synthetic and natural cryolite were essentially unchanged representing 10,200 mt of 92% fluorspar equivalent.

WORLD REVIEW

World fluorspar consumption and production increased compared with 1988. China, Mexico, Mongolia, the U.S.S.R., and the Republic of South Africa were the major producers. International prices increased despite market pressures caused by a massive Chinese presence in the export market.

Capacity

The data in table 8 are rated capacity for mines and beneficiation plants 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.

Normal production practices for many underground fluorspar operations are two-shift-per-day mining operations with one shift for blasting and ventilation; associated milling operations are continuous with two or three shifts per week

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Canada:				
Houston	12,617	$1,645	17,737	$2,152
Laredo	1,023	147	—	
New Orleans	14,420	1,860	20,975	3,067
Total	28,060	3,652	38,712	5,219
China:				
Houston	40,831	3,672	68,051	7,912
Laredo	—	—	6,402	736
New Orleans	38,215	3,787	84,853	10,492
Total	79,046	7,459	159,306	19,140
France: New York	—	—	18	7
Germany, Federal Republic of:				
Wilmington	5	4	1	11
Kenya:				
Houston	15,102	1,410	4,830	579
Laredo	9,788	3,365	—	—
Total	24,890	4,775	4,830	579
Mexico:				
Baltimore	—	—	—	—
El Paso	73,385	6,352	63,789	6,592
Houston	28,085	2,593	34,115	3,731
Laredo	38,079	4,090	64,165	7,799
New Orleans	42,075	4,789	20,853	2,585
Pembina	—	—	869	82
Philadelphia	905	78	612	64
Total	182,529	17,902	184,403	20,853
Morocco: New Orleans	—	—	38,145	5,430
South Africa, Republic of:				
Baltimore	1,209	167	—	—
Houston	33,091	3,436	10,382	1,453
Laredo	1,999	265	—	—
New Orleans	139,257	16,659	106,909	15,914
Total	175,556	20,527	117,291	17,367
Italy: New Orleans	15,771	1,774	—	—
Spain: New Orleans	39,649	5,338	11,097	1,791
Grand total	545,506	61,427	553,803	70,397
CONTAINING NOT MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Canada:				
Buffalo	68	11	—	—
Seattle	31	2	160	23
Total	99	13	160	23
China: New Orleans	17,112	1,172	2,860	243
Italy: San Francisco	34	18	—	—
Mexico:				
Baltimore	11,848	1,146	12,616	1,331
Buffalo	155	16	—	—
El Paso	4,425	517	—	—

See footnotes at end of table.

TABLE 6—Continued

U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Mexico—Continued				
Houston	—	—	72	4
Laredo	18,304	$908	8,381	$579
New Orleans	85,206	5,812	71,519	6,890
Philadelphia	6,356	635	—	—
Seattle	92	14	285	45
Total	126,386	9,048	98,767	9,212
Grand total	143,631	10,251	101,787	9,478

[1] Customs, insurance, and freight (c.i.f.) value at U.S. port.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF HYDROFLUORIC ACID (HF), BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	37,645	$36,660	33,858	$37,416
Colombia	—	—	—	—
France	—	—	—	—
Germany, Federal Republic of	53	165	74	172
Israel	—	—	—	—
Japan	2,392	2,215	1,202	1,651
Malawi	—	—	19	21
Mexico	78,578	67,313	82,804	77,588
Monaco	—	—	68	73
Sweden	—	—	0	1
United Kingdom	388	547	877	998
Total	119,056	[2]106,901	114,676	117,920

[1] Customs, insurance, and freight (c.i.f.) value at U.S. port.

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

Source: Bureau of the Census.

dedicated to maintenance and cleaning.

Brazil

Brazil's fluorspar reserves are located in the southern part of the country. The majority of reserves are in the States of Paraná, Santa Catarina, and Rio de Janeiro. In 1989, Mineracào Del Rey Ltda. opened a new mine and beneficiation plant at Mato Preto, in Paraná State. This subsidiary of E. I. du Pont de Nemours & Co. is expected to produce about 60,000 mt per year of acid grade and 10,000 to 20,000 mt of metallurgical grade. The acid-grade material is intended for export and to supply the domestic aluminum industry; the metallurgical-grade material is intended for the domestic steel industry.[5]

China

Fluorspar exports from China continued to increase with reported exports of 912,000 mt in 1988 and 1,180,000 mt in 1989. Based on reported export data and estimates of domestic consumption, it is estimated that China produced 1.7 million metric tons in 1989. This would be nearly twice the production of Mexico, which has been historically the world's leading producer and exporter. U.S. imports from China continued to grow dramatically, especially in acid-grade fluorspar. The United States doubled its acid-grade imports from the previous year, from 79,000 mt to over 159,000 mt.

Namibia

Although the presence of fluorspar occurrences in Namibia (formerly Southwest Africa) has been known since the 1920's, production has only occurred briefly in the 1950's and 1970's. In early 1988, development by Okorusu Fluorspar (Pty.) Ltd. began at the site of the largest fluorspar outcroppings in the Okorusu Mountain area, which is 50 to 60 kilometers north of Otjiwarongo and over 400 kilometers from Walvis Bay, the nearest port of shipment. By the end of 1989, production capacity had reached about 40,000 mt per year. Shipments were made to the Federal Republic of Germany and to the United States.

OUTLOOK

There are three major components in fluorspar demand: consumption of metallurgical grade and briquets by the steel industry, consumption of acid grade by the aluminum industry for production of aluminum fluoride, and consumption of acid grade by the chemical industry for production of hydrofluoric acid.

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. Twenty years ago, the domestic steel industry produced 119 million mt of steel and consumed 519,000 mt of metallurgical-grade fluorspar. In comparison, in 1989, the steel industry produced 88 million mt and consumed approximately 140,000 mt of metallurgical-grade fluorspar. That is a decrease in steel production of 26%, with a much larger corresponding decrease in fluorspar consumption of 73%. Unless there is a large increase in domestic steel production, it is estimated that overall consumption of metallurgical-grade fluorspar will continue to decrease over the next 3 to 5 years.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF CRYOLITE, BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Brazil	54	$27	—	—
Canada	1,896	1,127	251	$1,759
China	218	134	—	—
Denmark	3,013	2,636	3,941	3,690
Germany, Federal Republic of	461	425	70	919
Greenland	19	24	—	—
Italy	218	628	—	—
Japan	1,647	1,695	—	—
Netherlands	425	416	45	561
Other	319	198	11	157
Total	8,270	7,310	[2]8,429	7,647

[1] Customs, insurance, and freight (c.i.f.) value at U.S. port.
[2] Total includes synthetic cryolite imports; data not available by country.

Source: Bureau of the Census.

TABLE 9

WORLD FLUORSPAR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand metric tons)

	Rated capacity[1 2]
North America:	
Canada	75
Mexico	1,220
United States	75
Total	1,370
South America:	
Argentina	35
Brazil	75
Total	110
Europe:	
Czechoslovakia	100
France	290
German Democratic Republic	100
Germany, Federal Republic of	100
Italy	200
Romania	30
Spain	320
U.S.S.R.	590
United Kingdom	320
Total	2,050
Africa:	
Kenya	105
Morocco	90
Namibia	50
South Africa, Republic of	680
Tunisia	45
Total	970
Asia:	
China	2,000
India	30
Korea, North	45
Korea, Republic of	10
Mongolia	925
Thailand	180
Total	3,190
World total	7,690

[1] Includes capacity at operating plants as well as plants on standby basis.
[2] In addition to the countries listed, Egypt, Greece, Iran, Pakistan, Sweden, and Turkey produce fluorspar, but available information is inadequate for the formulation of a reliable capacity determination.

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 by the aluminum industry is expected to remain at current levels over 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. Approximately 70% of HF production is used in the manufacture of CFC's, while the rest is used in chemical intermediates, glass and metal processing, petroleum alkylation, and other small uses. Most end uses of HF are expected to follow the trend of the economy and grow with the projected Gross National Product. However, the CFC situation is difficult to analyze. Some industry analysts see large increases in HF consumption for production of replacement HCFC's and HFC's. The new replacements contain more fluorine than present CFC's and are expected to reach the marketplace between 1991 and 1994. Other analysts predict any gains in HF consumption for HCFC's and HFC's will be offset by overall decreases in CFC usage, as nonfluorine replacements for some current uses are developed. HF producers are currently operating at about 90% of capacity and are studying possible expansions. Despite the uncertainties, during the next 3 to 5 years the outlook for consumption of acid-grade fluorspar is good in the short term and excellent in the long term.

BACKGROUND

Definition, Grades, and Specifications[6]

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, sulfides, or phosphates. It tends to occur in well-formed isometric crystals, in massive and earthy forms, and as crusts or globular aggregates with radial fibrous texture. In crystalline form, it can be colorless or may exhibit a wide range of colors, including yellow, blue, purple, green, rose, red, bluish and purplish black, and brown. It has a hardness of 4 on the Mohs' scale, a specific gravity ranging from 3.01 to 3.60, and a melting point of 1,378° C.

Three principal grades of fluorspar are available commercially: acid, ceramic, and metallurgical. Although the specifications for individual grades are generally well defined, some variation is permitted to satisfy the requirements of individual consumers.

In the United States, acid-grade fluorspar (acidspar) contains at least 97% CaF_2. Some manufacturers of hydrofluoric acid in the United States and Europe can use 96% CaF_2 or slightly lower if the remaining impurities are acceptable. User specifications may impose limits on silica, calcium carbonate, sulfide or free sulfur, calcite, beryllium, arsenic, lead, phosphates, and other constituents.

TABLE 10

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1985	1986	1987	1988[p]	1989[e]
Argentina	30,612	39,076	84,924	27,011	30,000
Brazil (marketable):					
Acid grade	42,681	53,555	58,736	54,050	55,000
Metallurgical grade	29,714	31,059	31,212	35,310	35,000
Total	72,395	84,614	89,948	89,360	90,000
Canada: Acid grade[e]	—	—	10,000	r40,000	50,000
China:[e]					
Acid grade	450,000	450,000	550,000	r950,000	1,200,000
Metallurgical grade	400,000	450,000	450,000	450,000	500,000
Total	850,000	900,000	1,000,000	r1,400,000	1,700,000
Czechoslovakia[e]	95,000	95,000	95,000	95,000	95,000
Egypt	85	80	776	1,849	1,800
France:					
Acid and ceramic grades	160,000	148,000	134,000	r e133,000	133,000
Metallurgical grade	64,000	50,000	50,000	50,000	50,000
Total	224,000	198,000	184,000	r e183,000	183,000
German Democratic Republic[e]	100,000	100,000	90,000	90,000	90,000
Germany, Federal Republic of (marketable)	83,138	88,834	85,201	e86,000	86,200
Greece	35	150	r e200	r e200	200
India:[e]					
Acid grade	4 11,107	7,633	8,259	8,200	8,400
Metallurgical grade	4 5,000	4,100	4,450	4,500	4,500
Total	4 16,107	4 11,733	4 12,709	12,700	12,900
Iran[e 5]	3,300	3,300	3,300	3,300	3,300
Italy:					
Acid grade	95,450	90,900	77,800	81,700	82,000
Metallurgical grade	56,762	54,536	56,600	58,157	58,200
Total	152,212	145,436	134,400	139,857	140,200
Kenya: Acid grade	r57,933	r37,146	61,504	99,092	100,000
Korea, North: Metallurgical grade[e]	40,000	40,000	40,000	40,000	40,000
Korea, Republic of: Metallurgical grade	705	243	63	261	250
Mexico:[6]					
Acid grade	378,722	423,614	409,846	577,000	595,000
Ceramic grade	27,226	13,593	12,015	—	—
Metallurgical grade	270,248	263,152	306,633	251,000	266,000
Sub-metallurgical grade	52,416	66,463	95,398	—	—
Total	728,612	766,822	823,892	828,000	861,000
Mongolia: Metallurgical grade[e]	787,000	790,000	r800,000	r800,000	800,000
Morocco: Acid grade	74,350	83,000	78,000	100,500	100,000
Namibia: Acid grade	—	—	—	e7,000	30,000
Pakistan	3,175	4,353	3,673	284	1,000
Romania: Metallurgical grade[e]	20,000	20,000	18,000	18,000	16,000
South Africa, Republic of:					
Acid grade	310,211	293,368	e279,000	282,986	315,880
Ceramic grade	5,724	7,703	e7,000	e8,000	7,810
Metallurgical grade	33,272	32,814	e30,606	e37,435	44,650
Total	349,207	333,885	316,606	328,421	368,340

See footnotes at end of table.

TABLE 10—Continued

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1985	1986	1987	1988[p]	1989[e]
Spain:					
Acid grade	266,774	257,108	147,757	[r e]150,000	150,000
Metallurgical grade	38,835	25,352	23,859	[r e]30,000	30,000
Total	305,609	282,460	171,616	[r e]180,000	180,000
Sweden	3,169	[r]265	220	225	150
Thailand:					
Acid grade	35,840	11,500	([7])	—	—
Metallurgical grade	263,059	156,409	102,398	76,321	98,000
Total	298,899	167,909	102,398	76,321	98,000
Tunisia: Acid grade	40,612	36,828	32,653	[r e]55,000	55,000
Turkey: Metallurgical grade[e]	5,000	10,000	10,000	[4]13,240	13,000
U.S.S.R.[e]	[r]410,500	[4]410,500	[r]410,500	[r]410,500	410,000
United Kingdom	167,390	133,420	120,400	103,797	110,000
United States (shipments)[e]	60,000	71,000	63,500	63,500	66,000
Grand total	[r]4,979,045	[r]4,854,054	4,843,483	5,292,418	5,731,340

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 25, 1990.

[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 1985–1987 were provided by the Instituto Mexicano de la Fluorita. Data for 1988 were provided by the Mexican Chamber of Mines, from the Secretaria de Energia, Minas y Industrial Paraestatal (Semip). Data for 1989 were provided by industry sources.

[7] Revised to zero.

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 1- to 1½-inch screen and contain less than 15% of material passing a 1⅛-inch screen.

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. U.S. producers use imported acid grade to take advantage of its lower tariff. Pellets have been made on balling machines using sodium silicate binder.

Geology—Resources[7]

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 carbon-

ate rocks. Some beds are replaced adjacent to structural features such as joints and faults. In frequent instances, 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 deeply weathered to depths of 30 meters or more.

7. Fluorspar may also occur as a major gangue mineral in lead and zinc veins. 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.

TABLE 11

WORLD FLUORSPAR RESERVES AND RESERVE BASE[1]

(Thousand metric tons contained CaF_2, 100% equivalent)

	Reserves[2]	Reserve base[3]
North America:		
Mexico	19,000	23,000
Canada	2,000	5,000
United States	W	W
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.	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	24,000	32,000
Mongolia	50,000	59,000
Thailand	1,000	2,000
Total	75,000	930,000
Other market economy countries	9,000	10,000
Other centrally planned economy countries	12,000	18,000
World total	238,000	329,000

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, 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).

Technology

Mining.—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 depth requires moving underground.

Narrow vein mining is often done by shrinkage stopping and open stopping where strong walls occur, while stratiform or bedded deposits use room and pillar patterns. Replacement and fissure vein deposits are mined with shrinkage stopping or cut-and-fill methods if they are deep, narrow occurrences. They may also be mined by open pit or strip mining techniques where they are 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 all mined with open pit methods. However, replacement deposits in Mexico are extracted by stopping or cut-and-fill methods.[8]

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 of over 3.0 for spar and less than 2.8 for most gangue minerals.

Heavy-media cone and drum separators are particularly effective in the 1½- by 3/16-inch size range, either for producing metallurgical gravel or for preconcentrating the 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 are being preconcentrated to yield a flotation feed of 40% CaF_2 or more. Lead and zinc sulfides and barite concentrate with the fluorspar to enrich the flotation feed with these valuable minerals. In some cases, washing plants are also used prior to flotation to remove clay or manganese oxides (wad).

Ceramic and acid grades of fluorspar are produced by multistage froth flotation. Ore from the mine is crushed and ground to proper size; care is taken not to overgrind and cause fluorspar to be lost in the slimes. If lead and zinc sulfides are present, they are preferen-

tially 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.[9]

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[5] O'Driscoll, M. Brazil's industrial minerals—Seeking success against all odds. Industrial Miner. (London). No. 266, Nov. 1989, pp. 53–54.

[6] Pelham, L. Fluorspar. Ch. in Mineral Facts and Problems, 1985 Edition. BuMines B 675, 1985, pp. 279–280.

[7] Pages 16 and 17 of work cited in footnote 4.

[8] Work cited in footnote 4.

[9] Page 281 of work cited in footnote 6.

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GALLIUM

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Nonferrous Metals. She has covered gallium for 6 years. Domestic survey data were prepared by Lura Nightlinger, Nonferrous Metals Data Section.

Gallium demand in the United States declined in 1989, principally because penetration of gallium arsenide (GaAs) devices into commercial applications did not occur as rapidly as expected. This also resulted in the closure of two large U.S. GaAs manufacturers and the decision of a Canadian firm to withdraw from its gallium recovery and purification businesses. In addition, two companies in the United Kingdom ceased or significantly reduced their activities in GaAs manufacturing.

Despite the gallium consumption downturn, world gallium production capacity increased significantly as a large gallium recovery plant began operation in Australia in 1989. Also, a U.S. firm planned to reopen a gallium and germanium recovery plant in Utah in 1990. Substantial research and development on new GaAs-based devices and novel fabrication techniques was continued, funded by both Government and private industry.

DOMESTIC PRODUCTION

Hecla Mining Co. purchased the gallium-germanium mine and processing plant in St. George, UT, from St. George Mining Corp. early in 1989 for about $5.5 million. St. George Mining had filed for bankruptcy in 1988, and the plant had been idle since 1987. Using solvent-extraction technology, developed by Cominco Ltd., Hecla planned to reopen the mine and plant in early 1990 and recover a sodium germanate concentrate and 99.99%-pure gallium metal. Annual plant capacity was estimated to be 7,000 kilograms of gallium metal and 20,000 kilograms of sodium germanate.

Eagle-Picher Industries Inc., Quapaw, OK, recovered and refined gallium from both imported and domestic materials. Recapture Metals Inc., Blanding, UT, recovered gallium from scrap materials.

CONSUMPTION

The growth of commercial applications for integrated circuits apparently slowed and led to the closure of two GaAs wafer manufacturing facilities in 1989. Morgan Semiconductor Div. of Ethyl Corp. closed its plant in Garland, TX, in June, and Spectrum Technology Corp. closed its plant in Holliston, MA, in December. Texas Instruments Inc. bought the assets of Morgan Semiconductor. Spectrum Technology agreed to sell some of its assets and inventory to M/A-Com Inc., another large GaAs wafer manufacturer.

Several companies participating in the U.S. Department of Defense Microwave/Millimeter Wave Monolithic Integrated Circuits program (Mimic) developed new GaAs-based integrated circuits for use in defense applications. Texas Instruments Inc. and Raytheon Co. shipped GaAs amplifier devices to the military for use in high-speed antiradiation missiles early in 1989. This was believed to be the first use of devices produced under the Mimic program in an actual product. Manufacturing the integrated circuits from GaAs was expected to increase performance of the devices.

Harris Microwave Semiconductor Div. of Harris Corp. had several monolithic microwave integrated circuit (MMIC) products incorporated into military electronics systems. These systems were included in the Advanced Medium-Range Air-To-Air Missile, the B-1B bomber, and the Combined Altitude Radar Altimeter. In addition, Harris Microwave worked with General Electric Co. and Hughes Aircraft Co. to develop airborne and ground-based phased-array radar systems. Harris Microwave produces about 50,000 MMIC and 400,000 microwave devices annually.[1]

Honeywell Inc. and Magnesys Corp. reportedly signed an agreement to put bubble memory systems, manufactured by Magnesys, into a portable battlefield communication terminal. This represented the first high-volume application for a bubble memory system in a production model military computer. Initial orders were for 575 terminals containing more than $1 million in bubble memory systems. Additional purchases of 3,200 units were planned over a 3.5-year period. Bubble memories store information in small magnetic domains that form in a garnet epitaxial layer over a gallium-

TABLE 1

SALIENT U.S. GALLIUM STATISTICS

(Kilograms unless otherwise specified)

	1985	1986	1987	1988	1989
Production[e]	—	[1]750	W	—	—
Imports for consumption	7,961	17,202	12,490	12,160	15,284
Consumption	7,396	16,043	10,729	10,741	9,667
Price per kilogram	$525	$525	$525	$525	$525

[e] Estimated. W Withheld to avoid disclosing company proprietary data.
[1] Reported figure.

gadolinium-garnet substrate when a magnetic field is applied.[2]

TABLE 2

U.S. CONSUMPTION OF GALLIUM,[1] BY END USE

(Kilograms)

End use	1988	1989
Optoelectronic devices:		
Laser diodes and light-emitting diodes	3,891	3,383
Photodetectors and solar cells	2,178	2,768
Integrated circuits:		
Analog	2,320	564
Digital	829	1,520
Research and development	1,235	1,214
Specialty alloys	83	110
Other	205	108
Total	10,741	9,667

[1] Includes gallium metal and gallium compounds.

PRICES

Quoted prices of gallium metal have not changed since 1986. Yearend prices for gallium quoted in the American Metal Market were as follows, in 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

FOREIGN TRADE

Gallium export data were combined with data for other metal exports by the Bureau of the Census and could not be separately identified. The Journal of Commerce Port Import/Export Reporting Services (PIERS) provided some information on gallium materials exported by ship. According to PIERS, about 300 kilograms of gallium in scrap materials was exported in 1989, principally to Belgium.

TABLE 3

STOCKS, RECEIPTS, AND CONSUMPTION OF GALLIUM,[1] BY GRADE

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1988:				
97.0% to 99.9%	109	—	93	16
99.99% to 99.999%	2	239	205	36
99.9999%	211	6,516	6,368	359
99.99999%	410	4,042	4,075	377
Total	732	10,797	10,741	788
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

[1] Consumers only.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF GALLIUM (UNWROUGHT, WASTE AND SCRAP), BY COUNTRY

Country	1988		1989	
	Kilograms	Value	Kilograms	Value
Canada	177	$50,046	—	—
France	4,923	1,923,249	8,266	$3,152,094
Germany, Federal Republic of	1,129	378,165	3,825	1,320,316
Italy	294	65,834	—	—
Japan	51	29,185	126	122,815
Mexico	17	7,299	—	—
Netherlands	—	—	39	8,225
Singapore	91	23,960	—	—
Spain	11	4,795	—	—
Sweden	—	—	23	13,560
Switzerland	5,423	1,844,675	2,586	898,645
United Kingdom	44	13,707	419	149,051
Total	12,160	4,340,915	15,284	5,664,706

Source: Bureau of the Census.

The average value of gallium imports into the United States in 1989 was $371 per kilogram.

Changes in 99.9999%-pure gallium prices from 1960 to 1988 and a brief analysis of the factors that influenced these changes were included in a Bureau of Mines report on nonferrous metals prices.[3]

WORLD REVIEW

Gallium production was estimated to be about 50,000 kilograms in 1989. Most gallium was recovered in the Federal Republic of Germany, France, and Japan. With the opening of Rhône-Poulenc S.A.'s gallium recovery facility in Australia, it is expected that Australia will become one of the leading gallium producers in the next few years.

Australia

Rhône Poulenc's 50,000-kilogram-per-year gallium extraction plant opened in April near Pinjarra, Western Australia. Crude gallium produced at the plant was shipped to Rhône-Poulenc's refinery in France for production of 99.9999%- and 99.99999%-pure gallium. Feedstock for the Australia plant comes from Alcoa of Australia Ltd.'s alumina refinery nearby.

Canada

In June, Alcan Aluminium Ltd. announced that the company was withdrawing from its gallium operations. Alcan owned a 10,000-kilogram-per-year gallium purification plant in Switzerland and a 10,000-kilogram-per-year gallium scrap recycling facility in Kingston, Ontario. The company also had planned to construct a 4,000-kilogram-per-year gallium recovery plant in Jonquiere, Quebec.

United Kingdom

Imperial Chemical Industries Ltd. (ICI) announced that it would sell its Wafer Technology subsidiary, which processed GaAs. The company cited the slow progress in developing applications for GaAs because of its cost and the manufacturing complexity. Earlier in 1989, Plessey PLC, another GaAs producer, significantly reduced its activities in the technology.

CURRENT RESEARCH

IBM Corp. reportedly demonstrated two experimental GaAs integrated circuits for sending and receiving data over fiber optic lines at speeds of 1 billion bits per second. These components, which contain 50 times more electronic and optical components than previously assembled on 1 chip, were designed as precursors to high-speed optical links between computers. Many new computer applications, including national economic forecasts and aircraft simulations, would be suited for the new technology because they create images composed of billions of data bits. Sending these images from one place to another would require new data transmission techniques.[4]

Scientists at SRI International announced that they fabricated a GaAs laser diode that emits multiple lasers from a single diode. Instead of creating mirrorlike edges when the diode is cut from the wafer, the multiple laser diode uses a specialized waveguide that is 1/500th of the width of a human hair. This technique allows diodes to be made with tightly packed lasers that produce a stronger beam. The new diodes may allow integrated circuits in high-speed computers to relay information with light instead of wires.

A new transistor that can do the work of more than 20 conventional devices was developed at American Telephone & Telegraph Co.'s (AT&T) Bell Laboratories. Two very thin layers of indium gallium arsenide (InGaAs) clad with 2 aluminum indium arsenide layers, each 25 atoms thick, creates a quantum structure. Although commercial manufacture of quantum devices is years away, AT&T has used the new transistor in complex circuits to detect transmission errors in digital telephone systems. Normally this task requires 24 conventional transistors, but because the AT&T transistor can operate in multiple states, it can function as a parallel processor, doing several tasks at once.

Engineers at the University of California at Santa Barbara reported that they constructed and tested a lattice of quantum wires constructed of GaAs bounded by an insulation of aluminum arsenide. These wires are so tiny, 6 million of which would equal the width of a human hair, that they behave as if they only have two dimensions—length and width. These are precursors of a new family of components that would lead to even greater miniaturization of computer components and electronic equipment, although commercialization of the devices is likely more than 15 years away. A review of quantum technology outlines some of the recent U.S. developments.[5]

Ferranti Instrumentation Ltd. of the United Kingdom announced the development of an optical communications system for use in battlefield radio communication. The new system, based on the use of GaAs laser diodes, would allow users to communicate without fear of revealing their position, and the system also resists jamming. Testing of the communications system was performed on a military helicopter, and the company claimed that there may be applications in land- and sea-based military equipment.

Spire Corp. received several contracts from Government agencies in 1989 to develop new GaAs-based components. The company received a contract from the National Aeronautics & Space Administration to develop an InGaAs photodetector that is capable of detecting wind-shear conditions and would be incorporated into a system that can be carried on airplanes to monitor air turbulence. The U.S. Air Force awarded two contracts to Spire. One contract was to develop a long-wavelength GaAs-gallium aluminum arsenide (GaAlAs) superlattice photodetector for infrared imaging applications. The second contract was for the development of lighter, more radiation-resistant GaAs solar cell assemblies. In addition, Spire also received a contract from the Naval Weapons Support Center for development of GaAs complementary heterojunction bipolar technology.

Varian Associates Inc. reported the development of a terrestrial solar cell with a 27.6% solar-to-electric-power conversion rate, which was the highest rate ever reported. The new solar cell was made with layered GaAs and GaAlAs. Varian also received a $2.6 million contract from the U.S. Air Force to develop three-junction cascade solar cells with a 30% conversion rate.

TABLE 5

WORLD ANNUAL PRIMARY GALLIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Kilograms)

North America: United States[2]	3,000
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	125,000

[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, 1989.

The unit would consist of GaAs sandwiched between GaAlAs and InGaAs and would be designed to operate at 75° to 100° C.[6]

Scientists at the University of California's Lawerence Berkeley Laboratories announced the development of a new method of GaAs crystal growth that significantly reduces crystal defects. GaAs crystals were grown in a completely sealed crucible that uses microprocessors to control temperature gradients and growth rates. Using an advanced vertical freeze technique, the researchers produced 2-inch-diameter crystals with 5 to 10 times fewer defects than crystals produced by conventional methods. Fewer crystal defects should result in increased GaAs device yields from the crystal.

Scientists at Bell Communications Research reported using a technique called epitaxial lift-off to produce thin layers of GaAs that can be separated from the substrate on which they are grown and transferred to another material. In normally produced GaAs optoelectronic devices, over 90% of the device is present to mechanically support the thin active layer. By separating the active layer from the support, GaAs optical devices can be combined with silicon-based integrated circuits, virtually eliminating difficulties surrounding the growth of GaAs on a silicon substrate. In the new technique, a dissolvable film of aluminum arsenide is deposited directly on a GaAs substrate, then the active layers are deposited on the aluminum arsenide surface. Treatment with hydrofluoric acid dissolves the aluminum arsenide layer, and the active layers can be separated from the substrate, which can be reused. The active layers can then be transferred to a smooth surface such as a polished silicon wafer.

OUTLOOK

Nearly all the gallium consumed in the United Sates, and throughout the world, is used as gallium compounds, particularly GaAs, for optoelectronic devices and integrated circuits. The technology to produce these devices is still developing and a significant portion of the funding for research and development is provided by the Department of Defense. If total defense funding is cut back, as has been anticipated in view of recent world events, it is likely that funding for GaAs device development will be reduced. With slower technological advancements, penetration of GaAs devices into new applications would be greatly reduced, and consumption would remain flat or may decline.

At the same time, GaAs components are still undergoing "head-to-head" competition with silicon components in markets in which GaAs had expected to replace silicon. Continued developments in silicon production technology have led to the development of more powerful devices that can compete with GaAs devices in these applications and are much less costly. This factor also would lead to flat or reduced gallium consumption.

Although many companies are working to reduce the cost of GaAs device production, improve materials yields, and develop devices for large-scale commercial applications, it is likely that U.S. gallium demand over the next few years will remain at about the same level as that in 1989.

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GEM STONES

By Gordon T. Austin

Mr. Austin, a physical scientist with over 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.

The value of production of natural gem materials in the United States during 1989 decreased slightly to $42.9 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 $18.8 million, about a 15% increase over that of 1988. Synthetic gems are manmade 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 manmade 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 shows, cutting factories, and jewelry manufacturers were the major purchasers of domestic gem materials.

DOMESTIC DATA COVERAGE

The 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 358 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 358 operations surveyed in 1989 were an increase of about 19% compared with the number of operations surveyed in 1988. The response rate was essentially the same as that of 1988. The Bureau estimated the production by nonresponding operations, by professional collector, 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. The Bureau is totally dependent on the cooperation of the producers, brokers, dealers, and collectors for the formal voluntary survey and the informal surveys. Individuals and companies have been very cooperative and forthcoming with information. The Bureau is very appreciative of this cooperation.

PRODUCTION

Each of the 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, with their 1988 standing shown in parenthesis, were Tennessee (1), Arkansas (4), California (2), Arizona (3), Montana (5), Nevada (12), Oregon (6), North Carolina (7), Maine (16–17), and Utah (10). 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 ever 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 $12.5 million a year, with a high of $43.5 million in 1988 and a low of $6.9 million in 1980. The value of production for the past 10 years must be separated into two trends. The first trend was the period between 1979 to 1985, during which time approximately 24 operations reported production. Production averaged $7.5 million a year and was generally level. During the second trend, 1986 to the present, production averaged $24.2 million and was the result of an increase of 1,392% in the number of producers surveyed.

The reported production value of synthetic and simulant gem materials was $18.8 million in 1989. The reported value of production increased 15%; however, the quantity of materials produced was significantly greater. A shift in the types of materials produced, primarily a change from colored cubic zirconia to colorless cubic zirconia, resulted in the production of lower valued material. 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.

Dia Em Resources Ltd. and LKA International Inc. completed the evaluation of their Rist and Ellis Emerald Mines at Hiddenite, NC, in 1988, and disposed of the property in 1989. LKA's plans to sell the two largest emerald crystals ever found in the United States, the 1,438-carat Stephenson and the 1,686.3-carat LKA crystal, have not been successful to date.

Crystal Exploration Inc. of Denver, CO, a subsidiary of Restech International Ltd. of Sydney, Australia, continued exploration for diamonds on mineral leases in Michigan. It purchased the leases from Dow Chemical Co. in 1988. Crystal took advantage of the north-central U.S.'s cold winter weather to explore for diamonds on the frozen grounds of swamps in Michigan and Wisconsin.

Amselco Exploration Inc., a subsidiary of British Petroleum Co. of Canada, and Exmin Corp., a subsidiary of the Belgian company Sibeka (Societe d'Entreprises et d'Investissements S.A.), continued exploration for diamonds on leased lands in Michigan and Wisconsin. Exmin also continued diamond exploration efforts in Minnesota.

Three firms continued their diamond exploration project in the State Line district on the Colorado-Wyoming border.

The Arkansas State Parks, Recreation, and Travel Commission voted 12 to 0 to enter a cooperative agreement with four mining companies to undertake a testing program at Crater of Diamonds State Park. Their vote enacted the recommendation of the Diamond Mining Task Force. The program will decide if commercial diamond mining at the park would be feasible. The four companies will pay for the testing, plus any litigation costs. Each firm also will appoint a representative to a technical advisory team that will manage the testing. The four firms are (1) Continental Diamonds, a joint venture between Continental Diamonds Inc. and Galactic Resources Ltsd., (2) Diamond Development Co., a equal ownership joint venture between Sunshine Mining Co., Rhombus Inc., Exdiam Inc., and Boulle Partnership, (3) Capricorn Diamonds Ltd., and (4) Kennecott Inc. The testing would cost about $350,000 and would include drilling about 30 core holes. Two environmental groups, the Sierra Club and Friends of the Crater of Diamonds, have promised to sue to stop the testing.

In June, the U.S. Forest Service held the first ever bid opening for quartz mining parcels in the Ouachita National Forest. A total of 76 bids, worth more than $25,000, were received on 84 parcels. The successful bids covered only 46 of the 84 parcels, representing about 522 hectares (1,289 acres) valued at $18,464. The parcels ranged in size from about 4 hectares (10 acres) to about 32 hectares (80 acres). A successful bidder will be issued a 5-year contract on the parcel and will be required to pay an annual fee to retain the contract. The revenues generated by the program, bids, and annual fees will be divided equally between the Federal and State Governments. The State plans to return its share to the county containing the lease parcel.

Mines in southern Oregon continued to produce a large amount of gem Labradorite. Production included both material that contained schiller, commonly known as sunstone, and nonschiller material, called helidorite by some. The Ponderosa Mine furnished the material to cut an extremely fine bright red color stone of over 10 carats. The mine at Opal Buttes in Morrow County continued to produce several varieties of very high-quality opal.

Hobbyist and commercial production of sapphire in Montana increased significantly during the year. Improvements in the techniques for heat treating the material and better commercial acceptance of the Montana sapphires were the major reasons for this increase. The increase in production occurred at all three of the major producing areas, the Missouri River, Rock Creek, and Yogo Gulch.

Plumbago Mining Corp. of Rumford, ME, mined amethyst for the entire permitted mining season, June through September, at the Sweden, ME, property of the Saltman family. Gems & Gemology reported production was about 2,270 kilograms, of which most was specimen quality. An officer of Plumbago reported the cutting of a 12-carat stone from material from the mine and that some material recovered would yield stones as large as 20 carats.

Sugar Hill Minerals reported the recovery of the largest gem morganite ever found in North America. The rose colored beryl was found at the company's Bennett Quarry near Buckfield, ME. The large crystal produced about 23 kilograms of varying sized blocks of gem rough for the company's gem inventory.

American Pearl Farms of Tennessee completed its third significant harvest of cultured freshwater pearls. American currently has five pearl farms under operation and purchased additional water acreage for a sixth farm to be established during 1991. The new farm will be nine times larger than the existing farms.

Pala International reported the discovery in May of the largest gem pocket found at the Himalaya Mine during the past 12 years. The pocket was approximately 0.7 by 1 by 3.7 meters and yielded about 500 kilograms of tourmaline. Approximately 50% of the material was suitable for carving or cabochons, with less than 1% suitable for faceting. The Himalaya Mine is in the Mesa Grande District of San Diego County, CA.

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, and other art objects. Some industrial applications requiring clean homogeneous stones used low-quality gem diamond.

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.

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 estimated value of U.S. apparent consumption was a record high $3,711 million, but only a slight increase over that of 1988. The average annual estimated consumption for the past 10 years was $2,737 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 199% total increase or an annual compounded growth rate of about 13%.

The value of U.S. estimated apparent consumption of diamonds increased slightly to $3.1 billion. The average annual value of apparent consumption of diamonds for the past 10 years was $2,158 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 216% over the period.

The 1989 estimated apparent consumption of colored stones, led by emerald, ruby, and sapphire, was valued at $406.9 million, an increase of 31%. The annual average value of consumption of colored stones for the past 8 years was $316.0 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 8 years was one of fluctuating increases and decreases, but the general trend was one of increased consumption.

The estimated apparent consumption of pearls—natural, cultured, and imitations—was $146.9 million, a decrease of about 18% from 1988. The value was about 53% greater than the 8-year low in 1982, but was about 18% less than the 8-year average of $178.9 million a year.

Estimated apparent consumption of synthetic and imitation gem materials decreased about 49% to $43.7 million. Average apparent consumption of synthetic and imitation gem materials for the past 8 years was $50.3 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 8 years was one of generally strong growth until the significant decrease in 1989. Even with the 1989 decrease, annual apparent consumption increased about 214% over the 8 years.

Estimates of U.S. diamond jewelry sales by jewelers were $11.6 billion during 1989, up slightly from the $11.3 billion in 1988.

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 Central Selling Organization's (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–H color and IF through VS2 clarity) of a 1-carat diamond fluctuated between $7,256 and $7,202 and was $7,044 at yearend. The average value per carat of all grades, sizes, and types of gem-quality diamond imports was $408, a 9% increase compared with that of 1988. The average value of diamond imports for the past 10 years was $407 a carat, with a high of $541 in 1980 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 increase.

The average yearend wholesale purchase price of a fine-quality 1-carat ruby, paid by retail jewelers on a per stone or memo basis, was $3,500, unchanged from 1988. The average value of ruby imports increased 9% to $33.75 a carat. The average annual value of

TABLE 1

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.

ruby imports for the past 8 years was $25.33 per carat, with a high of $34.04 in 1982 and a low of $16.42 in 1984. The trend for the value of ruby imports for the past 8 years was one of rapid decline, 52% for the period from 1982 to 1984. This was followed by a steady, moderate increase of 16% per year.

The average yearend wholesale purchase price of a fine-quality 1-carat sapphire, paid by retail jewelers on a per stone or memo basis, was $1,400, unchanged from 1988. The average value of sapphire imports increased 5% to $24.28 per carat. The average annual value of sapphire imports for the past 8 years was $23.43 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 8 years was one of fluctuating increases and decreases. The 8-year period ended with the 1989 value slightly 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, an increase of 6%. The average value of emerald imports decreased 23% to $61.00 per carat. The average annual value of emerald imports for the past 10 years was $56.47 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 1980 through 1984. A steady moderate growth followed, resulting in the 1989 average value being about 55% greater than the 1980.

FOREIGN TRADE

The export value of gem materials increased 17% to $1,180 million, a record high. The quantity of diamonds exported increased 17% to 692,588 carats, and the value of diamond exports increased about 20% to $1,086.6 million. The average annual quantity of diamonds exported for the past 10 years was 369,264 carats, with a high of 590,412 in 1988 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 4 years, followed by significant growth, 219%, from 1982 to 1989. The average annual value of diamond exports for the past 10 years was $521.6 million, with a high of $908.9 million in 1988 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 significant decline, 113%, over 4 years, followed by a moderate growth of 32% in 3 years, and then a significant growth of 136% over the last 3 years. This resulted in record exports in 1989.

The export of other precious stones, cut but unset and other than diamonds and pearls, decreased about 36% to $43.6 million. The average annual export value for the past 8 years for these natural gem stones was $39.4 million, with a high of $68.5 million in 1988 and a low of $27.7 million in 1984. The 8-year trend for the value of exports for these types of gem materials was one of increases and decreases, but ultimately resulting in a significant total increase of 131% for the period.

Exports of synthetic gem material increased by 667%, to $46.0 million. The average annual value of exports for the past 8 years was $15.6 million, with a high of $46.0 million in 1989 and a low of $6.0 million in 1987 and 1988. The 8-year trend for the value of exports was one of extreme decline, 52%, for 1982–83, followed by steady moderate growth of 62% over the next 5 years and showing a significant gain in the last year.

Export of natural, cultured, and imitation pearls, not set or strung, increased about 55% to $3.4 million.

Reexports of gem material decreased 24% to $293.2 million. The quantity of diamonds reexported decreased about 77% to 0.4 million carat, the lowest amount in the past 10 years. The value of diamonds reexported decreased about 51% to $157.1 million. The average annual quantity of diamonds reexported for the past 10 years was 1.8 million carats, with a high of 3.0 million carats in 1981 and a low of 0.4 million in 1989. The 10-year trend for the quantity of diamonds reexported was highly mixed. The period started with 2 years of extreme increase, 171%, followed by 3 years of moderate decline, 37%, followed by 3 years of essentially stabile reexports, and then the most recent declines in 1988 and 1989. The average annual value of reexported diamonds for the past 10 years was $285.0 million, with a high of $412.8 million in 1981 and a low of $157.1 in 1989. The 10-year trend for the value of reexports was one of increase, 4%, for 1980–81, moderate decline, 55%, the next 4 years, followed by 3 years of significant increase, 72%, and then the major decrease in 1989. The value of 1989 reexports was 61% less than that of 1980.

The reexport of natural gem materials, cut but not set, other than diamonds and pearls, decreased about 92% to $4.6 million, a record low for the 8-year period for which data were available. The average annual value of reexports for the past 8 years was $33.0

TABLE 2

PRICES OF U.S. CUT COLORED GEM STONES, BY SIZE[1]

Gem stones	Carat weight	Price range per carat in 1989[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.

million, with a high of $55.1 million in 1988 and a low of $4.6 million in 1989. The 8-year trend for the value of reexports was one of alternating decreases and increases.

The reexport of natural gem materials not cut or set, other than diamonds and pearls, increased about 473% to $127.3 million. The extremely large increase was most likely the result of reexporting colored stones to worldwide cutting centers for cutting and reexport to the United States as finished gems. The average annual value of reexports for the past 8 years was $25.0 million, with a high of $127.3 million in 1989 and a low of $1.3 million in 1987. The 8-year trend for the value of reexports was one of extreme increases and decreases, with the value over the period increasing 1,575%.

Reexports of natural, cultured, and imitation pearls and synthetic gem materials were $3.9 million and $0.4 million, respectively.

The value of gem materials imported increased slightly to a record high of $5,115 million. The value of imported gem diamonds accounted for about 85% of the total. The average annual value of gem material imports for the past 10 years was $3,661 million, with a high of $5,115 million in 1989 and a low of $2,384 million in 1982.

The value of imported gem diamonds increased slightly to a record high of $4,358 million. The 10-year trend for the value of diamond imports was one of generally steady continuous growth with an increase of 94% for the period. During the period, the value of imported uncut diamonds decreased 44%, while the value of cut stones imported increased 203%.

The imports of cut diamonds increased slightly in quantity and value to 8.9 million carats and $3,805.5 million, respectively. The average annual quantity of cut diamonds imported was 6.3 million carats, with a high of 8.9 million in 1989 and a low or 1.3 million carats in 1980. The trend for cut diamond imports for the past 10 years was one of continued increases; the period ended with imports 246% greater than at the beginning of the period. The average annual value of imported cut diamonds was $2,549.6 million, with a high of $3,805.5 in 1989 and a low of $1,256.0 million in 1980. 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 203% greater than at the beginning.

The value of imports of other gem materials, led by emerald, ruby, and sapphire, was $756.4 million, about the same as those of 1988. Emerald imports increased about 19% to 207.5 million. The average annual value of emerald imports for the past 10 years was $149.8 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 16% to 83.4 million, the fourth highest value for the past 10 years. The average annual value of imports for the past 10 years was $75.8 million, with a high of $93.8 in 1981 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 42% from the 10-year low, but still 11% below the high for the period.

The value of sapphire imports increased 23% to $100.0 million, the high

TABLE 3

U.S. EXPORTS AND REEXPORTS OF DIAMOND (EXCLUSIVE OF INDUSTRIAL DIAMOND), BY COUNTRY

Country	1988		1989	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Exports:				
Belgium	163,246	$142.4	178,220	$187.1
Canada	24,104	18.4	24,957	30.0
France	7,946	11.4	5,577	11.4
Germany, Federal Republic of	3,736	4.7	2,717	4.4
Hong Kong	92,067	208.1	112,529	234.5
Israel	169,433	137.9	222,424	192.6
Japan	74,566	196.2	65,407	199.7
Singapore	5,135	9.2	3,274	10.1
Switzerland	23,929	141.9	16,800	133.3
Thailand	16,082	12.2	39,575	16.4
United Kingdom	3,641	20.6	7,263	44.6
Other	6,527	5.9	13,845	22.5
Total	590,412	908.9	692,588	1,086.6
Reexports:				
Belgium	833,081	104.4	101,462	29.7
Canada	5,855	1.2	765	1.1
China	14,009	0.3	677	(2)
Germany, Federal Republic of	31,236	2.6	5,523	0.9
Hong Kong	34,682	19.6	28,157	19.0
India	139,684	5.0	49,240	3.4
Israel	137,820	65.9	28,464	21.6
Japan	114,904	10.2	49,227	7.1
Netherlands	89,000	9.4	12,125	3.5
Switzerland	34,234	77.5	25,401	47.4
United Kingdom	26,929	12.6	3,188	16.0
Other	83,026	10.3	53,671	7.4
Total	1,544,460	319.0	357,900	157.1

[1] Customs value.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF DIAMOND, BY KIND, WEIGHT, AND COUNTRY

Kind, range, and country of origin	1988		1989	
	Quantity (carat)	Value[1] (millions)	Quantity (carat)	Value[1] (millions)
Rough or uncut, natural:[2]				
Belgium	305,142	$111.8	57,962	$18.0
Brazil	349,461	10.7	33,709	5.7
Israel	38,734	8.2	12,979	7.1
Netherlands	57,791	7.9	24,424	11.7
South Africa, Republic of	48,515	44.9	9,130	13.8
Switzerland	14,307	8.2	12,268	11.9
United Kingdom	619,461	317.5	747,397	254.0
Venezuela	684	.1	7,275	.9
Other	210,203	79.3	284,292	229.5
Total	1,644,298	588.6	1,189,436	552.6
Cut but unset, not over 0.5 carat:				
Belgium	1,035,452	406.7	1,531,997	962.7
Brazil	34,554	13.7	39,200	16.2
Canada	9,156	4.1	7,754	5.5
Hong Kong	285,268	63.1	101,828	48.1
India	3,758,747	886.1	3,136,459	792.4
Israel	1,109,474	532.8	1,784,444	1,104.3
Netherlands	27,588	26.8	19,227	24.1
South Africa, Republic of	5,532	5.1	10,707	15.7
Switzerland	76,169	36.8	41,986	75.6
United Kingdom	23,406	22.9	37,581	37.3
Other	160,707	37.9	138,808	57.0
Total	6,526,053	2,036.0	6,849,991	3,138.9
Cut but unset, over 0.5 carat:				
Belgium	709,527	578.9	266,164	99.0
Hong Kong	59,949	40.1	68,930	19.5
India	386,422	111.3	1,176,503	312.0
Israel	906,752	675.2	318,288	178.5
Netherlands	7,859	12.9	4,809	10.5
South Africa, Republic of	22,762	40.6	1,245	.4
Switzerland	24,281	95.1	21,420	13.4
United Kingdom	17,546	45.3	11,116	8.2
Other	92,028	81.8	151,614	25.1
Total	2,227,126	1,681.2	2,020,089	666.6

[1] Customs value.
[2] Includes some natural advanced diamond.

Source: Bureau of the Census.

value for the past 10 years. The average annual value of sapphire imports for the past 10 years was $78.7 million, with a high of $100.0 million in 1989 and a low of $50.3 million in 1980. The 10-year trend for the value of imports was one of extremely fluctuating increases and decreases. The period ended with the value 96% greater than at the beginning and at the high for the period.

The value of imported gem materials other than diamond, emerald, ruby, and sapphire decreased 15% to $365.5 million. The average annual value of imports was $314.7 million, with a high of $429.5 in 1988 and a low of $110.6 in 1980. The 10-year trend for the value of imports was one of fluctuating increases and decreases resulting in a total increase of 230% for the period.

WORLD REVIEW

Diamond sales by De Beers Consolidated Mines Ltd.'s CSO in the second half of 1989 were $1.77 billion. This was 24% less than the $2.32 billion for the first half of 1989 and 10% less than for the second half of 1988. Total diamond sales by the CSO were $4.09 billion in 1989, about 2% less than the 1988 record high of $4.17 billion. According to diamond dealers, the reduced sales were most likely the result of a sagging U.S. demand. Estimates of the annual world market for diamond jewelry are approximately $40 billion. The U.S. share of this market dropped in 1989 from the historical level of about 33% to 29%. The three largest consumers are Japan (30%), the United States (29%), and Europe (18%). The amount of diamonds in the pipeline between the CSO rough sales and the retail purchaser is of equal importance to the CSO sales. Estimates of the material in the pipeline in 1989 were about $15 to $18 billion, measured at wholesale polished prices, or 2.5 years of sales. Sales of colored gem stones remained very 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—the 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 Government-owned and operated diamond mining company, sold over 1 million carats of diamonds in 1989 valued at about $200 million. But when diamonds taken in UNITA raids and smuggling are considered, the county's production was most likely nearly double the official sales. UNITA representatives recently offered $10 million worth of rough for sale on the U.S. market.

De Beers signed a declaration of intent with Endiama to help in developing Angolan diamond deposits. The agreement, worth $180 million annually, is for co-operation in prospecting, mining, and marketing. Further discussions and technical studies, leading to the establishment of a joint venture, are underway. Endiama may start marketing a "significant proportion" of production through the CSO in 1990, moving toward an exclusive agreement as production increases. It is also the intentions of the parties to build a diamond sorting building in Luanda in which to sort Angolan production before its sale to the CSO.

Australia

Poseidon Exploration Ltd. purchased Freeport Bow River Properties Inc., the joint venture of Freeport-McMoRan Australia Ltd. and Gem Exploration and Minerals Ltd. The joint venture owned and operated the Bow River alluvial diamond project. Production from Bow River averages 20% gem quality, 70% near-gem quality, and 10% bort.

Argyle Diamond Mines Pty. Ltd.'s annual diamond production from the AK-1 pipe was essentially unchanged at about 34.4 million carats. Argyle's annual production accounted for about 37% of the world's production of natural diamonds.

Many firms continued their diamond exportation efforts. Gem Exploration Ltd. reported success in a sampling program for the Kununurra Project in Western Australia, and Terres Resources NL also worked in the Kununurra area. Poseidon-Trian Minerals continued to explore in the Phillips Range in Western Australia, as did the Capricorn Resources, Copperfield, and Moonstone joint venture. Auridiam-Afro-West worked on its project at Mount Wynne in Western Australia, as

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF NATURAL PRECIOUS AND SEMIPRECIOUS GEM STONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1988		1989	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Emerald:				
Belgium	11,963	$5.6	10,605	$1.2
Brazil	80,199	6.4	80,829	12.8
Colombia	243,521	63.8	429,390	73.1
France	13,817	3.2	5,345	4.0
Germany, Federal Republic of	34,376	2.4	23,902	3.2
Hong Kong	135,384	14.7	135,423	18.9
India	1,205,636	20.4	2,068,254	25.9
Israel	89,399	24.7	89,559	24.7
Japan	20,102	1.0	10,178	1.1
South Africa, Republic of	4	(2)	146	(2)
Switzerland	65,021	20.6	60,265	28.6
Taiwan	256	(2)	1,681	.7
Thailand	216,501	3.8	366,925	5.0
United Kingdom	8,026	2.9	6,187	2.5
Other	91,701	5.1	112,866	5.8
Total	2,215,906	174.6	3,401,555	207.5
Ruby:				
Belgium	8,926	1.3	7,760	1.1
Brazil	4,945	.2	8,093	(2)
Colombia	258	(2)	337	(2)
France	5,885	3.4	21,483	3.5
Germany, Federal Republic of	26,530	1.0	20,822	.8
Hong Kong	47,152	4.6	79,583	6.1
India	318,575	1.1	455,954	1.6
Israel	38,593	1.6	26,326	3.8
Japan	11,572	.8	796	.4
Switzerland	40,183	11.6	70,098	19.7
Thailand	1,822,557	40.5	1,778,218	38.9
United Kingdom	8,443	3.6	3,596	2.9
Other	61,703	2.3	73,345	4.6
Total	2,395,322	72.0	2,546,411	83.4
Sapphire:				
Australia	2,883	.2	30,439	.4
Austria	603	(2)	377	(2)
Belgium	20,024	.9	26,155	2.2
Brazil	9,528	.2	8,705	.2
Canada	16,177	.9	5,622	.6
Colombia	1,398	(2)	358	.2
France	46,296	2.3	7,825	1.4
Germany, Federal Republic of	26,750	1.0	31,999	1.4
Hong Kong	123,689	5.8	102,671	8.4
India	149,488	1.2	112,937	1.0
Israel	8,931	1.1	29,535	4.7
Japan	22,662	.6	2,532	.6

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF NATURAL PRECIOUS AND SEMIPRECIOUS GEM STONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country	1988 Quantity (carats)	1988 Value[1] (millions)	1989 Quantity (carats)	1989 Value[1] (millions)
Sapphire—Continued				
Korea, Republic of	6,438	(2)	9,024	(2)
Singapore	4,705	$.2	481	(2)
Sri Lanka	39,259	2.4	63,184	$4.1
Switzerland	32,446	10.2	67,086	15.6
Thailand	2,878,129	50.2	3,576,666	55.1
United Kingdom	10,102	2.9	9,435	2.5
Other	110,301	1.4	34,348	1.6
Total	3,509,809	81.5	4,119,379	100.0
Other:				
Rough, uncut:				
Australia		.9		1.4
Brazil		29.7		36.0
Colombia		2.4		10.5
Hong Kong		.5		2.2
Nigeria		.2		.7
Pakistan	NA	1.0	NA	1.4
South Africa, Republic of		4.8		.2
Switzerland		1.7		1.3
United Kingdom		.6		(2)
Zambia		.9		.5
Other		5.5		11.1
Total	NA	48.2	NA	65.3
Cut, set and unset:				
Australia		12.6		10.7
Brazil		18.6		5.0
Canada		.4		.2
China		2.3		1.1
Germany, Federal Republic of		15.8		12.2
Hong Kong	NA	27.4	NA	21.2
India		5.1		3.7
Japan		144.5		118.3
Switzerland		3.1		1.3
Taiwan		11.3		1.8
Thailand		14.2		10.0
United Kingdom		1.7		2.4
Other		17.7		15.7
Total	NA	274.7	NA	203.6

NA Not available.
[1] Customs value.
[2] Less than 1/10 unit.

Source: Bureau of the Census.

TABLE 6

VALUE OF U.S. IMPORTS OF SYNTHETIC AND IMITATION GEM STONES, INCLUDING PEARLS, BY COUNTRY

(Million dollars[1])

Country	1988	1989
Synthetic, cut but unset:		
Austria	2.0	3.7
France	.6	.4
Germany, Federal Republic of	9.1	9.4
Japan	2.1	0.4
Korea, Republic of	8.1	4.3
Switzerland	6.0	3.8
Other	5.6	7.4
Total	33.5	29.4
Imitation:		
Austria	49.4	40.0
Czechoslovakia	2.7	3.1
Germany, Federal Republic of	6.7	1.6
Japan	4.6	.4
Other	6.2	12.2
Total	69.6	57.3

[1] Custom value.

Source: Bureau of the Census.

did Stockdale, a subsidiary of De Beers, in the Ellendale area. Pemlya Mines NL and Noranda Pty. Ltd.'s joint venture searched for diamonds in the Eastern Pilbara. Cluff Resources Pacific Ltd. explored the Copeon-Bingara area of New South Wales. Cambridge Gulf Exploration NL started a search for diamonds on leases covering about 2,000 square kilometers on either side of the Ord rivermouth. Quicksilver Resources was seeking investors to finance the exploration of three diamond prospects in Western Australia, the Byro Project, Mount Edith, and Tier Range. The Mount Gipps Ltd. and Reedy Lagoon Corporation NL joint venture will begin drilling for diamonds in the Reedy Lagoon region of South Australia during 1990.

Australia held its first culture pearl auction in October at Darwin. Long the leading producer in the quantity of cultured South Sea pearls, it was time also to claim the title of number one in quality. For this reason, the nine pearl farms that account for an estimated 80% of the production decided to sell the bumper pearl crops at home instead of in Japan. The auction was a large success with 60 firms worldwide spending $33.5 million. The Japanese were the largest purchaser, buying about $23 million.[1]

A new form of gem orthoclase, named Rainbow Lattice Sunstone, was discovered in an area known as the

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF PRECIOUS AND SEMIPRECIOUS GEM STONES

(Thousand carats and thousand dollars)

Stones	1988		1989	
	Quantity	Value[1]	Quantity	Value[1]
Diamonds:				
Rough or uncut	1,644	588,611	1,189	552,557
Cut but unset	8,753	3,717,151	8,870	3,805,590
Emeralds: Cut but unset	2,216	174,623	3,402	207,546
Coral: Cut but unset, and cameos suitable for use in jewelry	NA	2,967	NA	NA
Rubies and sapphires: Cut but unset	5,905	153,552	6,666	183,344
Marcasites		1,229	NA	NA
Pearls:				
Natural	NA	3,389	NA	4,382
Cultured	NA	171,693	NA	144,335
Imitation	NA	7,198	NA	5,456
Other precious and semiprecious stones:				
Rough, uncut	NA	48,186	NA	65,298
Cut, set and unset	NA	79,056	NA	55,909
Other	NA	19,795	NA	NA
Synthetic:				
Cut but unset	81,096	28,995	99,292	29,368
Other	NA	4,485	NA	3,441
Imitation gem stone	NA	62,404	NA	57,323
Total	XX	5,063,334	XX	5,114,549

NA Not available. XX Not applicable.
[1] Customs value.

Source: Bureau of the Census.

Mud Tank Zircon Field in the Harts Range of the Northern Territory. The material was named for the unique lattice pattern of aventurescence it displays. Inclusions of ilmenite and hematite oriented on the crystal lattices causes this effect.[2]

Heavy rains during the month of March severely disrupted opal production from Coober Pedy, Mintabie, and Andamooka. The rains collapsed mine shafts and flooded tunnels and opencut mines. It will take 6 months, and in some cases a year, to get back into full production. The lost production will result in an increase in the price of Australian opal.

Brazil

Glencairn Explorations Ltd. received a positive feasibility study on the Feijao Cru diamond deposit in Bahia. It was estimated that production would be 42,000 to 84,000 carats annually and would average 80% gem quality. The original discovery was made by Mineracao Piracicaba Ltd., a Brazilian company. Glencairn can earn 50% interest in Piracicaba by investing an additional $250,000. There are about 25 small mines operating in the Chapada Diamantina region of Bahia.

Mineracao Tejucana, the joint venture between Sibeka's wholly owned Sibradiam Participacoes Ltda. and Union Miniere, produced more than 34,000 carats of diamonds and 107 kilograms of gold from its dredging operations on the Jequitinhoha River. The joint venture operated four dredges on the Lamarao flat and a fifth dredge was located outside of the main production area.

A discovery of tourmaline of unusual colors was made in Paraiba. The material, called "Paraiba" tourmaline, ranged in color from a highly saturated medium bluish green to medium dark blue-green and to a dark blue to violetish blue. The saturation and depth of color is outstanding. The stones demand a high price with 30 to 50 point stones selling for as much as $150 per carat and 5-carat stones going for as much as $2,500 per carat.

Canada

Cameco and Uranerz Exploration and Mining reportedly found seven kimberlite pipes on their joint-venture Fort a la Corne property east of Prince Albert, Saskatchewan. Microdiamonds were found in one pipe. The two firms have staked 170,000 hectares for exploration in the Fort a la Corne area. Additionally, Uaranerz is acquiring land to the north in the Choiceland-Snowden-Smeaton area for exploration. The race to claim land for diamond exploration in Saskatchewan is growing. The staking of a 200,000 hectare parcel between Prince Albert and Saskatoon increased the total amount of land held for diamond exploration to 647,000 hectares. Monopros, the Canadian exploration arm of De Beers, started the staking rush in 1988.

Corona Corp. discovered kimberlite rocks on the Sturgeon Lake exploration property of Claude Resources. A drill intersected kimberlite at a depth of 37 meters and was still in kimberlite at 111 meters. To date, there is no indication that the kimberlite contains diamonds; additional work will be necessary to determine if diamonds are present. The property is located north of Prince Albert, Saskatchewan.

Central African Republic

A joint venture, founded in 1987 between Osborne & Chappel Goldfields and Societe d'Enterprise et d'Investissements SA, continued their diamond exploration program with encouraging results. The joint venture has exploration rights for alluvial diamonds along a 170-kilometer stretch of the Mamber River. To date, reconnaissance drilling, geophysical testwork, and small-scale bulk sampling has been completed.

China

The production of colored gem stones increased about 30% in the past year. The five most commonly mined gem stones were aquamarine, tourmaline, sapphire, topaz, and nephrite jade. Other gem materials produced include amazonite, amber, amethyst, andalusite, aventurine, azurite, bowen-

ite, diopside, garnets, jet, kunzite, malachite, peridot, quartz, ruby, turquoise, and zircon.[3]

Ashton Mining Ltd. of Australia was granted exclusive exploration, mining, and marketing rights for diamonds in the Hunan Province. The company will share equally in any production, processing, and sale of diamonds with the provincial government. A cutting factory will be established in Hunan when diamond production begins.

In Laioning Province, the Wafandian diamond deposit, potentially the largest in China, is being developed for mining and is scheduled to begin operation in late 1990. Production is forecasted to be 118,000 carats per year. The Wafandian Mine would be China's fifth diamond mine, joining the Bin-Hai also in Laioning Province, and the Chang Ma, Tao Cheng, and Linshu Mines in Shandong Province.

Columbia

At the Muzo emerald mine in Boyaca, two major leaseholders, Tecminas and Coesminas, have begun using shafts and underground tunnels in addition to strip mining to recover emeralds. The relative flatness of the Muzo mining area and the accumulation of hundreds of years of mine tailings resulted in limiting access to some areas for production and exploration. The shafts and tunnels may allow the producers to relocate some of the old production veins and to discover new productive areas. The tunnels have encountered problems both with ground support and the inflow of water.[4]

Finland

The Finnish Geological Survey (GSI) reported the discovery of a 2,250-carat emerald. The totally transparent gem was estimated to be valued at approximately $250,000. The GSI drew up plans to intensify the exploration work in a 2-hectare area.

Guinea

A 255.61-carat diamond, recovered from the Aredor Mine, was purchased for slightly more than $10 million. At $39,300 per carat, it was not the highest per carat price ever paid for a rough diamond; a 181.77-carat rough diamond from Aredor sold for $47,400 per carat in 1988. However, the total purchase price was the highest ever paid for a rough diamond. In February, Aredor was granted a 405-square-kilometer extension to its mining lease. The new ground is believed to contain high-quality alluvial reserves.

India

During fiscal year April 1, 1988, to March 31, 1989, the value of finished diamonds exported increased 75% to $2.95 billion. The value was the greatest for any country and accounted for about 28% of the value of diamonds and 70% of the stones used in diamond jewelry. The increase was the result of a general increase in demand for diamonds, a depreciation of the rupee, falling labor costs, and favorable Government policies aimed at boosting exports. India plans to increase its share of the market to near 50% of the value within 2 years. The diamond industry employs approximately 1 million skilled and semi-skilled workers.

The Indian Minerals Exploration Corp. Ltd. and the French BRGM company entered into an agreement to explore for diamonds and develop any commercial deposits discovered in the Pana, Krishna, and Vajnakarur areas.

Israel

Diamond imports and exports increased for the year. Imports increased about 6% to $2.6 billion and exports were approximately $2.7 billion, an increase of over 7% compared with that of 1988. Approximately 43% was exported to the United States and about 35% to the Far East.

Dov Riger of Israel and Tasaki Shinju of Japan opened a joint-venture automated polishing factory at Beit Shean, in northern Israel. The factory employs 30 workers using automatic piermatic polishing machines. The entire output of the factory is committed to the Japanese parent company. Tasaki Shinju has annual sales of about $200 million.

Namibia

Consolidated Diamond Mines of South-West Africa (CDM), the De Beers Consolidated Mines, Ltd. subsidiary that controls the majority of the diamond mining concessions in Namibia, began development of two new diamond operations. The Elizabeth Bay operation will recover about 250,000 carats per year of small stones from windblown deposits. The mine is located about 30 kilometers south of the town of Luderirtz and will mine and process about 4 million metric tons per year during its projected 10-year life. Production is scheduled to begin in March 1991. The Auchas Mine along the Orange River will recover about 40,000 carats per year of large stones. The mine is scheduled to begin production in July 1990. CDM also is undertaking offshore diamond recovery research at depths of up to 90 meters in its offshore concessions.[5]

The Namibian West Coast Diamond Co. started a major exploration program in the deep-sea area of its concession. The concession starts about 2 kilometers offshore, continues to about 10 kilometers, and is roughly 90 kilometers long. A 250-ton survey and research vessel was purchased to survey, test, and map the deepwater area. In the past 2 years, the company has recovered about 26,000 carats of diamonds from the concession. However, it is estimated that large-scale commercial mining of the concession is still 10 years in the future.

It was reported that in Swakopmund, fake diamond octahedra and imitation tsavorite garnet rough were being sold to gem stone buyers. The fake diamonds were made from cubic zirconia and the tsavorites from cut green bottle glass.

Sierra Leone

In January, the Ministry of Mines began issuing export licenses to private firms and individuals for the export of diamonds. The Ministry granted 26 licenses for diamond exporting, 11 of which were granted to foreign individuals or companies. Applicants must pay a fee for the licenses, a fixed fee and/or a royalty, post a performance bond of $500,000, and must achieve a performance goal of exporting 250,000 in diamonds monthly, or forfeit the bond. The new regulations eliminate the diamond dealers and recognizes only two legal players in the diamond fields—the miners and the exporters. The Ministry believes that privatization will increase diamond production as well as increasing diamonds sold or exported through official markets.

South Africa, Republic of

The Kim Diamond Cutting Works, currently under construction, will proc-

ess 30,000 carats of rough a week. The cutting factory will employ at least 1,280 workers. Using local rough, it will process stones from 1 to 30 points for the overseas market. The factory is scheduled for completion by the end of April 1990.

A new open pit diamond mine, the Samanda, is being developed in the Orange Free State Province. The mine is forecasted to begin production in the second quarter of 1990. The developer is apparently a private concern.

De Beers announced that, in cooperation with Saturn Mining Ltd. of the Anglovaal group, it will open a new diamond mine on the Venetia farm in The Transvaal. The mine will cost approximately $280 million and will be the largest investment De Beers has ever made in a single mine. The mine is scheduled to begin production in the second half of 1990 at a rate of about 4 million carats per year.

Gemgold Mining Ltd. commenced mining diamonds from a open pit mine in the Cape Province. The company expects to produce about 40,000 carats in 1990 and 100,000 carats in 1991.

Tanzania

Williamson Diamonds Co. received a $4.7 million loan from Willcroft Co. Ltd. The funds will be used to modernize Williamson's diamond treatment plant, which has been in operation for over 30 years. The condition of the treatment plant has adversely affected Tanzania's diamond production for a number of years.

Zaire

In April, the Government of Zaire enacted new regulations on the purchase and export of diamonds. The purchasers of artisanal diamonds, called comptoirs, were required to pay a license fee and deposit of $300,000, compared with the old fee and deposit of $100,000. Additionally, comptoirs were allowed to purchase diamonds in Kinshasa if stones were offered for sale. Because Kinshasa is not an official buying location, there are not the same controls that are present in the interior where representatives from the National Evaluation Center are required to be present at all transactions.

Pilfering and smuggling from the diamond-producing areas was rampant according to the Societe Miniere de Bakwanga (Miba). Miba estimated that illegal mining and trafficking of diamonds in the two Kasai provinces cost the Government somewhere between $140,000 and $350,000 every month. Tough security measures are difficult to enforce because state security men connive with the smugglers, giving them protection as they go about their business. The law allows Zairian nationals the freedom to mine industrial diamonds anywhere in the country as long as the diamonds are sold through Miba. The system is no longer working because of access to better markets outside of Miba.

A substantial diamond deposit was reportedly discovered at a rubber plantation owned by the Amcit Blattner family at Kaparata. The plantation was sealed off by soldiers, which denied the owners access. The Blattners may enter into an agreement with a well-known diamond firm to exploit the deposit. It is possible that local residents are digging diamonds after gaining access by bribing the soldiers that are guarding the plantation.

Zambia

The Government of Zambia centralized the future marketing of emeralds by allowing the export only of cut and polished stones. Gem-Impex Ltd. of Zurich, Switzerland, was appointed the sole distributor of emeralds cut and polished in Zambia to implement the centralization. Gem-Impex will market Zambian emeralds worldwide for the state-owned Zambian Emerald Industries Ltd. Zambian Emerald, which operates a 50-cutter factory in Ndola, has the exclusive right to cut and polish emeralds produced in Zambia. Production from the Ndola factory was about 5,000 carats per month in a variety of shapes and sizes.

CURRENT RESEARCH

Mr. Zvi Yehuda of Ramat Gan, Israel, developed a new diamond enhancement process. The process improves the apparent clarity of diamonds by filling surface-reaching cleavages and fractures. The process replaces the air that normally fills the cleavages and fractures with a transparent material that has an index of refraction near that of diamond. The result is that the cleavages and/or fractures are less visible and thus the appearance and apparent clarity of the diamond is improved. The treatment can be detected using a standard darkfield-equipped gemological microscope. The orange and blue flash effects, flow structures, and flattened, trapped gas bubbles evident in the filled areas are easily detected. Yehuda also has founded a firm in the United States that uses a similar procedure to improve the appearance and apparent clarity of emeralds.[6]

The technology to improve the apparent color of diamonds in the very light to light yellow color ranges has been used occasionally to increase the value of a stone. The addition of a grayish or bluish material to the surface of "J" or "K" color stones can give the stone the appearance of a "G" color. This deceptive treatment could affect the value of a 1.00 carat "VS1" "K" stone by as much as $1,600 by changing its appearance to that of a "VS1" "G." The coating may be a fluoride compound similar to that used for lens coating in optics. The coating generally can be detected by careful examination under 30 to 45 power magnification.

Miners from Santa Terezinha de Goias, Brazil, developed a new process for treating rough and cut emeralds to improve their appearance, similar to the use of oil and Canada balsam on emeralds in the past. The treatment is based on the filling of the fractures that reach the surface of the stones. The stones are cleaned, dried, heated, and then treated with a synthetic fracture sealant marketed under the trade name Opticon. Individuals in the United States have improved and expanded upon the process to include treating stones, primarily cut emeralds, with Opticon in a heated vacuum vessel.

OUTLOOK

World demand for gem diamond can be expected to rise because of the rising average personal income of the population of the United States and other industrialized countries. Demand is expected to increase because of highly effective promotional campaigns. These promotions are changing social customs in many Far East countries, particularly in the use of diamond engagement rings.

TABLE 8

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

(Thousand carats)

Country	Natural												Synthetic[3]	Natural			Synthetic[3]
	1985			1986			1987			1988[p]				1989[e]			
	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total	Gem[2]	Industrial	Total		Gem[2]	Industrial	Total	
Angola	464	250	714	240	10	[e]250	180	10	[e]190	950	50	[e]1,000	—	950	50	1,000	—
Australia	4,242	2,828	7,070	13,145	16,066	29,211	13,650	16,683	30,333	17,517	17,517	35,034	—	17,540	17,540	35,080	—
Botswana	6,318	6,317	12,635	9,590	3,500	[r]13,090	9,368	3,840	13,208	10,660	4,569	15,229	—	10,676	4,576	[4]15,252	—
Brazil	233	217	450	310	315	625	320	325	645	353	180	533	—	350	200	550	—
Central African Republic	190	87	277	259	99	358	304	108	412	284	59	343	—	280	60	340	—
China[e]	200	800	1,000	200	800	1,000	200	800	1,000	200	800	1,000	15,000	200	800	1,000	15,000
Cote d'Ivoire (formerly Ivory Coast)[e 5]	15	5	20	10	4	14	15	6	21	[r]8	[r]3	[r]11	—	11	4	15	—
Czechoslovakia	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	5,000
France	—	—	—	—	—	—	—	—	—	—	—	—	[e]4,000	—	—	—	4,000
Ghana[6]	60	576	636	88	498	[r]586	65	400	465	165	495	[r e 7]660	—	168	452	[7]620	—
Greece	—	—	—	—	—	—	—	—	—	([8])	—	([8])	[e]1,000	—	—	—	1,000
Guinea[6]	123	9	132	190	14	204	163	12	175	136	10	146	—	[4]138	[4]10	[4]148	—
Guyana[e]	4	7	11	3	6	[4]9	[r]2	[r]5	[r]7	1	3	[4]4	—	2	3	5	—
India	14	2	16	13	3	16	13	3	[r]16	12	3	15	—	3	11	14	—
Indonesia[e]	5	22	27	[r]6	22	[r]28	[r]7	[r]22	[r]29	[r]7	[r]22	[r]29	—	7	25	32	—
Ireland	—	—	—	—	—	—	—	—	—	—	—	—	[r]60,000	—	—	—	60,000
Japan	—	—	—	—	—	—	—	—	—	—	—	—	[e]25,000	—	—	—	25,000
Liberia	66	72	138	63	189	252	60	190	[e]250	67	100	167	—	68	102	170	—
Namibia	865	45	910	970	40	1,010	971	50	1,021	901	37	938	—	970	30	1,000	—
Romania	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	4,500
Sierra Leone[5]	243	106	349	215	100	315	150	75	225	100	75	[e]175	—	100	75	175	—
South Africa, Republic of:																	
Finsch Mine	1,770	3,184	4,954	1,821	3,208	5,029	1,455	2,701	4,156	1,372	2,548	3,920	—	1,613	2,997	[4]4,610	—
Premier Mine	820	1,864	2,684	882	1,977	2,859	772	1,713	2,485	696	1,543	2,239	—	689	1,526	[4]2,215	—
Other De Beers' properties[9]	1,500	569	2,069	1,428	529	1,957	1,427	546	1,973	1,388	531	1,919	—	1,360	520	[4]1,880	—
Other	460	35	495	342	41	383	409	30	439	361	65	[r e]426	—	348	63	411	—
Total	4,550	5,652	10,202	4,473	5,755	10,228	4,063	4,990	9,053	[r]3,817	[r]4,687	[r e]8,504	[r e]55,000	4,010	5,106	9,116	60,000
Swaziland	13	8	21	23	16	39	[r]48	[r]32	[r e]80	44	29	73	—	33	22	[4]55	—
Sweden	—	—	—	—	—	—	—	—	—	—	—	—	[e]25,000	—	—	—	25,000
Tanzania	165	71	236	133	57	190	105	45	[e]150	105	45	[e]150	—	105	45	150	—
U.S.S.R.[e]	4,400	6,400	10,800	4,400	6,400	10,800	4,400	6,400	10,800	4,500	6,500	11,000	41,500	4,500	6,500	11,000	41,500
United States	—	—	—	—	—	—	—	—	—	—	—	—	W	—	—	—	W
Venezuela	35	180	215	45	189	234	35	63	98	55	53	108	—	55	60	115	—
Yugoslavia	—	—	—	—	—	—	—	—	—	—	—	—	[e]5,000	—	—	—	5,000
Zaire	4,032	16,127	20,159	4,661	18,643	23,304	3,885	15,540	19,425	2,734	15,493	18,227	—	2,850	16,150	19,000	—
Total	[r]26,237	[r]39,781	66,018	[r]39,037	[r]52,726	[r]91,763	38,004	49,599	87,603	42,616	50,730	93,346	[e]241,500	43,016	51,821	94,8372	46,000

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

[1] Table includes data available through May 16, 1990. 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 (1985–87), Botswana (1987), Brazil (1987), Central African Republic (1985–88), Guinea (1985–89), and Liberia (1985–86), 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] Includes estimates for artisanal production.

[8] Revised to zero.

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

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.

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 25000 B.C. Later, the Phoenicians in their writings described 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.

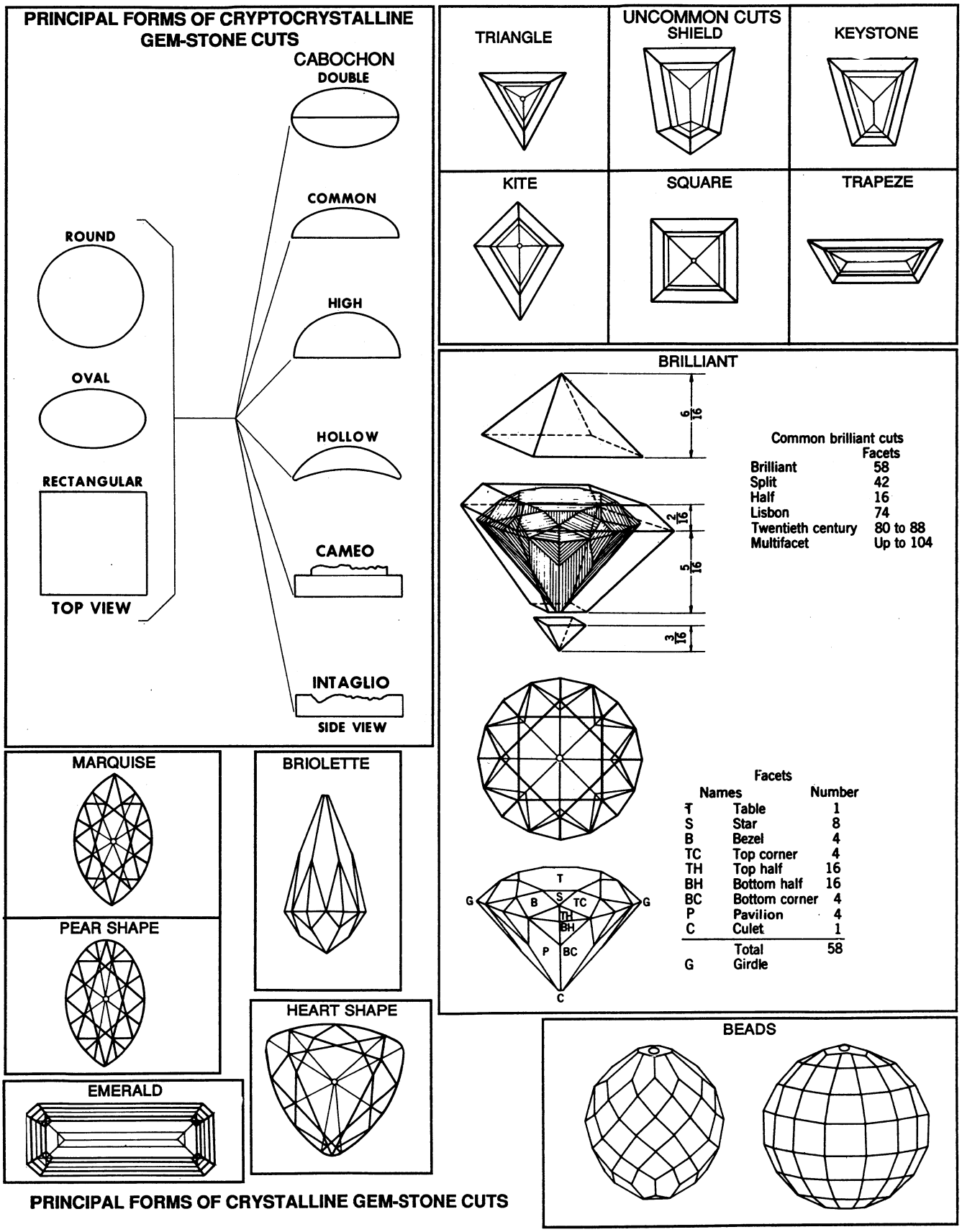
Cabochons are cut in four operations: sawing, grinding, sanding, and polishing. Sawing, the initial step in cutting, is customarily done with a diamond saw to obtain a slab or slice of the desired size and thickness from the rough gem material. The cabochon outline is scribed onto a flat surface, most 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

FIGURE 1

PRINCIPAL FORMS OF CRYPTOCRYSTALLINE AND CRYSTALLINE GEM STONE CUTS



"round brilliant" and some other common cuts are illustrated in figure 1.

Industry Structure

The world market for diamonds is controlled by De Beers Consolidated Mines Ltd. It is by far the most strictly controlled of the world's commodity markets. An estimated 80% to 85% of gem and natural industrial diamond is marketed by De Beers' wholly owned subsidiary, the Diamond Corp. Ltd. The marketing is done through the CSO by the Diamond Trading Co. Ltd. and the Industrial Distributors Ltd., divisions of the CSO. The CSO sells uncut gem diamonds on behalf of De Beers and most other major producers at sights (approved bidder viewings) in London, England; Lucerne, Switzerland; and Kimberley, Republic of South Africa.

Diamonds reach the CSO sights through three channels. First, South African and Namibian production goes directly to the Diamond Producers Association. The principal members of this association are De Beers, the South African Government, and the Namibian administration. Second, contractual sales by foreign producers are handled by the Diamond Corp. Ltd., which represents the foreign producers on the Diamond Producers Association. Third, open-market competitive sales and West African sales go directly through the Diamond Trading Co.

The Diamond Producers Association funnels the production of the first two groups into the Diamond Purchasing and Trading Co. (50% held by De Beers), part of the CSO. From this point, the diamonds go through the Diamond Trading Co. The Diamond Trading Co. markets diamond to South African cutters at a 10% discount on world prices; and, through its branch in London, diamonds are sold at sights on world markets. The third group's production is handled directly by the Diamond Trading Co.'s London Branch.

The CSO has been extremely successful at maintaining the rough diamond market for about 100 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 effect of these increases is a price increase of about 1,800% over the approximate 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 located in Belgium and Israel, with a certain amount of the larger stones being cut in the United States. Today there is estimated to be over 450,000 cutters as the result of the development of a large cottage industry in India that started in the early 1980's. This has had 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 0.07–0.14 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 are composed of silicate minerals, about one-fifth of alumina-silicates, 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 in table 10.

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

TABLE 9

DE BEERS CSO ROUGH DIAMOND PRICE INCREASES, BY PERCENTAGE

Sept. 1949	25.0%	Nov. 1967	16.0%	Aug. 1973	10.2%	Sept. 1982	2.5%
Mar. 1951	15.0	Sept. 1968	2.5	Dec. 1974	1.5	Apr. 1983	3.5
Sept. 1952	2.5	July 1969	4.0	Jan. 1976	3.0	Aug. 1986	7.5
Jan. 1954	2.0	Nov. 1971	5.0	Sept. 1976	5.8	Nov. 1986	7.0
Jan. 1957	5.7	Jan. 1972	5.4	Mar. 1977	15.0	Sept. 1987	10.0
May 1960	2.5	Sept. 1972	6.0	Dec. 1977	17.0	Apr. 1988	13.5
Mar. 1963	5.0	Feb. 1973	11.0	Aug. 1978	30.0	Mar. 1989	15.5
Feb. 1964	7.5	Mar. 1973	7.0	Sept. 1979	13.0	Mar. 1990	5.5
Aug. 1966	7.5	May 1973	10.0	Feb. 1980	12.0		

TABLE 10

GUIDE TO SELECTED GEM STONES AND GEM MATERIALS USED IN JEWERLY

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	do.	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	do.	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	do.	Low	3.0	2.72	Double (strong)	1.49–1.66	Silicates, banded agate, alabaster gypsum	Translucent.
Mexican onyx	do.	do.	do.	do.	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.

See footnotes at end of table.

TABLE 10—Continued

GUIDE TO SELECTED GEM STONES AND GEM MATERIALS USED IN JEWERLY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Corundum—Continued										
Sapphire	Aluminum oxide	Blue	Medium	High	9.0	3.95–4.10	Double	1.78	Synthetics, including spinel	Inclusions, double refraction, dichroism.
Sapphire, fancy	do.	Yellow, pink, white, orange, green, or violet	Medium to large	Medium	9.0	3.95–4.10	do.	1.78	Synthetics, glass and doublets	Inclusions, double refraction, refractive index.
Sapphire and ruby stars	do.	Red, pink, violet blue, 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, blue, or red	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	do.	Gray with blue and bronze sheen color play	do.	do.	6.0–6.5	do.	—	1.56	do.	do.
Moonstone	do.	White	do.	do.	6.0–6.5	2.77	—	1.52–1.54	Glass or white onyx	Blue sheen, opalescent.
Garnet	Complex silicate	Brown, black, yellow, green, ruby red, or orange	Small to medium.	Low to high	6.5–7.5	3.15–4.30	Single strained	1.79–1.98	Synthetics, spinel, glass	Single refraction, anomalous strain.
Jade:										
Jadeite	do.	Green, yellow, black, white, or mauve	Large	Low to very high	6.5–7.0	3.3–3.5	Crypto-crystalline	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.

See footnotes at end of table.

TABLE 10—Continued

GUIDE TO SELECTED GEM STONES AND GEM MATERIALS USED IN JEWERLY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Peridot	Iron magnesium silicate	Yellow 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.
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.	do.	7.0	2.65–2.66	do.	do.	do.	Do.
Crystal, rock	do.	Colorless	do.	do.	7.0	2.65–2.66	do.	do.	do.	Do.
Jasper	do.	Uniform or spotted red, yellow, or green	do.	do.	7.0	2.58–2.64	—	—	do.	Opaque, vitreous.
Onyx	do.	Many colors	do.	do.	7.0	2.58–2.64	—	—	do.	Uniformly banded.
Rose	do.	Pink, rose red	do.	do.	7.0	2.65–2.66	Double	1.55	do.	Refractive index, double refraction, translucent.
Spinel	Magnesuim 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.	do.	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.	do.	do.	do.		Synthetic spinel	Do.

See footnotes at end of table.

TABLE 10—Continued

GUIDE TO SELECTED GEM STONES AND GEM MATERIALS USED IN JEWERLY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with-	Recognition characters
Tanzanite	Complex silicate	Blue	Small	High	6.0–7.0	3.30	Double	1.69	Sapphire, synthetics.	Strong trichroism.
Topaz	do.	White, blue, or 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, 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—over 50 car.
[2] Low—up to $25 per carat; medium—up to $200 per carat; high—over $200 per carat.

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 11.

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.[7]

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

TABLE 11

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)	Do.
	Zone melt	Seiko	Do.
	Melt pulling	Kyocera (Inamori)	1970's
	Verneuil	Various producers	1900's
Star ruby	do.	Linde (Div. of Union Carbide)	1940's
	Melt pulling	Kyocera	1980's
		Nakazumi	Do.
Sapphire	Flux	Chatham	1970's
	Zone melt	Seiko	1980's
	Melt pulling	Kyocera	Do.
	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	Do.
		U.S.S.R.	Do.
	Hydrothermal	Lechleitner	1960's
		Regency	Do.
		Biron	1980's
		U.S.S.R.	Do.
Alexandrite	Flux	Creative crystals	1970's
	Melt pulling	Kyocera	Do.
	Zone melt	Seiko	1980's
Cubic zirconia	Skull melt	Various producers	1970's

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.[8]

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.[9]

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, Namibia, the Republic of South Africa, 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 beneficiation 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.

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[1] Focus. Modern Jeweler, v. 89, No. 2, Feb. 1990, pp. 46–48.

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GERMANIUM

By Thomas O. Llewellyn

Mr. Thomas O. Llewellyn is a physical scientist with the Branch of Nonferrous Metals. He has covered germanium for 3 years. Domestic survey data prepared by Lura Nightlinger, Nonferrous Metals Data Section.

The estimated domestic refinery production and consumption of germanium decreased compared with the levels of 1988. Infrared systems and fiber optics continued to be the major end uses. The domestic fiber-optic market for germanium decreased for the fourth consecutive year and consumption for this application was about 25% less than that of 1988.

DOMESTIC DATA COVERAGE

Domestic refinery production and consumption data for germanium are estimated by the Bureau of Mines based on discussions with domestic producers.

LEGISLATION AND GOVERNMENT PROGRAMS

In September, the Defense Logistics Agency (DLA) contracted to purchase 9,000 kilograms of germanium metal in two separate and equal solicitations. DLA scheduled the first lot for delivery starting July through November 1990 and the second lot for the period between September 1990 and January 1991. The contract price for both lots was $609 per kilogram. DLA rejected bids ranging from $559 to $582 per kilogram received from European and African producers and selected Eagle-Picher Industries Inc. The main reason for the selection was a clause in the solicitation that indicated the agency may be required to follow a "Buy American" policy for the acquisition of strategic and critical materials that are mined and refined in the United States (Amendment No. 7, Public Law 98-473, October 12, 1984).[1]

STRATEGIC CONSIDERATIONS

The Federal Emergency Management Agency (FEMA) established the importance of germanium as a strategic and critical material on July 6, 1984, and an initial National Defense Stockpile (NDS) goal of 30,000 kilograms of germanium metal. Based on the U.S. Army's estimates for actual emergency conditions of mobilization, FEMA established a new goal of 146,000 kilograms on July 24, 1987.

Some of the metal inventory acquisitions made in 1988 were delivered in 1989 and, as of December 31, the stockpile inventory was 38,282 kilograms of germanium metal.

DOMESTIC PRODUCTION

The Bureau of Mines estimated domestic refinery production from both primary and secondary materials at 20,000 kilograms, a decrease of 5% compared with that of 1988.

Hecla Mining Co. bought the assets of St. George Mining Corp. of St. George, UT, for $5.5 million. St. George, a subsidiary of the Canadian company Musto Explorations Ltd. recovered and mined germanium and gallium as principal products until 1987 when it closed its operation. The new owners expected to resume mine and refinery production during the first quarter of 1990 and reach full production levels before yearend.

CONSUMPTION AND USES

The Bureau also estimated that consumption of germanium decreased about 10% compared with the level of 1988. The estimated consumption pattern by end use of germanium in 1989 was as follows: infrared systems, 65%; fiber optics, 6%; gamma-ray, X-ray, and infrared detectors, 8%; semiconductors, 8%; and other, 13%.

The largest end use for germanium continued to be in infrared optics, mainly for military use in guidance and weapon-sighting systems. Germanium containing lenses and windows transmit thermal radiation similarly to visible light transmission by optical glass. Germanium glass was also used for nonmilitary surveillance and monitoring systems in fields such as satellite systems and fire alarms.

The U.S. fiber-optic market for germanium continued the downward trend of the previous 3 years, and consumption of germanium in this application decreased about 25% compared with that of 1988. Germanium is used as a dopant in the core of many optical fibers employed in telecommunications. The decline resulted from the development of new manufacturing processes that achieved more efficient use of germanium.

American Telephone & Telegraph Co. (AT&T) of Morristown, NJ, and Kousai Denshin Denwa of Japan completed installation of a 8,271-mile underwater fiber-optic cable system that links the Guam, Japan, and the United States. This system, known as the Pacific Link, is capable of carrying 40,000 phone calls simultaneously. The underwater cable from Point Arena, CA, goes to an undersea branching unit offshore of Japan. At this point the cable splits, and one branch goes to Tanguisson, Guam, and the other to Chikura, Japan.[2]

AT&T and Zenith Electronic Corp. signed a joint agreement to develop a system for high-definition television (HDTV). This application was poten-

tially a large market for fiber-optic applications in transmission network.[3] Although not used in all fiber-optic systems, germanium is an important constituent in many fiber-optic cables.

Two of the U.S. Navy's guided-missile cruisers were outfitted with fiber-optic cable systems that transmit several voice and data functions, including combat system displays and a damage control sensor system. Fiber-optic cable for shipboard communications offered a dramatic advantage in terms of weight and immunity to electromagnetic interference compared to coaxial copper cable. As an example, a 750-foot coaxial cable for an advanced 3-D radar system weighing about 7 tons and measuring 18 inches in diameter can be replaced by a 40-pound fiber-optic cable measuring less than 1 inch in diameter. More information on the present market for fiber-optic components and their applications were described in the study "U.S. Navy Market for Fiberoptic Components," available from Kessler Marketing Intelligence, 31 Bridge Street, Newport, RI 02840.[4]

PRICES

Throughout 1989 domestic producer prices for germanium metal and dioxide, published by *Metals Week*, remained at the levels established in late 1981 ($1,060 and $660 per kilogram, respectively). However, discounting by producers was evident during 1989 because of competition from imported material.

The Belgian producer price for germanium metal, published by *Metal Bulletin* (London), remained throughout the year at about $754 per kilogram.[5]

FOREIGN TRADE

A comparison of the value per kilogram of imported germanium material with the published foreign producer price for germanium metal was used to estimate the germanium content of imported materials. In 1989, the estimated germanium content of total imports was calculated to be approximately 33,000 kilograms.

TABLE 1

U.S. IMPORTS OF GERMANIUM,[1] BY CLASS AND COUNTRY

Class and country	1988		1989[2]	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap:				
Australia	100	$33,960	—	—
Belgium	6,419	4,105,962	15,985	$12,027,567
Canada	88	54,337	2,407	1,470,524
China	1,986	1,184,120	3,195	1,607,868
France	3,949	2,154,821	7,973	5,313,134
Germany, Federal Republic of	244	162,147	3,421	1,145,407
Hong Kong	—	—	16	6,480
Israel	—	—	55	35,221
Japan	—	—	8	3,034
Netherlands	140	78,501	849	281,574
Singapore	—	—	15	8,503
Switzerland	—	—	3,260	182,166
United Kingdom	2,765	1,597,641	2,921	1,707,877
Total	15,691	9,371,489	40,105	23,789,355
Wrought:				
Belgium	2,646	3,211,285	—	—
France	259	191,942	—	—
Germany, Federal Republic of	254	330,467	—	—
Israel	78	36,233	—	—
Netherlands	54	49,821	—	—
United Kingdom	309	347,583	—	—
Total	3,600	4,167,331	—	—

[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] Beginning in 1989, only data for unwrought and waste and scrap are available.

Source: Bureau of the Census.

WORLD REVIEW

World refinery production was estimated at 82,000 kilograms. Primary germanium was produced by Métallurgie Hoboken-Overpelt S.A. (MHO), Belgium; Johnson Matthey Electronics, Canada; Société Minière et Métallurgique de Peñarroya S.A., France; Preussag AG and Otavi Minon AG, Federal Republic of Germany; Società Mineraria e Metallurgica di Pertusola Sud S.A., 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 2 represent rated annual production capacity for refineries as of December 31, 1989. Rated capacity was defined as the maximum quantity that could 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 included both operating plants and plants temporarily closed that in the judgment of the author could be brought into production within a short period of time with minimum capital expenditure.

Refineries rated capacity of germanium was estimated based on discussions with some officials from private industry, past and present production rates, and published capacity data.

Brazil

Telebras, Brazil's state-owned telecommunications company, ordered 35,000 kilometers of optical fibers from Philips Optical Fiber, Eindhoven, the Netherlands. The optical fibers will

TABLE 2

WORLD ANNUAL GERMANIUM REFINERY PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand kilograms)

	Capacity
North America:	
Canada	10
United States	45
Total	55
Europe:	
Belgium	50
France and Italy	35
Germany, Federal Republic of	35
Centrally planned economy countries	40
Total	160
Asia:	
China	10
Japan	35
Total	45
World total	260

be used by several Brazilian companies to manufacture fiber-optic cables, in great demand by the communications industry.[6]

Canada

Canstar Communications, a division of Canada Wire & Cable Ltd. of Toronto, Canada, was awarded a contract by the New York City Transit Authority to supply and install a fiber-optic communications network. This network will interconnect 107 transit stations in the Bronx, Brooklyn, Manhattan, and Queens. The project, using 800 kilometers of fiber-optic cable, will be completed by 1992. Fiber-optic cable and accessories for this network will be manufactured in Canada and the United States.[7]

Japan

Germanium metal production was 3,346 kilograms, a decrease of about 20% compared with 1988 metal production levels. Dioxide production also decreased from 13,883 kilograms in 1988 to 13,302 kilograms in 1989.[8]

Poland

Installation of an underwater fiber-optic cable between Poland and Denmark was started by Nordiske Kabel & Traadfabiken A/S of Denmark. The cable will connect the Danish island of Bornholm in the Baltic Sea with the settlement of Mielno near Koszalin, Poland. The 150-kilometer network system was scheduled for completion by 1990 and was expected to greatly upgrade Poland's communication capacity with the United States and Canada through Denmark via the United Kingdom. Total project cost was estimated at $4.5 million and will be jointly financed by Poland and the telecommunications authorities of Denmark, Finland, Norway, and Sweden.[9]

OUTLOOK

Abundant supplies of germanium materials on the market through 1989 could not be absorbed by a rather stagnant demand. Producers were forced to lower prices to maintain their share of the market. Germanium supplies are likely to remain high for the next 2 years, owing to larger availability of concentrates from Canada and resumed mining operations by Hecla Mining Co. at their recently acquired gallium-germanium Apex Mine in Utah.

Domestic short-term demand for germanium metal probably will fall below the 1989 level. A reduced spending rate for strategic programs, as a consequence of recent events in Eastern Europe, could have a negative impact on germanium consumption for infrared systems for conventional weaponry.

BACKGROUND

Germanium was recovered as a minor byproduct of the refining of base metal ores, and the potential supply of this metal, which was 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. This decline was caused mainly by the increasing use of electronic-grade silicon, which was replacing germanium. However, the reduced demand for germanium in the electronics field was offset by a dramatic increase in demand for germanium in both infrared night vision systems and fiber-optic communication networks.

Definition, Grades, and Specifications

Germanium has a metallic appearance and is grayish white in color, lustrous, hard, and very brittle. It is a semiconductor, with electrical properties between those of a metal and an insulator.

The National Stockpile Purchase Specification P-114-R, December 16, 1989, for intrinsic germanium metal specifies an electrical resistivity of 50 ohm-centimeter at 20° C (40 ohm-centimeter at 25° C) over the entire ingot length.

Germanium is available commercially as a tetrachloride and high-purity oxide and in the form of zone-refined ingots, single-crystal bars, castings, doped semiconductors, optical materials, optical blanks, and other specialty products.

Industry Structure

Most germanium occurs as a minor constituent of certain base metal ores and coal deposits. Those producers that currently recover primary germanium for the most part depend on germanium-rich residues, mainly from zinc derived from past or present base metal smelting operations.

In the United States, Eagle-Picher'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 Inc. in Revere, PA, and Atomergic Chemetals Co., Plainview, NY, produced germanium from reprocessed scrap and semirefined foreign material.

The Jersey Minière Zinc Co. in Clarksville, TN, continued to produce germanium-rich residues as a byproduct of processing zinc ores from its Gordonsville and Elmwood Mines. These residues were shipped to MHO in Belgium for germanium recovery and refining.

Little information was available on

the financial structure of U.S. and world germanium industries. Germanium refiners usually were involved in the production and sale of many different metals and specialty products.

Geology-Resources

Minerals in which germanium is concentrated are germanite, a sulfoarsenite of copper, iron, and germanium with an average of 5% germanium; argyrodite, a double sulfide of germanium and silver containing 5% to 7% germanium; renierite, a complex sulfide of copper, iron, germanium, tin, zinc, and arsenic with 6% to 8% germanium; and several other minerals such as canfieldite, utrabasite, itoite, and stottite. 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.[10]

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 the burning of certain coals for power generation.

Technology

Germanium is obtained commercially as a byproduct of base metal refining and extracting. Improvements have been developed, 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. The 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 electronics and infrared optics. Zone refining produces polycrystalline germanium.[11]

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.

TABLE 3

U.S. IMPORT DUTIES FOR GERMANIUM MATERIALS

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1989	Non-MFN Jan. 1, 1989
Germanium: Waste and scrap	8112.30.3000	Free	Free
Germanium other: Unwrought	8112.30.6000	3.7% ad val.	25% ad val.
Germanium other: Other	8112.30.9000	5.5% ad val.	45% ad val.

Economic Factors

Table 3 shows import duties for germanium products, which became effective in 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 (Btu) per net ton of germanium ingot.

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[3] Laser Focus World. World News Breaks. V. 25, No. 4, Apr. 1989, p. 13.

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[6] Photonics Spectra. Brazil Orders Philips Fibers. V. 23, No. 9, Sept. 1989, p. 74.

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GOLD

By John M. Lucas

Mr. Lucas, a geologist with 29 years of Federal, State, and foreign and domestic mineral industry experience, has been the Bureau of Mines commodity specialist for gold since 1980. Domestic survey data were prepared by Eraina C. Dixon, Lisa P. Conley, and Stephen L. Hays, Nonferrous Data Section. International data tables were prepared by Giovanni P. Jacarepaqua, International Data Section.

Gold production by the domestic and international mining industry continued at record levels during 1989. With production rising more than 33% over that of 1988, the domestic industry completed its 10th successive year of growth. Nevada continued as the Nation's principal gold-producing State, having increased production nearly twentyfold since 1979. The overall demand for gold for use in fabricated products in the market economy countries exceeded the record level set in 1988. Jewelry was again the dominant end-use sector. Hoarding of gold bars, exclusive of North America and Europe, surpassed the record level reached during the previous year.

LEGISLATION AND GOVERNMENT PROGRAMS

On June 14, under legislation approved in 1988, gold and silver coins commemorating the Bicentennial of the U.S. Congress (1789–1989), were struck on four 7-ton coin presses mounted temporarily in front of the U.S. Capitol. The ceremony marked the first time since 1792 that official U.S. coins were struck outside of a U.S. Mint facility. The enabling legislation provided for surcharges from the sale of the coins to go to the U.S. Capitol Preservation Commission to maintain and restore the Capitol. Up to 2,239 kilograms (kg) (72,000 ounces[1]) of gold and 33,090 kilogram (1.064 million ounces) of silver will be used in minting the coins.

In 1989, legislation affecting gold was enacted by a number of States. Laws regulating the use of cyanide in gold and other mineral processing operations were enacted in Montana and South Dakota. A new Montana law requires that small placer or dredge mining operations that disturb 0.8 or more hectares (2 or more acres) must comply with the State's general mine reclamation requirements. In a special election held in May, Nevadans approved a tax on gold mining. The measure amended the State constitution and increased the net profits tax on all mineral production from about 2% to 5%. In June, the Governor of Nevada signed into law that State's first program for reclamation of mined lands. The law requires that all public and private lands disturbed by mining or exploration activities be reclaimed in an economically and technically practical manner to a safe, stable condition capable of supporting a productive postmining land use.

A law exempting the sale of precious metal bars and bullion coins from a 4% State sales tax became effective in New York on September 1. To be eligible for the exemption, the sale must be for $1,000 or more, with the price being based on the item's metal content, not its aesthetic value. Coins produced by the Republic of South Africa, with coins and bars produced for noninvestment purposes, were not eligible for the exemption. Texas and Ohio passed similar legislation during 1989.

In June, the U.S. Forest Service announced that, effective May 1, 1990, it will require certification of its examiners who investigate and evaluate unpatented mining claims located on National Forest System lands. Under the certification program, mineral examiners will have to be mining engineers or geologists and have had training in mineral examination, experience in mining claim validity examinations, surface use determinations, or mining law-related actions. The new certification process pertains only to Forest Service employees. Private mining consultants wishing to perform mineral examinations on the National Forest lands will have to meet the same qualifications as a Certified Forest Service Mineral Examiner before being awarded a contract to work on National Forest System land.

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 1989. Large quantities of gold are 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.

PRODUCTION

Of the 266 metric tons of gold (8.5 million ounces) produced in the Nation, 75% was attributed to the 25 leading producers. The average recoverable gold content of precious metals ores processed from lode mines was 1.37 grams per metric tons (0.04 ounce per short ton), while placer gravels yielded an average of 1.23 grams per cubic meter (0.03 ounce per cubic yard) of material washed.

The individual company production and performance data in this chapter

TABLE 1

SALIENT GOLD STATISTICS

		1985	1986	1987	1988	1989
United States:						
Mine production	kilograms	75,495	116,297	153,870	200,914	265,541
Value	thousands	r$771,035	r$1,376,860	$2,216,026	$2,831,281	$3,266,208
Percentage derived from:						
Precious metal ores		92	96	91	W	W
Base-metal ores		5	2	6	W	W
Placers		3	2	3	2	2
Refinery production:						
Domestic and foreign ores	kilograms	64,583	75,618	112,368	137,829	183,685
Secondary (old scrap)	do.	49,824	47,266	63,843	52,807	36,895
Exports:						
Refined	do	89,837	110,555	71,177	271,335	123,599
Other	do.	33,541	44,810	48,453	56,902	87,492
Imports for consumption:						
Refined	do.	197,849	429,242	75,365	57,590	96,967
Other	do.	58,008	60,621	44,174	r34,867	55,537
Gold contained in imported coins[1]	do.	64,198	34,245	33,716	[2]17,947	[2]13,218
Net deliveries from foreign stocks in Federal Reserve Bank	do.	15,054	145,938	95,146	208,277	132,231
Stocks, Dec. 31:						
Industry[3]	do.	18,538	28,771	23,390	r38,360	24,828
Futures exchange[4]	do.	65,628	87,370	81,647	44,634	69,727
Volume of U.S. Gold Futures Trading[5]	metric tons	24,723	26,365	33,100	29,920	31,330
Department of the Treasury:						
American Eagle gold coin sales	kilograms	—	(6)	[7]82,704	[7]17,416	[7]16,544
Bicentennial of the U.S. Congress[8]		—	—	—	—	1,508
Bicentennial of the U.S. Constitution coin sales	do.	—	—	(9)	[10]6,463	—
U.S. 1988 Olympic coin sales[11]	do.	—	—	—	2,477	93
Consumption in industry and the arts	do.	96,318	97,234	100,566	r97,842	98,742
Price:[12] Average per troy ounce		$317.66	$368.24	$447.95	$438.31	$382.58
Employment[13]		6,900	8,300	11,100	13,100	15,000
World:						
Production, mine	kilograms	1,531,858	1,602,215	1,658,142	p1,847,840	e1,971,004
Official reserves[14]	metric tons	35,616	35,625	r35,563	35,763	35,538

e Estimated. p Preliminary. r Revised. 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.

including the references cited at the end of this report were derived from published sources such as company annual reports.

Alaska

Gold was the most valuable mineral product, accounting for 39% of total mineral production revenues. According to a Summary of 1989 Mineral Activity prepared by the Alaska State Div. of Geological and Geophysical Surveys (DCGS), gold production was reported from 222 operations; 217 placer mines and 5 lode mines.[2] The total number of operations in 1988 according to DCGS was 211. Gold production in Alaska of 5,756 kg (185,055 ounces) was reported to the Bureau of Mines by 17 operations. However, an informal annual survey by the DGGS suggested that 8,852 kg (284,616 ounces) was produced.

Alaska's largest gold producer in 1989, the Valdez Creek Mining Co.'s placer operation east of Cantwell, produced 2,237 kg (71,942 ounces) of raw unparted gold during the 1989 operating season. The Alaska Gold Co. operated its two onshore gold dredges at Nome while offshore of Nome Western Gold Exploration and Mining Co. Ltd. Partnership (WestGold) recovered about 899 kg (29,000 ounces) of gold with its mining vessel, the *BIMA*.

Five lode mines reporting production during the year were: the new Greens Creek Mine near Juneau, the State's second largest gold producer, the Ryan Lode Mine, the Grant Mine, and the Democrat Mine, all located near Fairbanks, and the old Independence Mine near Hatcher Pass.

Following a trend established in recent years, funds expended by corporations exploring for precious metals accounted for nearly 92% of the $46 million spent in 1989. Of funds expended, 59% was on three advanced gold exploration projects: the Fort Knox Mine project of Fairbanks Gold Ltd. near Fairbanks and Echo Bay Mines Ltd.'s two advanced projects—the rejuvenation of the old A-J Mine at Juneau and the Kensington Mine project at Berners Bay, 80 km (50 miles) north of Juneau.

The relaxation of tensions between the U.S.S.R. and the United States resulted in an exchange during 1989 of visits by scientific personnel from both countries. Gold Mines in the Magadan Oblast region of neighboring Siberia were visited by personnel from the Bureau of Mines and by representives from Alaskan State, educational, and industrial organizations.[3]

A brochure on Placer Mining in Alaska prepared by the U.S. Bureau of Land Management was published in 1989. The brochure provided an overview of placer mining methods used on public lands in Alaska and offered suggestions for avoiding or reducing the environmental effects of placer mining and for reclamation of placer mining sites.[4]

TABLE 2

MINE PRODUCTION OF GOLD IN THE UNITED STATES, BY STATE

(Kilograms)

State	1985	1986	1987	1988	1989
Alaska[1]	1,391	1,501	3,812	4,210	5,756
Arizona	1,619	W	1,791	4,549	2,810
California	5,842	13,238	18,277	22,442	29,804
Colorado	1,347	3,743	5,561	5,126	3,448
Idaho	1,378	2,191	3,041	3,218	3,057
Michigan	W	W	W	W	W
Montana	4,985	W	7,143	9,175	11,623
Nevada	39,692	r65,330	83,342	114,322	154,573
New Mexico	1,401	1,240	W	W	1,076
North Carolina	—	(2)	—	—	—
Oregon	W	W	W	W	W
South Carolina	W	W	W	W	W
South Dakota	11,076	W	W	13,981	16,123
Utah	4,214	W	W	W	W
Washington	W	W	W	W	W
Total	75,495	116,297	153,870	200,914	265,541

r Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1] These figures, reported to the Bureau of Mines, probably understate production. Data collected by the State indicate production to have been as follows, in kilograms: 1985—5,910; 1986—4,977; 1987—7,154; 1988—8,258; and 1989— 8,852.

[2] Less than 1/2 unit.

Arizona

At Arizona's largest gold mine, Cyprus Gold Co.'s Copperstone Mine near Quartzite in LaPaz County, underground development was suspended because lower ore grades were encountered. However, the company continued the open pit operation. Copperstone had a productive capacity of nearly 2,200 kg (70,000 ounces) per year.

Several mines produced gold-bearing flux ore that was shipped directly as a flux to copper smelters where the gold values were ultimately recovered as a byproduct of copper refining.

After less than 1 year of operation, mining at the McCabe Mine in Yavapai County was halted in early 1989. The owner, Stan West Mining Corp., later transferred ownership of the facility to Elders Resource Finance Inc. of Australia.

Exploration for gold continued to be widespread throughout Arizona. Exploration accompanied by drilling was conducted at a number of properties, including the following: the Yarnell Mine in Yavapai County by joint-venture partners ASARCO Incorporated and Norgold Resources Inc. and the Mexican Hat property in Cochise County by venture partners Placer Dome U.S. Inc. and Oneida Resources Inc. Other sites included DRX Inc.'s Commonwealth property and Queenstake Resources Ltd.'s Gold Prince Mine, both in Cochise County; and East West Minerals Inc. at the Clementine Mine, U.S. Borax and Chemical Corp. at the Picacho project, and Westmont Mining Inc. and Aur Resources Inc. at the Newsboy deposit, all in Maricopa County.

California

For the third consecutive year, California has ranked as the Nation's second largest gold-producing State. Three California gold mines, McLaughlin, Mesquite, and Jamestown, were among the top 25 gold producers during 1989.

The McLaughlin Mine of Homestake

Mining Co., located about 113 km (70 miles) north of San Francisco, produced a record 8,823 kg (283,843 ounces) of gold during 1989. A new oxide ore processing circuit commissioned in early 1989 and new cost control measures initiated during the year combined to improve productivity and led to an increase in production of 2,489 kg (80,016 ounces) over that of 1988. California's second largest gold mine, the Mesquite Mine owned by Gold Fields Mining Corp., recovers about 5,750 kg (185,000 ounces) annually using heap leaching. Gold ore, mined from several surface deposits at the Imperial County site, was processed and stacked on the heaps at a rate of about 18,000 metric tons per day.

Improved gold recovery and higher throughput of ore contributed to an increase in gold production to 3,461 kg (111,300 ounces) in 1989 at the Jamestown Mine in Tuolumne County. The large surface mine opened in late 1986 by Sonora Gold Corp. employed flotation methods to produce a gold concentrate. The concentrate was processed for gold recovery at the Buckskin leach plant at Yerington, NV.

Several new mines began production in 1989, and several others were closed. The new Royal Mountain King Mine near Copperopolis, Calaveras County, began open pit mining and milling in February. This new mine, owned by Meridian Gold Co. and Mother Lode Gold Mines Consol., was expected to recover about 1,866 kg (60,000 ounces) of gold annually. In September, the American Girl Mining Corp. poured the first gold at its new open pit heap leaching American Girl Canyon Mine in Imperial County. The Carson Hill Mine at Angels Camp, Calaveras County, closed in October. Leaching of previously mined ore and site reclamation were proceeding at yearend. The Sixteen-To-One Mine in Sierra County was placed on a care-and-maintenance status late in the year.

In September, Bond International Gold Inc. sold its 67% interest in the Yuba dredge placer operation near Marysville, Yuba County, to WestGold. Yuba dredge reportedly recovered 732 kg (23,540 ounces) gold during the fiscal year ending June 30, 1989.

While a dozen or more other mines continued to produce gold in California, other properties undergoing exploration or moving toward production included the following: Viceroy Resources Corp.'s Castle Mountain property in San Bernardino County, Amax Gold's Hayden Hill property in Lassen County, Centurion Gold Ltd.'s Grey Eagle Mine and American Gold Mineral Inc.'s Siskon Mine in Siskiyou County, and the Long Valley prospect of Royal Gold Inc. and Standard Industrial Minerals Inc. in Mono County.

Colorado

A nearly 33% decline in gold production from the previous year reflected to some extent the closure of two mines and the failure of several new mines to reach production.

The principal producing gold mines were the Summitville Mine in Rio Grande County, the Sunnyside Mine at Silverton, and the combined operations of the Cripple Creek and Victor Mining Co. in Teller County. Several other smaller producers such as the Bessie G Mine in La Plata County were also active during the year.

Mining at Galactic Resources' seasonal Summitville Mine was halted in mid-June following the discovery of an unstable area in the embankment of the leach pad. About 170 employees were laid off and studies to remedy the leach pad problem were initiated. Leaching of previously mined ore continued, and nearly 1,000 kg (32,000 ounces) of gold was recovered. More than twice that amount was recovered during the previous year.

Underground mining operations at the Sunnyside Mine in San Juan County were continued by the mine's operator and owner of a 33% share, Washington Mining Co. Gold production during the year declined about 5% from that of the previous year to about 921 kg (29,612 ounces).

In Teller County, Cripple Creek and Victor Gold Mining Co. recovered nearly 1,100 kg (34,507 ounces) of gold from its Mine Dump Rock and Gold Star Projects and its Portland open pit. Mining of the Portland pit was completed and reclamation of the affected area was being planned at yearend. The company reportedly had several new local exploration projects under study.

Battle Mountain Gold Co. decided in early 1989 to modify its mining plan at its developing San Luis project in Costilla County and thereby limit gold recovery to milling only rather than milling and heap leaching combined. The decision necessitated the amendment of the company's mining permit and was expected to delay the targeted startup until early 1991. The San Luis project was expected to yield about 1,870 kg (60,000 ounces) of gold per year for at least 8 years.

The Empire (Grace) Mine project that was expected to produce in 1989 was further delayed while the owner, Nevada Goldfields Corp., negotiated a joint venture for further exploration and development. The proposed open pit heap-leaching project is located in Clear Creek County about 64 km (40 miles) west of Denver.

Exploration and development was continued at a number of other Colorado gold properties, including the Platoro gold-silver mine in Conejos County, Levon Resources Ltd.'s Carbonate Hill property in Teller County, and Hendricks Mining Co.'s Cross Mine, an underground mine at Caribou in Boulder County.

Idaho

The number of active exploration projects in Idaho, dominated by interest in precious metals, increased from 68 in 1988 to 82 in 1989 according to a review of State mineral activities prepared by the Idaho Geological Survey.[5] The State defined an active project as one that had some significant work such as sampling and trenching or drilling, not just claim staking.

Despite the heightened level of exploration that may eventually lead to increased production, total Idaho gold production during 1989 remained near the level achieved during the previous year. Producing gold mines in Idaho during 1989 included Nerco Minerals Co.'s DeLamar Mine in Owyhee County, Pioneer Metals Corp.'s Stibnite-West End and Coeur d'Alene Mines Corp.'s Thunder Mountain Mine, both in Valley County, and Idaho Gold Corp.'s newly opened Champagne Mine in Idaho County. All of these properties were open pit heap-leaching operations, except that DeLamar also employed a vat-leaching recovery system.

Nerco announced that it had begun development of its Stone Cabin deposit, formerly referred to as Florida Mountain. Stone Cabin is adjacent to the DeLamar Mine. The property, reportedly containing more than over 18,000 kg (580,700 ounces) of recoverable gold, was to be developed as a satellite opera-

tion of the DeLamar Mine with mining projected to begin by early 1992. Nerco also signed an agreement with War Eagle Mining Co. Inc. to explore War Eagle's claims on War Eagle Mountain about 6.4 kilometers (4 miles) east of Nerco's DeLamar property.

Hecla Mining Co.'s Yellow Pine unit in Valley County did not operate during the 1989 season. Instead, a new $4.5 million heap-leach facility was constructed. Startup of the new plant was scheduled for the second quarter of 1990 with an anticipated seasonal output of about 1,900 kg (60,000 ounces). U.S. Antimony (USAC) continued to process ore from its various mining operations at its mill at Preacher's Cove in Lemhi County. The company signed joint-venture agreements with WestGold to further explore USAC's Yellow Jacket Mine and Estes Mountain property, both in Custer County.

Grouse Creek Mining Co., a subsidiary of CoCa Mines Inc. of Denver, moved ahead with development of its Grouse Creek deposit and newly acquired Sunbeam property on nearby Jordan Creek in Custer County. A new milling process was devised that would work with both deposits as well as address concerns of environmentalists. A conventional milling technique with zero discharge was selected and should be operational by 1992.

Interest in the potential for further gold discoveries in the Salmon area in Lemhi County, Southwestern Idaho, were heightened by the 1988 discovery by Meridian Minerals Co. of their large Beartrack deposit. Among the companies reported by the State to be exploring in the Salmon area during the year were AMAX, American Gold Resources Corp., Corona Gold Inc., FMC Gold Corp., GEXA Gold Corp., Hecla, Homestake, Placer Dome, Sovereign Explorations Inc., and many others.

Michigan

In early October, Callahan Mining Corp. of Phoenix, AZ, announced that its Ropes gold mine, near Ishpeming, MI, the Nation's only underground gold mine east of the Mississippi, had been shut down indefinitely owing to the low price of gold and ground control problems near the main production shaft. Nearly 550,000 metric tons of ore bearing 2.33 grams per metric ton (0.069 ounce per short ton) was hoisted and milled during the 9-month period prior to closure.

Montana

Mining and mineral developments in Montana during the year were summarized in a report prepared by the Montana Bureau of Mines and Geology.[6] The number of mining plans, most of which included gold, filed with the U.S. Forest Service increased from 246 plans in 1988 to nearly 400 in 1989. Similarly, mineral exploration, again focused primarily on gold, continued to expand. The State reported that 35 new State exploration permits were issued during the year, bringing the total to 210 compared with 192 in 1988 and only 56 in 1982. All mining activity in Montana, whether on private, State, or Federal land, is regulated by the Montana Department of State Lands. Exploration, including drilling, sampling and mapping, was continued at many properties throughout the mineralized areas of the State, and some properties were moved a step closer toward development and production.

Gold production from Montana's active mines increased 27% over the previous year, reflecting in part, improved performance at some operations plus the contribution of newly opened mines, including the Beal Mountain Mine and the Mineral Hill Mine.

The new Mineral Hill Mine at Jardine in south-central Park County opened in September. Mineral Hill, an underground operation and joint venture of American Copper and Nickel Co. and Homestake, was initially expected to produce about 1,300 kg (42,000 ounces) annually.

In June, Pegasus Gold opened its new open pit Beal Mountain Mine at German Gulch Southwest of Butte, Silver Bow County. The new heap-leaching operation was designed to produce nearly 1,100 kg (35,000 ounces) per year over a mine life conservatively estimated at 10 years. Pegasus also operates three other large gold mines in Montana: the Zortman/Landusky Mine in Phillips County; the Montana Tunnels gold, silver, lead, and zinc mine in Jefferson County; and the Basin Creek Mine, formerly known as the Pauper's Dream Mine, in Lewis and Clark County. Other principal gold-producing mines in the State include Placer Dome's Golden Sunlight mine in Jefferson County near Whitehall, the Kendall Mine of Canyon Resources Corp. near Lewistown, and Blue Range Mining Co.'s Geis Mine, both in Fergus County. Operations at another Fergus County mine, the Spotted Horse, were suspended during the year, reportedly for economic reasons.

Numerous, generally small, intermittent placer operations were active along favorable drainages in Western Montana. In September, Highland Gold Properties Inc., working their placer claims in Cooley Gulch on the Fish Creek drainage in Silver Bow County, recovered an 855 gram (27.495 ounce) nugget; reportedly the largest gold nugget found in Montana during this century.

Nevada

Nevada's percentage contribution to the Nation's total gold production increased yet again over that of the previous year. Fifteen of the Nation's leading 25 gold mines during 1989 were located in Nevada.

Newmont Gold Co. (NGC), with operations generally centered in Eureka and Elko counties near the town of Carlin, was once again the largest gold producer in Nevada as well as in the Nation and in North America. As the largest producer, NGC also controlled the Nation's largest block of gold ore reserves; exploration by the company increased reserve by 27% during 1989 to a total of 640 metric tons (20.7 million ounces) contained in 10 deposits located along a northwest-trending geological structure frequently referred to as the Carlin trend. During the year, NGC produced a record 45,648 kg (1.47 million ounces) of gold from ore mined at six open pits in Eureka and Elko Counties. Newmont also operated five separate mills and four leaching facilities in the same counties. The company's Gold Quarry Mine in Eureka County produced almost as much gold during 1989 as the entire Nation produced in 1980. According to the company, total production costs, including deprecation depletion and amortization, were $273 an ounce in 1989 compared with $266 an ounce the previous year. Pursuant to a decision announced the previous year, NGC moved its corporate headquarters from New York to Denver, CO, in 1989.

American Barrick Resources Corp. planned to develop its Betze deposit sulfide reserve and its Post deposit oxide reserves at the company's Goldstrike Mine. Goldstrike, adjacent to NGC's operations on the Carlin trend in north-

ern Eureka County, was one of the leading gold-producing mines in 1989. During 1989, Goldstrike yielded more than 6,446 kg (207,264 ounces), well above its production target of 5,598 kg (180,000 ounces). In June, Goldstrike received the first of six 1,500-ton-per-day autoclaves to be installed to convert the mine's gold-bearing sulfide ores to oxides for subsequent cyanide treatment and gold recovery. Construction and commissioning of the new autoclave was completed near yearend. Exploration by Barrick in the Goldstrike area encountered three new areas of gold mineralization.

Nevada's second largest gold mine and the fourth largest in the Nation, the Jerritt Canyon Mine of Freeport McMoRan and FMC in Elko County, reported gold production of 9,234 kg (296,900 ounces) during 1989 at a production cost of $166 per ounce. Freeport also holds a majority interest in the nearby Big Springs Mine where 1,882 kg (60,500 ounces) was produced. During the year expansion programs begun the previous year at both mines were completed. New and proprietary ore-roasting facilities became operational in June at Big Springs and in September at Jerritt Canyon. The roasting facilities increased the mines' ore reserve base and production capacities by allowing the milling of previously unacceptable ore.

In Lander County, expansion work on Echo Bay's McCoy-Cove gold and silver mine moved ahead with completion of a new mill in July and the driving of two access ramps, one to 183 meters (600 feet) below the surface at the Cove deposit and another 274 meters (900 feet) below McCoy. Underground mining at Cove began in December. Gold production from both surface and underground workings at McCoy-Cove more than doubled during 1989 to 6,673 kg (214,566 ounces). Underground problems related to poor ground conditions and substantial waterflows at Cove forced the company to modify its planned underground mining rate. A problem related to contaminated samples derived by reverse-circulation drilling below the water table resulted in a substantial negative revision of Cove's ore reserves.

At the nearby Lander County operations of Battle Mountain Gold Co., more than 7,800 kg (251,000 ounces) of gold was recovered during the year from the company's Canyon Placer Mine and two open pit lode mines, the Fortitude and the Surprise.

The world's largest heap-leach gold mine, the Round Mountain Mine in Nye County, completed a 2 year expansion program in 1989 that effectively doubled its tonnage capacity. Published company data reported gold production during the year at 9,909 kg (318,616 ounces). In January, the mine's owners, Homestake, Echo Bay, and Case Pomeroy & Co., merged Echo Bay's nearby properties, including the Manhattan mill, into the Round Mountain operations, thereby enabling the mine to achieve better recovery rates on its high-grade ore than could otherwise be achieved by heap leaching.

Just west of the town of Beatty in Southern Nye County, Bond Gold Bullfrog Inc. poured its first gold in July at the newly commissioned Bullfrog Mine and mill. Bullfrog was expected to produce more than 6,344 kg (204,000 ounces) in its first full-year of production. Several kilometers to the east the U.S. Nevada Gold Search Joint Venture began production near yearend at its new open pit, heap-leaching Mother Lode Mine.

The mines previously mentioned were only a small portion of the scores of gold properties in Nevada that were in operation during 1989, undergoing design, construction or permitting, expanding production capacity, or in various stages of exploration from claim staking to reserve evaluation.

Oregon

A State-prepared review of mining in Oregon during 1989 listed 10 active gold mines; 2 seasonal lode mines, the Pyx and the Lower Grandview; and 8 placer mines.[7] Of the 34 active exploration sites and areas in Oregon during the year, only 4 sought commodities additional to gold.

Oregon's total gold production for the year was attributable mostly to the Bonanza Mining Co.'s 46 cubic meter per day (60 cubic yd per day) placer operation on Pine Creek in Baker County. The State reference noted that although stripping and mining progressed in one area of the pit, backfilling and site reclamation was proceeding in another part.

The rush precipitated by the 1988 discovery of the large Grassy Mountain deposit in Malheur County by Atlas Precious Metals Co. accelerated during 1989. Near yearend, close to 8,000 new claims had been located mostly in northern Malheur County, thus bringing the county total to more than 21,000. Exploration drilling was done on at least 16 properties. In the meantime, at Grassy Mountain, Atlas continued drilling while preparing feasibility studies and collecting supporting environmental and water-quality data. An operating plan calling for the development of two open pits and a heap-leach recovery system was submitted to the U.S. Bureau of Land Management in November.

Also in northern Malheur County, Chevron Resources Co. continued exploration of three different areas, including their Hope Butte and Quartz Mountain properties.

In Lake County, south-central Oregon, Quartz Mountain Gold Corp. formed a joint venture with Pegasus Gold to further explore and develop a mine plan for two large gold deposits discovered in 1986.

South Carolina

Near the town of Ridgeway in Fairfield County, the Ridgeway Mine of Ridgeway Mining Co. completed its first full-year of operation. The first year's performance at the new mine, a joint venture between Galactic Resources Ltd. and the RTZ Corp. PLC, was consistently in excess of expectations, producing 5,365 kg (172,505 ounces) of gold compared with a budgeted production of 4,978 kg (160,064 ounces). According to Galactic Resources, the average production cost during 1989 amounted to $140 per ounce, significantly lower than the $167 per ounce expected earlier. The lower cost reportedly reflected high mill throughput, enhanced recoveries, and low reagent consumption.

Despite lower gold prices and production delays attributed to bad weather, Piedmont Mining Co.'s Haile Mine near Kershaw in Lancaster County produced an increased amount of gold compared with the previous year. Gold production at the open pit, heap-leaching operation was 481 kg (15,458 ounces) in 1989 compared with 365 kg (11,738 ounces) in 1988. Surface mining and heap leaching was continued at the Brewer Mine just west of Jefferson in Chesterfield County. The mine, opened in 1987, is owned by Westmont Mining Inc.

In McCormick County, Gwalia (U.S.A.) Ltd., a wholly owned subsidiary of Gwalia International Ltd. of

Perth, Western Australia, conducted exploration and drilling aimed at reopening the old gold mines around the town of McCormick. The old mines, including the old Dorn Mine, produced gold between the 1850's and 1930's. Gwalia's operation was referred to as the Barite Hill Project.

South Dakota

Gold was produced by five primary gold mines, including the Homestake Mine, the Nation's third largest. All five mines were located in Lawrence County.

The 114-year-old Homestake Mine's production in 1989 was 11,874 kg (381,788 ounces), down slightly from the 1988 record level of 12,134 kg (390,162 ounces). Homestake operated both surface and underground mines at the town of Lead. The surface operation, referred to as the Open Cut, was begun in 1985, on the site of the original 1876 gold strike. During the year Homestake processed about 2.3 million metric tons of ore from both the surface and underground operations. The grade of underground ore declined about 4% to 6.17 grams per metric ton (0.180 ounce per short ton) and, this, combined with slightly higher labor costs, caused production costs to increase slightly to $301 per ounce. During the year Homestake completed construction of a new plant to process tailings dam water for an expected annual recovery of an additional 218 kg (7,000 ounces) of gold. Exploration, mostly below the 2,073 meter (6,800 foot) level, added about 28,000 kg (0.8 million ounces) of gold to the mine's reserves.

Bond Gold-Richmond Hill Inc. began production in early 1989 at its Richmond Hill Mine located 8 km (5 miles) northwest of Lead. The new open pit, heap-leaching mine was expected to produce about 1,244 kg (40,000 ounces) of gold annually. Wharf Resources (USA) Inc. continued production at its Annie Creek open pit, heap-leaching operation near Terry Peak. A new treatment plant completed in late 1988 was expected to increase Wharf's 1989 production by about 30% over the previous year's level of 1,850 kg (59,500 ounces). Golden Reward Mining Co. began production at its new open pit and heap-leaching Golden Reward Mine in November. The first gold bar was poured in mid-December.

MinVen Gold Corp. completed its first full year at its Gilt Edge Mine located 6.4 km (4 miles) south of Lead. In early 1989, the company submitted a plan to the U.S. Forest Service that, if approved, could quadruple the size of the new open pit, heap-leaching facility. The expansion was aimed at utilizing the mine's sulfide ore deposits adjacent to, and deeper than, the oxide ore presently being mined.

An environmental group based in Rapid City filed a petition in November to place an acreage limit on Black Hills surface mining. The group wants an initiative on the November 1990 general election ballot that would limit to 1,255 hectares (3,100 acres) the amount of land that could be mined at any one time by large-scale precious metals mining companies in the Black Hills.

Utah

The year witnessed the first full-year of copper and byproduct gold production at the giant Bingham Canyon Mine near Salt Lake City since completion of a $400 million modernization program begun several years earlier. Bingham Canyon, owned by RTZ and operated by the Kennecott Corp., was the Nation's second largest producer in 1989 of both copper and byproduct gold. The mine was the State's largest producer of both gold and silver. In the fall of the year, Kennecott began

TABLE 3

TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES IN 1989, 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	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Corp.	Copper ore.
3	Homestake	Lawrence, SD	Homestake Mining Co.	Gold ore.
4	Jerritt Canyon (Enfield Bell)	Elko, NV	Freeport-McMoRan Gold Co.	Do.
5	Smoky Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Do.
6	Mesquite	Imperial, CA	Goldfields Mining Co.	Do.
7	McLaughlin	Napa, CA	Homestake Mining Co.	Do.
8	Sleeper	Humboldt, NV	Amax Gold Inc.	Do.
9	Fortitude and Surprise	Lander, NV	Battle Mountain Gold Co.	Do.
10	Chimney Creek	Humboldt, NV	Gold Fields Mining Co.	Do.
11	Ridgeway	Fairfield, SC	Ridgeway Mining Co.	Do.
12	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Do.
13	Paradise Peak	Nye, NV	FMC Gold Co.	Do.
14	Goldstrike	Eureka, NV	Barrick Goldstrike Mines Inc.	Do.
15	Cannon	Chelan, WA	Asamera Minerals (U.S.) Inc.	Do.
16	Getchell	Humboldt, NV	FMG Inc.	Do.
17	Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.	Do.
18	Golden Sunlight	Jefferson, MT	Golden Sunlight Mines Inc.	Do.
19	Jamestown	Tuolumne, CA	Sonora Mining Corp.	Do.
20	Zortman-Landusky	Phillips, MT	Pegasus Gold Inc.	Do.
21	Borealis	Mineral, NV	Echo Bay Mining Co.	Do.
22	Crofoot and Lewis	Humboldt, NV	Hycroft Resources & Development Inc.	Do.
23	Florida Canyon	Pershing, NV	Florida Canyon Mining Inc.	Do.
24	Rochester	do.	Coeur Rochester Inc.	Do.
25	Robinson Project	White Pine, NV	Alta Gold Co.	Do.

TABLE 4

GOLD PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (kilograms of gold)	Lode					
		Gold ore		Gold-silver ore		Silver ore	
		Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1985	2,280	32,576,032	67,523	946,969	1,300	3,480,080	973
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	r181,191	W	W	9,573,505	2,075
1989:							
Alaska	W	W	W	—	—	—	—
Arizona	W	744,746	1,380	—	—	—	—
California	W	W	W	—	—	—	—
Colorado	22	W	W	—	—	—	—
Idaho	W	W	W	W	W	W	W
Michigan	—	W	W	—	—	—	—
Montana	(1)	14,857,997	9,720	—	—	W	W
Nevada	W	112,136,682	153,506	32,173	249	W	W
New Mexico	—	W	W	—	—	—	—
Oregon	W	23	(1)	—	—	—	—
South Carolina	—	W	W	—	—	—	—
South Dakota	—	6,183,359	16,048	—	—	—	—
Utah	—	4,440,675	5,129	W	W	292,175	21
Washington	—	W	W	—	—	—	—
Total	5,711	170,287,482	237,032	W	W	4,450,703	505
Percent of total gold	2	XX	89	XX	W	XX	(2)

	Lode				Total	
	Copper ore		Other[2]			
	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold[3]
1985	135,592,281	2,321	4,061,181	1,098	176,656,541	75,495
1986	105,936,857	1,643	303,845	582	167,098,800	116,297
1987	165,407,018	8,074	W	W	258,668,990	153,870
1988	r201,893,222	11,314	W	W	r340,614,832	200,914
1989:						
Alaska	—	—	W	W	451,462	5,756
Arizona	141,807,608	1,398	W	W	142,635,932	2,810
California	—	—	W	W	20,061,024	29,804
Colorado	—	—	W	W	1,554,215	3,448
Idaho	2,434,125	11	W	W	3,975,754	3,057
Michigan	—	—	—	—	W	W
Montana	W	W	W	W	20,999,774	11,623
Nevada	W	W	W	W	115,829,846	154,573
New Mexico	W	W	—	—	29,418,752	1,076
Oregon	—	—	—	—	W	W
South Carolina	—	—	—	—	W	W
South Dakota	—	—	92	75	6,183,451	16,123
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	W
Total	210,474,747	17,662	W	W	389,237,866	265,541
Percent of total gold	XX	7	XX	W	XX	100

r Revised. 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.
[3] Includes lode and placer production.

TABLE 5

LODE GOLD PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore		Total ore processed[1] (metric tons)	Total gold recovered (kilograms)
	Ore treated (metric tons)	Gold recovered (kilograms)	Ore treated (metric tons)	Gold recovered (kilograms)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Gold recovered (kilograms)	Ore smelted (metric tons	Gold recovered (kilograms)		
1985	18,880	116	35,926,506	64,970	140,510,381	2,921,563	7,207	200,774	[2]1,063	176,656,541	[2]73,356
1986	771,321	1,048	58,664,524	104,422	107,528,173	2,575,228	[2]8,171	134,782	[2]201	167,098,800	[2]113,842
1987	W	W	88,876,729	129,812	[r]169,472,280	3,430,726	17,548	W	W	[r]258,668,990	[2]148,788
1988	W	W	[r]133,047,109	173,493	[r]207,228,838	3,969,256	21,057	W	W	[r]340,614,832	[2]196,161
1989:											
Alaska	—	—	W	W	W	W	W	—	—	451,462	[2]5,756
Arizona	—	—	W	W	W	W	W	W	W	142,635,932	[2]2,810
California	W	W	17,878,351	25,355	W	W	W	—	—	20,061,024	W
Colorado	112,036	510	W	W	W	W	W	W	W	1,554,215	3,425
Idaho	—	—	3,071,381	W	904,373	42,467	W	—	—	3,975,754	W
Michigan	—	—	W	W	—	—	—	—	—	W	W
Montana	—	—	14,888,203	9,527	W	W	W	W	W	20,999,774	11,623
Nevada	—	—	115,524,724	152,742	W	W	W	W	W	115,829,846	W
New Mexico	—	—	—	—	W	W	W	W	W	29,418,752	1,076
Oregon	—	—	23	[3]	—	—	—	—	—	23	[3]
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	6,183,359	16,048	—	—	—	92	75	6,183,451	16,123
Utah	—	—	4,732,850	5,150	W	W	W	W	W	W	W
Washington	—	—	W	W	W	W	W	—	—	W	W
Total	W	W	170,473,179	227,229	218,468,731	4,193,848	30,325	W	W	389,237,866	263,977

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[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.
[3] Less than 1/2 unit.

gold production at its new Barney's Canyon Mine located 6.4 km (4 miles) north of Bingham Canyon. The new open pit and heap-leaching mine was designed to produce approximately 2,500 kg (80,000 ounces) of gold per year.

Utah's second largest gold mine and the State's largest producer of primary gold, Barrick's Mercur Mine in Toole County, continued to operate at full capacity, producing 3,656 kg (117,536 ounces) of gold during 1989. A new autoclave unit for processing sulfide ore completed its first full-year of operation. Throughput exceeded design capacity of 680 metric tons per day, and the unit reportedly achieved an average recovery rate of 81.4% for the year. Barrick reported that a major increase in gold production resulted from improvements at the mine's dump-leaching facilities and that a third such facility was under construction at yearend.

Tenneco Minerals Inc., officially began operations in May at its new Goldstrike Mine near St. George in Washington County. The new open pit and heap-leaching operation has the capacity to produce 1,244 kg (40,000 ounces) each of gold and silver per year.

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[3]	
	Ore treated (metric tons)	Gold recovered[4] (kilograms)	Ore treated (metric tons)	Gold recovered (kilograms)
1985	18,636,045	48,392	17,290,462	16,578
1986	24,590,938	73,362	34,073,586	31,060
1987	29,408,635	74,807	59,468,094	55,005
1988	[r]30,784,205	100,817	102,262,904	72,676
1989	40,642,933	121,716	129,830,246	105,513

[r] Revised.
[1] May include small quantities recovered by leaching with thiourea, by bioextraction and by proprietary processes.
[2] Including autoclaves.
[3] May include tailings and waste ore dumps.
[4] May include small quantities recovered by gravity methods.

Washington

According to a review of Washington State's Mineral Industry prepared by the State, Washington's largest gold mine, the Cannon Mine at Wenatchee in Chelan County, produced an estimated 4,454 kg (143,200 ounces) of gold and about 9,330 kg (300,000 ounces) of silver during 1989.[8] Comparable data for 1988 was about 4,510 kg (145,000 ounces) of gold and about 7,775 kg (250,000 ounces) of silver. The mine, a joint venture between Asamera Minerals (U.S.) Inc., the operator, and Breakwater Resources Ltd., is the Nation's second largest underground gold mine. Underground exploration to locate additional reserves was continued by Asamera, especially in the northern and western extensions of the B–4 ore zone, in the B-west ore body, and in the B-north zone. Surface exploration was also conducted in the Wenatchee Heights area 5.6 km (3.5 miles) southeast of the mine.

Washington's second largest gold mine is the underground Republic Unit, or Knob Hill Mine, of Hecla in Republic, Ferry County. On May 26 the 2 millionth ounce (62.2 metric tons) of gold was hoisted from the Knob Hill No. 2 shaft. This 541-meter (1,774 foot) inclined shaft has made over 4 million trips since it was opened in 1940. During 1989, the Republic Unit recovered 2,312 kg (74,335 ounces) of gold and 9,375 kg (301,432 ounces) of silver. Hecla also completed modifications to the mine's 52-year-old concentrator during 1989, raising its capacity from 218 metric tons per day to 245 metric tons per day. Improved gold recovery circuits were also installed during the overhaul.

Development was continued at Echo Bay and Crown Resources Corp.'s Kettle River project. The project located in Ferry County, 18 km (11 miles) north of Republic, includes the new Kettle and Overlook underground mines. Construction of a new 1,260 metric-ton-per-day automated flotation mill, employing carbon-in-pulp and vat-leaching systems, was completed before yearend. Commercial production was begun in February 1990.

The State reported that more than 80 companies and individuals explored for metals in Washington during 1989. Gold, particularly gold in skarn and replacement deposits and epithermal gold-bearing deposits in Eocene-age rock in

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 (thousand cubic meters)	Gold recoverable		
				Quantity (kilograms)	Value (thousands)	Average value per cubic meter
Bucketline dredging:						
1985	3	4	3,026	997	$10,185	$3.366
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
Dragline dredging:						
1985	3	14	[2]119	[3]132	1,348	[4]2.908
1986	3	14	[2]11	[3]113	1,342	[4]16.823
1987	3	3	[2]71	[3]67	971	[4]8.190
1988	—	—	—	—	—	—
1989	—	—	—	—	—	—
Hydraulicking:						
1985	—	—	—	—	—	—
1986	1	1	76	1	17	0.217
1987	—	—	—	—	—	—
1988	—	—	—	—	—	—
1989	—	—	—	—	—	—
Nonfloating washing plants:						
1985	6	6	733	949	9,690	13.213
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
Underground placer, small-scale mechanical and hand methods, suction dredge:						
1985	19	19	474	202	2,061	4.343
1986	24	24	679	438	[r]5,180	7.631
1987	15	15	367	1,078	[r]15,529	42.330
1988	13	13	[2]838	[3]1,862	[r]26,225	[4]31.292
1989	20	20	[2]1,404	[3]2,899	35,654	[4]25.349
Total placers:[5]						
1985	31	43	[2]4,353	[3]2,280	23,284	[4]5.118
1986	35	47	[2]4,097	[3]2,281	[r]27,010	[4]6.309
1987	28	29	[2]8,210	[3]5,082	[r]73,187	[4]8.867
1988	22	23	[2]7,085	[3]4,754	[r]66,977	[4]9.453
1989	27	28	[2]7,036	[3]5,711	70,242	[4]9.975

[r] Revised.
[1] Data are only for those mines that report annually on the 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.

northeastern Washington, was the principal target of this exploration.

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 1989 on the Nation's futures exchanges represented about 31,330 metric tons (1,007 million ounces) compared with the previous year when the equivalent of nearly 30,000 metric tons (962 million ounces) were traded. The New York-based Commodity Exchange Inc. (COMEX) was, as in the previous year, by far the dominant exchange with an equivalent of more than 31,000 metric tons (999 million ounces) of gold traded during 1989.

Sales of newly-minted gold coins by the U.S. Mint declined somewhat from levels establish during previous years. The sales program for the Bicentennial of the U.S. Congress Commemorative coins began in June, and the sales program for the 1988 Olympic coins, begun in February 1988, was completed in June 1989. During the fiscal year ending on Sept 30, 1989 about 2,140 kg (68,800 ounces) of gold was used to satisfy various official minting programs.

Gold loan activity between commercial depository banks and gold producers continued to be a popular method of financing new mine development or expansion of existing facilities.

In addition to its age-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, connectors, keyboard contacts, miniaturized circuitry, and as a dopant in some semiconductors. Modern solid-state electronic devices such as computers employ very low voltages and currents, and thus require connectors, switch contacts, soldered joints, and certain other components that must remain completely free of high resistance tarnish films and 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 all spacecraft such as the *Hubble Space Telescope* that must function flawlessly over a long period of time in the harsh environment of outer space.

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 as-

TABLE 8

U.S. REFINERY PRODUCTION OF GOLD[1]

(Kilograms)

Raw material	1985	1986	1987	1988	1989
Concentrates and ores:					
Domestic and foreign	64,583	75,618	112,368	137,829	183,685
Old scrap	49,824	47,266	63,843	52,807	36,895
New scrap	46,964	50,785	39,723	75,150	120,554
Total[2]	161,370	173,668	215,933	265,786	341,135

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

TABLE 9

U.S. CONSUMPTION OF GOLD,[1] BY END USE SECTOR[2]

(Kilograms)

End use	1985	1986	1987	1988	1989
Jewelry and the arts:					
Karat gold	43,473	43,916	49,304	r48,037	49,120
Fine gold for electroplating	762	2,689	3,133	1,469	1,127
Gold-filled and other	6,716	6,780	6,706	4,581	4,106
Total[3]	50,951	53,385	59,142	r54,088	54,353
Dental	9,309	7,921	6,944	7,576	7,923
Industrial:					
Karat gold	1,216	1,202	1,176	233	252
Fine gold for electroplating	11,864	11,486	12,250	14,988	20,575
Gold-filled and other	22,748	23,050	20,948	20,950	15,632
Total[3]	35,828	35,738	34,374	36,172	36,459
Small items for investment[4]	231	189	106	7	7
Grand total[3]	96,318	97,234	100,566	r97,842	98,741

r Revised.
[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.

sembly 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 and 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 eqiupment 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.

STOCKS

Stocks of refined bullion held by industrial users at the end of the year were substantially lower than those held at the end of 1988. The sharpest declines in industrial stocks were reported during the first and second quarters of the year and may reflect a withdrawal of material by manufacturers to meet the continuing 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, increased substantially from those held at the end of the previous year.

TABLE 10

YEAREND STOCKS OF REFINED GOLD IN THE UNITED STATES

(Kilograms)

	1985	1986[r]	1987[r]	1988[r]	1989
Industry	18,538	28,771	23,390	38,360	24,828
Futures exchange[1]	65,628	87,370	81,647	44,634	69,727
Department of the Treasury[2]	8,170,019	8,149,938	8,160,251	8,144,782	8,146,255
Earmarked gold[3]	10,494,290	10,348,006	10,252,982	10,044,519	9,911,928

[r] Revised.
[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.

TABLE 11

U.S. GOLD PRICES[1]

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1985	284.64	Feb. 25	341.30	Aug. 19 and 28	317.66
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:					
January	395.32	Jan. 30 and 31	412.95	Jan. 3	405.35
February	381.70	Feb. 17	395.12	Feb. 9	389.08
March	384.25	Mar. 29	396.82	Mar. 20	391.46
April	378.84	Apr. 28	391.56	Apr. 13	385.70
May	361.01	May 22	379.89	May 3	372.61
June	359.96	June 13	377.59	June 29	368.90
July	369.58	July 31	386.81	July 6	376.29
August	361.06	Aug. 29 and 31	371.78	Aug. 4	366.19
September	357.00	Sept. 15	370.28	Sept. 27	363.16
October	362.31	Oct. 11	376.59	Oct. 31	368.16
November	374.33	Nov. 1	415.10	Nov. 27	393.64
December	399.93	Dec. 28	416.86	Dec. 11 and 12	410.44
Year	357.00	Sept. 15	416.86	Dec. 11 and 12	382.58

[1] Engelhard Industries daily quotation.

PRICES

The Engelhard Industries-London daily final price of gold ranged from a low of $357 per ounce in September to a year's high of nearly $417 per ounce in mid-December. Despite the strong surge in the price toward yearend, the average for the year amounted to about $383 per ounce or nearly $60 per ounce less than the average for 1988.

FOREIGN TRADE

U.S. exports of gold, though not as large as in the previous year, were nevertheless substantial when compared with many earlier years. Contrary to 1987 and 1988, when Taiwan was the principal recipient of U.S. refined bullion shipments, exports to that country all but ceased during 1989. Switzerland was instead the principal destination during 1989, receiving large quantities of both refined bullion and doré.

Canada continued to be the Nation's principal source of refined bullion. Imports of gold from Uruguay which began in earnest in 1980 and peaked in 1986, declined in 1989 to roughly their 1980 level. During the 1980–89 period, Uruguay, a country with little or no domestic production and no official

controls on gold trade, became an important conduit for newly mined gold originating in other Latin American nations, especially Brazil where the trade of gold is tightly controlled. The dramatic decline in exports of gold from Uruguay in February 1989 may in part have been related to the discovery and closure there of an international money laundering operation reportedly involving the export of gold plated lead bars.

WORLD REVIEW

In 1989, for the 10th consecutive year, world gold mine production exceeded that of the previous year. Gold Fields Mineral Services Ltd.,[9] continuing 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 1988.

The company began its summary by noting that in addition to the supply of

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)
1985	76	$771	30,486	$303,413	2,979	$30,147	89,837	$919,433	123,378	$1,253,764
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:										
Belgium	—	—	1,238	15,669	—	—	1	30	1,239	15,699
Brazil	—	—	—	—	—	—	104	1,339	104	1,339
Canada	9	110	7,959	95,729	5,251	64,257	11,730	138,550	24,948	298,647
China	—	—	69	323	—	—	—	—	69	323
Costa Rica	—	—	—	—	—	—	99	1,144	99	1,144
Dominican Republic	—	—	141	1,123	—	—	31	389	172	1,512
France	—	—	16,079	200,370	994	12,362	1,451	17,839	18,525	230,571
Germany, Federal Republic of	(5)	2	2,094	24,475	1,427	17,529	84	965	3,605	42,970
Haiti	—	—	216	2,110	—	—	—	—	216	2,110
Hong Kong	—	—	499	6,514	—	—	39,656	481,999	40,155	488,512
India	—	—	30	231	1	12	26	293	58	536
Israel	—	—	24	172	39	406	—	—	62	578
Italy	—	—	181	2,260	40	480	52	600	273	3,340
Japan	—	—	5	43	136	1,445	5,472	70,864	5,613	72,352
Korea, Republic of	7	53	(5)	4	—	—	33	374	40	432
Mexico	—	—	353	3,664	149	1,881	6,652	78,338	7,154	83,883
Peru	—	—	37	547	—	—	1,123	12,827	1,160	13,374
Poland	—	—	—	—	—	—	70	787	70	787
Singapore	—	—	—	—	—	—	5,874	69,410	5,874	69,410
Sweden	—	—	880	10,537	138	1,442	—	—	1,018	11,979
Switzerland	—	—	857	9,754	34,618	141,097	31,383	378,989	66,858	529,840
United Kingdom	—	—	13,857	168,481	110	1,436	19,020	226,847	32,987	396,764
Uruguay	—	—	—	—	—	—	472	5,500	472	5,500
Yugoslavia	—	—	—	—	—	—	215	2,426	215	2,426
Other	—	—	22	143	32	344	52	640	106	1,128
Total[4]	16	165	44,541	542,150	42,935	242,690	123,599	1,490,151	211,091	2,275,156

[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 Fedal 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 13

U.S. IMPORTS FOR CONSUMPTION 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)
1985	1,153	$11,628	11,411	$107,147	45,444	$468,227	197,849	$2,109,475	255,857	$2,696,478
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	r6,468	r79,483	25,778	355,763	r57,590	799,901	r92,457	r1,269,288
1989:										
Australia	—	—	35	305	—	—	165	2,013	200	2,318
Barbados	—	—	184	1,907	—	—	13	140	197	2,047
Belgium	1	6	—	—	—	—	576	7,085	577	7,091
Bolivia	—	—	497	3,578	—	—	1,759	22,178	2,256	25,755
Brazil	—	—	—	—	—	—	476	6,024	476	6,024
Canada	25	244	3,134	15,965	1,352	16,448	69,112	851,211	73,623	883,867
Chile	—	—	24	301	220	2,692	7,250	90,791	7,494	93,784
Costa Rica	148	396	—	—	—	—	—	—	148	396
Dominican Republic	—	—	1,288	6,575	5,167	62,176	—	—	6,455	68,751
Ecuador	1	16	41	308	—	—	164	1,937	207	2,261
Finland	—	—	—	—	26	335	91	1,153	117	1,488
France	—	—	108	1,068	—	—	1	13	109	1,081
Guyana	82	1,012	228	2,484	24	277	119	1,253	453	5,026
Haiti	—	—	240	1,950	—	—	—	—	240	1,950
Honduras	1,807	1,039	10	46	—	—	—	—	1,817	1,084
Hong Kong	—	—	40	170	1	12	22	286	64	468
Italy	—	—	47	479	—	—	69	930	116	1,410
Mexico	164	2,038	373	2,801	6,314	75,405	1,919	23,894	8,770	104,137
Netherlands	—	—	3,629	449	—	—	(5)	1	3,630	451
Panama	—	—	75	688	—	—	75	724	150	1,413
Peru	—	—	9	49	19	219	347	4,857	375	5,125
Singapore	—	—	8,630	2,615	—	—	1	6	8,630	2,621
Sweden	186	2,205	9	137	—	—	—	—	195	2,342
Switzerland	1	8	6,089	70,265	—	—	12,627	157,417	18,717	227,691
Taiwan	—	—	13,177	538	—	—	—	—	13,177	538
Trinidad	—	—	162	1,800	—	—	18	262	180	2,062
United Kingdom	—	—	1,771	404	—	—	1,192	14,894	2,962	15,298
Uruguay	—	—	—	—	—	—	662	7,986	662	7,986
Yugoslavia	—	—	—	—	—	—	151	1,885	151	1,885
Other	10	140	155	804	35	389	157	1,792	358	3,124
Total[4]	2,426	7,103	39,952	115,685	13,159	157,952	96,967	1,198,734	152,504	1,479,473

r Revised.
[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.

newly-mined gold and net sales to the MEC from the centrally planned economy (CPE) countries the main addition to the supply was derived from sales to the market by the world's central banks. Central banks, for the first time since 1984, were substantial net sellers of gold. Net sales by central banks amounted to 225 metric tons (7.2 million ounces), the highest since 1979. Gold releases to the market by investors in North America and especially Europe continued to be important sources of supply with much of this gold going directly to investors in Asia. Net sales of gold from the CPE Countries increased from 263 metric tons (8.5 million ounces) in 1988 to 296 metric tons

(9.5 million ounces) during 1989. Supplies of old gold scrap declined for the third consecutive year to 304 metric tons (9.8 million ounces).

Fabrication data on gold was assembled by Gold Fields from MEC data describing the trade in gold bullion and its use by industries in the MEC that transform bullion into marketable products. Gold, including gold scrap, fabricated into karat gold jewelry absorbed 1,811 metric tons (58 million ounces) or 23% more than in 1988. The company stated that the new gold component of jewelry manufacturing rose by as much as 30% because of the decline in available scrap. Jewelry fabrication grew steadily in North America and reached record levels in Europe and the Far East. Gold products fabricated for use in electronic applications rose by 3% from the previous year to 138 metric tons (4.4 million ounces) while gold used in other industrial and decorative applications grew by 6% to 62 metric tons (2.0 million ounces). The use of gold in dentistry declined slightly from the 1988 level to 49 metric tons (1.6 million ounces). Gold absorbed in the fabrication of medals and imitation coins rose fractionally to 19 metric tons (614,000 ounces). Gold minted into official coins declined 10% to 123 metric tons (3.9 million ounces); however, sales, at 127 metric tons (4.1 million ounces), were little changed from the previous year. The identified hoarding of gold bars outside of Europe and North America as measured by statistics for cross-border movement rose nearly 13% from 1988 to 516 metric tons (16.6 million ounces) in 1989.

Capacity

Rated annual production capacities for gold mines, as of December 31, 1989, 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 current output was conducted in late 1989. The survey indicated a current capacity utilization rate of better than 97%. Incomplete data on the utilization rate for those mines responsible for the remaining 25% of production suggested that although most are probably operating at a rate comparable with the leading producers, some, for a variety of factors, may be operating at rates low enough to reduce the overall utilization rate to about 96%, as reflected in table 14. This estimated rate was believed to reflect the level of performance in most of the other industrialized nations.

Because of to 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 must be 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 and applied to annual production data different conversion factors to approximate rated annual capacity for each producing nation.

Production data for individual nations were estimated to reflect a utilization rate from 75% of maximum capacity utilization for some essentially nonindustrialized nations up to a 96% utilization for most industrialized nations.

Reserves

Demonstrated U.S. reserves of gold were about 4,980 metric tons (about 160 million ounces), and the reserve base was 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 approximated 42,000 metric tons (1.4 billion ounces), of which nearly one-half are in the Republic of South Africa. The world reserve base for gold totals about 47,000 metric tons (1.5 billion ounces). Reserves of gold in the U.S.S.R. and China are believed to exceed 6,220 metric tons (200 million ounces).

Estimates of reserves become available only over a 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

With nearly 202 metric tons (6.5 million ounces) of gold produced during 1989, Australia maintained its position as the world's fourth largest gold producing nation. The Australian gold mining industry, like its U.S. counterpart, has experienced phenomenal growth in recent years, with production rising nearly twelvefold during the period from 1980 through 1989.

The State of Western Australia continued to maintain its dominance as the nation's largest gold-producing State, hosting, during 1989, 14 of the nation's 15 leading gold mines. The State and the nation's largest gold mine, the Boddington Mine located 113 km (70 miles) southeast of Perth, continued producing at or near its recently doubled capacity rate of nearly 12,500 kg (400,000 ounces) of gold per year. Boddington is managed by the Worsley joint venture. Production at Australia's second largest mine, Newmont Australia Ltd. and BHP Gold's large open pit Telfer Mine near Nullagine was setback during 1989 by labor problems and a mid-year collapse of one wall of the open pit. These setbacks, in turn, delayed the owner's plans to initiate the first stage of a planned underground development project designed to expand the mine's annual production rate to nearly 11,000 kg (350,000 ounces) by 1991.

Some other developments in Western Australia in 1989 included the following: In October, Homestake Gold of Australia Ltd. (HGAL) poured the first gold at its new wholly owned Fortnum Mine north of Meekathara. HGAL and Gold Mines of Kalgoorlie Ltd. completed a 50–50 joint-ownership agree-

TABLE 14

WORLD GOLD ANNUAL PRODUCTION CAPACITY, RESERVES, AND RESERVE BASE,[1] DECEMBER 31, 1989

(Metric tons)

	Rated mine capacity[e]	Reserves[2]	Reserve base[3]
Australia	210	1,800	2,020
Brazil	120	930	980
Canada	165	1,700	1,870
China	95	NA	NA
Other centrally planned economies	15	NA	NA
Other market economy countries	315	6,620	7,420
South Africa, Republic of	630	20,000	22,000
United States	275	4,840	5,130
U.S.S.R.	325	6,220	7,780
World total	2,150	[4]42,000	[4]47,000

[e] Estimated. NA Not available.
[1] Estimated as of Jan. 1989. Data may not add to totals shown because of independent rounding.
[2] Reserves listed for countries other than Australia, Canada, the Republic of South Africa, and the United States may, in some instances, include inferred reserves.
[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 resourses).
[4] Excludes China and other centrally planned economies.

ment of Kalgoorlie's famous Golden Mile. The partnership now manages the Consolidated Kalgoorlie operations, including the "Super Pit" and Mount Charlotte, the largest underground gold mine in the country, plus five mills, including the newly commissioned Fimiston Mill. The partner's offsite Gidji roaster also became operational before yearend. Other new mines beginning production during the year included Westralian Resource Projects Ltd.'s Porphyry Mine, Goldconda Minerals NL's Duketon Mine, Aztec Mining Co. Ltd's Bounty Mine, and Poseidon Ltd.'s Kaltails project. Kaltails was developed to reprocess the vast gold-bearing tailings accumulated around mines developed along Kalgoorlie's Golden Mile.

The Western Australian Mint opened its new gold refinery in Perth. The mint's companion refinery in Kalgoorlie began operations during the previous year. The two facilities have a combined annual capacity of about 10,500 kg (3.4 million ounces).

In Australia's State of Queensland, the nation's third largest individual gold mine, the Kidston, produced nearly 6,400 kg (205,361 ounces) during 1989, and in September the mine's operator, Kidston Gold Mines Ltd., celebrated the production of its millionth ounce of gold. Several of Queensland's other gold mines, including the Red Dome Mine of Elders Resources Ltd. and the Mount Leyshon Mine of Pan Australian Mining Ltd., announced plans to expand their production capacities.

Canada

Canadian gold production increased for the ninth consecutive year with most of the 1989 increase of nearly 18% attributable to gold mines in the Province of Ontario. New gold mines opened at an average of one per month during the year, thus bringing to 70 the total number of primary gold mines operating in the country. Seven mines were also closed during the year.[10]

New mines opened in Ontario during 1989 included Placer Dome's Dona Lake Mine and Flanagan McAdam Resources Inc. and Windarra Minerals Ltd.'s Magnacon Mine in the Mishibishu area of Ontario. In mid-year the Supreme Court of Canada confirmed a 1986 ruling by the Supreme Court of Ontario that the Page-Williams Mine at Hemlo belonged to Corona Corp. The ruling ended an 8-year legal battle between Corona and Lac Minerals Ltd. The Page-Williams Mine, producing nearly 15,400 kg (494,000 ounces) of gold in 1989, was the nation's largest gold producer. The old Kerr Addison Mine at Virginatown and the Surlaga Mine near Wawa were both closed owing to technical and financial difficulties.

Quebec, Canada's second largest gold-producing Province, accounted for nearly 36,000 kg (1.16 million ounces) of new Canadian gold production during the year. New Quebec gold mines becoming operational during 1989 included the Kierens Mine of Aur Resources Inc., the Beauchastel Mine near Rouyn-Noranda by Augmitto Explorations Ltd., and the nearby Pierre Beauchemin Mine and the Lucien C. Beliveau Mine near Val-d'Or, both opened by Cambior Inc. Several mines were at the final preproduction stage and at least one mine, the Bachelor Lake Mine, was closed.

Three new mines with a planned production rate in excess of 1,000 kg (32,000 ounces) per year began production in British Columbia during the year; they were the Lawyers Mine of Cheni Gold Mines Inc.; the Golden Bear Mine, an open pit, underground operation owned by Chevron Canada Resources Ltd. and Homestake; and the Premier Mine of Westmin Resources Ltd. Exploration and development was continued at a number of gold projects throughout the Province with a lot of the exploration interest focused in the Iskut River-Eskay Creek areas of Northwestern British Columbia.

Gold mining activity in the Maritime Provinces was increased with the opening in September of the new Murray Brook Mine near Bathurst, New Brunswick. Several Gold Mines in Saskatchewan and Manitoba were closed owing to depletion or financial difficulties. Production at gold mines is the Yukon and Northwest Territories increased about 4% from that of the previous year.

Latin America

Gold production in Brazil, Latin America's largest gold-producing nation, was slightly lower than that of the previous year. Factors contributing to the decline reportedly included heavy rains that affected some placer mining areas, increased regulation, higher costs, and declining grades.

In early 1989, the president of Brazil signed a decree prohibiting the use of mercury and cyanide in gold mining unless approved by Brazilian State environmental agencies. The mercury amalgamation process to collect gold concentrated during placer mining operations has

been used for many years by unregulated independent gold miners or "garimpeiros." The States most affected by mercury contamination have been those in the Pantanal and Amazon regions of Brazil.

According to Gold Field's annual review[11] production increased in the unregulated mining areas or garimpos of Roraima and Rondonia along the Western frontier near Venezuela. Production decreased in the major garimpos of Alta Floresta and Tapajós to the east, where mining was slowed by heavy rains. Although production at the Serra Pelada Mine declined sharply from the peak production year of 1983, news of a new gold discovery there reportedly caused some garimpeiros who thought the mine was depleted to flood back into the region. The new discovery, in the main street of the minesite boomtown spawned by the original mine, reportedly developed quickly into a pit large enough to threaten the foundations of nearby homes and stores. Police action was required to halt mining until an orderly development plan could be found.

Production by the formal or regulated gold mining sector rose only slightly during the year. The dominant producer, Minerçâo Morro Velho S.A., maintains interests in gold mines in the Brazilian States of Bahía and Minas Gerais as well as Goiás where, in 1989, the company began production at its new 50%-owned Crixas Mine. Some other large gold mining concerns in Brazil include Sao Bento Mineraçáo S.A., Cia Vale do Rio Doce, and Rio Paracatú Mineraçáo S.A.

Chile's favorable geological potential as well as its increasingly attractive investment climate has encouraged a large number of companies in recent years to explore for gold as well as other commodities such as copper, silver, and zinc. With an estimated 7,000 kg (225,000 ounces) of gold production in 1989, Compañía Minera El Indio was Chile's largest producer. The company produces gold from its EL Indio and nearby Tambo mines in the Fourth Region. Other large mines owned and operated by foreign and/or domestic firms include the Choquelimpie, El Bronce, and El Hueso Mines. About 30% of Chile's gold production was derived as a byproduct of base metal mining while the remainder was attributed to numerous small lode and placer mines.

In early 1989, Placer Dome and Consolidated TVX Mining Corp. opened their new La Coipa Mine in the Third Region of northern Chile. The mine was expected to produce about 6,220 kg (200,000 ounces) of gold per year by late 1991. Minera Anglo-American Chile also opened its Marte Mine in the Third Region during 1989 and planned to open its nearby Lobo project by 1992. Because of the high number of exploration and mine development projects now under way, Chile's gold production was expected to rise substantially over the next several years.

In some other large gold-producing nations of Latin America such as Bolivia, Colombia, Ecuador, and Peru, the climate for investment in mining may not be as favorable as that in Chile. As a result, much of the gold production may be attributed to the informal sector; that is, as in Brazil, to more or less unregulated miners working individually or in cooperative groups. Exploration for gold and the development of new mines in these areas was also actively pursued by the respective Governments and/or foreign and domestic firms.

Oceania

The high level of activity in gold mining and the development of new mines in many nations of the southwestern Pacific was sustained for another year. For exploration companies, the principal targets continued to be high tonnage, low-grade empithermal gold deposits similar to many recently discovered and/or developed deposits in various Western Pacific nations such as Fiji, Indonesia, Japan, New Zealand, Papua New Guinea, the Philippines, and elsewhere.

Gold production in Papua New Guinea declined about 8% from the previous year's level, reflecting in part the suspesion of operations at CRA's 53.6%-held Bougainville copper-gold mine. The Bougainville Mine, on Bougainville Island, was closed on May 15 because of continuing violence stemming from a political movement aimed at gaining the island's independence from Papua New Guinea. As a result of the closure, byproduct gold production from the mine declined to about 7,340 kg (236,000 ounces) from the nearly 14,400 kg (462,400 ounces) produced in the previous year.

In March, Placer Pacific Ltd. opened its new Misima Island gold and silver mine in Milne Bay, thus, to some extent, offsetting the loss in production from the closure of Bougainville. The first gold from the new 12,440-kg-per-year (400,000 ounces) operation was poured in May. To the west, in the highlands of Enga Province, Placer and its three partners moved toward a planned September, 1990 startup of the new Porgera Mine. At Mount Fubilan, about 200 km (124 miles) further west of Porgera, the OK Tedi copper-gold mine, the nation's largest gold mine, reportedly produced about 15,900 kg (495,00 ounces) of gold compared with the previous year's output of about 18,000 kg (581,000 ounces). The decline in 1989 production apparently reflected a combination of both labor and operational problems, plus the expected gradual depletion of the gold-enriched "cap" overlying the principal lower-grade copper-gold ore body.

Other gold-producing mines in the nation included New Guinea Goldfields Ltd.'s nearly depleted deposit at Wau and Niugini Mining Ltd.'s small Mount Victor Mine. A number of promising deposits continued to be evaluated in Papua New Guinea; Niugini Mining and RTZ prepared a final feasibility study of their extensive Lihir Island deposit; CRA was developing its Hidden Valley and Mount Kare deposits.

To the west in Indonesia's Province of West Irian, Freeport Indonesia Inc. continued copper-gold mining at its Ertsberg property while simultaneously moving toward an early 1990 startup of mining at the new Grasberg copper-gold deposit. Ertsberg is Indonesia's largest gold producing mine. In the island provinces to the west, the pace of gold exploration and development moderated somewhat from the previous year's level of activity. In January, the P.T. Ampalit Mas Perdana Mine began production in Central Kalimantan. Several major gold projects under construction or final evaluation included Royal Dutch Shell's Billiton Group's Lerokis Mine under construction on Wetar Island in Maluku Province; CRA's Kelian Gold Project Team moved at yearend to gain Government approval to begin development of its Kelian Project in East Kalimatan.

The recently reopened Martha Hill

Mine at Waihi, New Zealand, was the only lode mine operating in that country during 1989. The startup of several developing mines was delayed until operational or environmental issues could be resolved.

Gold production at the two principal mines in Fiji increased over the previous year because of the mining of higher grade ore at the Emperor Mine and improved efficiency at the newly opened Tavua Basin Mine.

South Africa, Republic of

Despite escalating production costs and steadily declining ore grades, the Republic of South Africa's gold mines continued to dominate the world gold mining scene, collectively producing more than 30% of total world production during 1989.

Most of the 603 metric tons (19.38 million ounces) of gold produced in the Republic of South Africa during the year was produced by the 34 mines that represent the membership of the Chamber of Mines of South Africa. The remainder was produced by several dozen small independent mines or as a byproduct of other mining sectors. The total ore milled by Chamber members, including ore milled by producers of byproduct and coproduct uranium, amounted to nearly 114 million metric tons or about 10 million tons more than the previous year. The average grade of ore milled during 1989 was nearly 5.0 grams per metric ton (0.146 ounce per short ton) compared with 5.13 grams per ton (0.150 ounce per ton) during 1988. Working costs for Chamber members averaged about $277 per ounce (23,340 rands per kg) and ranged from about $171 per ounce (14,407 rands per kg) at the East Driefontein Mine to about $442 per ounce (37,189 rands per kg) at East Rand Proprietary.[12] Production by the six major mining groups was as follows: Anglo American Corp. of South Africa Ltd. (AAC), 253.1 metric tons; Gold Fields of South Africa Ltd. (GFSA); 113.1 metric tons; Gencor Ltd, through its newly created subsidiary General Mining, Metals and Minerals (Genmin), 86.1 metric tons; Rand Mines Ltd., 52.4 metric tons; Anglovaal Ltd., 43.4 metric tons; and Johannesburg Consolidated Investment Co. Ltd. (JCI), 41.5 metric tons.

The largest gold mines in terms of individual output, in metric tons of gold,

TABLE 15

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	882	944	990	938	[3]933
Australia	[4]58,521	75,079	110,696	156,950	[3]202,900
Bolivia	561	763	2,755	4,889	[3]3,594
Botswana[e 5]	10	20	25	20	250
Brazil[e 6]	72,160	67,500	83,700	100,200	100,000
Burkina Faso[e]	1,555	1,866	6,843	10,575	8,500
Burundi	26	31	26	14	25
Cameroon	7	8	[e]8	[e]8	8
Canada	87,561	102,899	115,818	134,813	158,440
Central African Republic	188	[e]187	223	382	300
Chile	17,240	17,938	17,035	20,614	20,000
China[e]	61,000	66,000	72,000	78,000	80,000
Colombia	35,532	39,995	26,550	29,020	[3]27,090
Congo[e]	[3]16	16	16	16	16
Costa Rica[7]	498	361	300	313	350
Cote d'Ivoire (formerly Ivory Coast)	—	5	7	6	6
Dominican Republic	10,202	8,837	7,664	5,785	5,500
Ecuador	9,331	9,870	9,500	7,962	[3]9,331
Ethiopia[8]	470	923	642	728	[3]745
Fiji	1,888	2,952	2,962	4,273	4,500
Finland	595	1,172	[e]1,800	[e]2,000	2,100
France	2,127	2,382	2,225	2,525	2,600
French Guiana	249	326	514	[e]500	500
Gabon[9]	50	62	79	138	140
Germany, Federal Republic of[e]	35	35	25	15	[3]50
Ghana	9,322	8,931	10,201	11,601	[3]13,358
Guinea	—	—	[9]74	[e 10]1,300	[e 10]2,053
Guyana	321	437	1,568	[e]2,330	3,200
Honduras	156	63	131	127	130
Hungary[e]	620	560	560	560	500
India[11]	1,828	1,874	1,874	1,900	2,000
Indonesia[12]	2,619	3,300	3,654	4,734	[3]6,155
Japan	5,309	10,280	8,590	7,310	6,100
Kenya	13	73	278	17	[3]15
Korea, North[e]	5,000	5,000	5,000	5,000	5,000
Korea, Republic of[11]	2,403	4,648	7,600	11,121	12,000
Liberia[e 13]	150	625	470	[3]677	700
Madagascar[e]	4	4	[3]40	[3]90	90
Malaysia	2,809	2,718	3,512	2,929	2,860
Mali	[r]560	[r]498	700	[14]2,650	2,740
Mexico	8,264	7,795	7,988	9,098	8,300
Namibia	194	184	172	195	200
New Zealand	[r]886	1,265	1,148	2,404	2,700
Nicaragua	762	892	948	878	1,100
Papua New Guinea	36,908	35,075	33,250	38,129	35,000
Peru	6,621	8,846	8,772	9,472	[3]8,428
Philippines	33,063	40,322	32,599	35,300	35,000
Portugal	288	191	248	267	300

See footnotes at end of table.

TABLE 15—Continued

GOLD: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Romania[e]	2,000	1,900	1,900	1,900	1,750
Rwanda	7	6	10	[e]9	10
Saudi Arabia[e]	—	—	—	1,000	3,000
Sierra Leone[15]	591	373	467	404	400
Solomon Islands	65	98	[e]124	47	—
South Africa, Republic of	670,754	638,047	596,456	618,369	603,000
Spain	5,770	5,200	5,008	[e]5,132	5,000
Sudan[e]	[r]55	[r]70	[3]85	[3]500	500
Suriname[e]	15	20	22	[r]30	[3]31
Sweden[e]	[3]4,631	4,040	4,040	4,200	4,000
Taiwan[11]	953	910	533	236	250
Tanzania	55	85	201	52	100
U.S.S.R.[e]	270,000	275,000	275,000	280,000	285,000
United States	75,495	116,296	153,870	200,914	[3]265,541
Venezuela	2,307	2,494	3,860	3,673	[3]3,900
Yugoslavia	[e]3,420	3,583	5,348	4,620	4,500
Zaire	1,960	5,220	4,372	3,563	3,500
Zambia[16]	285	268	356	227	250
Zimbabwe	14,691	14,853	14,710	14,191	14,500
Total	1,531,858	1,602,215	1,658,142	1,847,840	1,971,004

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through May 30, 1990.

[2] Gold is also produced in Burma, Cuba, Czechoslovakia, the German Democratic Republic, 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] Excludes gold in gold ore and concentrate from South Australia.

[5] Only the combined total of gold and silver production is reported, which for this table is estimated to be divided thus: 83.5% gold-16.5% silver, the approximate ratio for combined 1982–83 production.

[6] Officially reported figures are as follows, in kilograms: Major mines: 1985—7,597; 1986—9,348; 1987—13,120; 1988—24,012 (estimated); and 1989—24,900 (estimated). Small mines (garimpos): 1985—22,076; 1986—14,776; 1987—22,660; 1988—55,053 (estimated); and 1989—56,000 (estimated).

[7] Gold purchased by Banco Central from placer deposits and mines; actual production estimated to be at least twice this amount.

[8] Year ending June 30 of year listed.

[9] Does not include undocumented production from small artisanal production

[10] Figures include reported mine production of 320 kilograms in 1988 and 1,059 kilograms in 1989. Remainder represents approximate reported sales to Government of artisanal production. Figures do not include artisanal production smuggled out of country.

[11] Refinery output.

[12] Excludes production from so-called people's mines, estimated at 15,000 kilograms per year during 1986–89, 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, artisanal production and undocumented gold entering Mali.

[15] Data are based on official exports and do not reflect gold moved through undocumented channels.

[16] Year beginning Apr. 1 of year listed.

included AAC's Freegold Mine with 110.9, Vaal Reefs with 75.5, Driefontein with 54.4, Western Deep Levels with 40.6, and Hartebeestfontein with 31.2.

In mid-December, Rand Mines poured its first bar of gold at its new Barbrook Mine near Barberton in the Orange Free State (OFS). Barbrook is the first grass-roots mine opened by Rand Mines in many years. In late 1989, Genmin announced plans to proceed with the development of its new Weltevreden Mine near Orkney in the OFS. The new mine, scheduled to begin production in the second half of 1992, was expected to extract ore from the gold-bearing Vendersdorp Contact Reef. A relatively shallow mine by South African standards, Wellevreden's ore will be extracted using low-cost trackless mining methods operating from 100 to 1,100 meters below the surface.

CURRENT RESEARCH

The Bureau of Mines conducts research into various aspects of the gold mining industry.[13] 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. The Bureau's current research relating to gold mining generally focused on the use of cyanide in the recovery process. Through its work, the Bureau addressed several questions regarding the use of cyanide, its long- and short-term persistence, and effects in the environment. These questions included such topics as the persistence of cyanide, the mass balance of cyanide in the leaching process, the mobility of metals in the heap during heap leaching, and the protection of wildlife.

The Bureau sponsored university research through its mineral industry waste treatment and recovery generic center. A joint Bureau-university-industry effort was recently 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 protection, acid mine drainage, and cyanide alternatives.

Several reports on research relating to gold were issued by the Bureau during 1989.[14]

OUTLOOK

As an internationally traded commodity serving not only the industrial and jewelry end use sectors but the investment sector as well, the outlook for gold supply and demand must be viewed from a global viewpoint.

Gold Fields Mineral Services[15] in its annual review of supply and demand, acknowledges the pitfalls of long-term forecasting by limiting its outlook to the immediate future. Gold Fields, in addressing the outlook for prices greater than those achieved near yearend, noted that several underlying factors favoring a higher price were evident. These factors included their forecast for a levelling-off of mine production in the market econ-

omy countries during the early 1990's and a lower level of accelerated supplies from other sources such as the gold loans and forward sales that were featured most prominently during 1988. Gold production in the U.S.S.R. may decline during the present economic crisis while pressure to sell gold to raise foreign exchange will continue. Sales of gold by central banks and sales of bullion coin holdings by European investors may be somewhat less than in 1989 and the amount of scrap entering the market should remain at the present low level.

Gold Fields concluded its supply forecast by stating that, in the absence of exceptional sales from CPE countries, the record supply level of 1989 is unlikely to be repeated in the immediate future. On the demand side, Gold Fields expects that the rate of growth in jewelry demand of the past 3 years may decline as consumer spending slows. Similarly, an expected decline in physical bar hoarding in Brazil and Some Far Eastern Nations may be softened by increased demand from the Republic of Vietnam.

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. 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 predicatable regulatory climate will continue to prevail.

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 the continuance of acceptable gold prices, variable fashion trends, and the continued success of industry product advertising to attract new jewelry buyers. Jewelry demand may level off somewhat in the near term as discretionary consumer funds tighten. The use of gold in electronic applications may experience continued growth as the demand, for sophisticated and more reliable electronic goods expands to match the 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.

BACKGROUND

Gold lore and the use of gold predates written history. Gold has been considered a precious metal since ancient times, and the search for gold has stimulated world exploration and world trade for more than 60 centuries.

Gold mining in the United States began about 1800 in North Carolina, with Georgia becoming a producer in 1829 and Alabama in 1830; Virginia, Tennessee, and later New Mexico began producing as prospectors moved west. The most important gold discovery, because of its influence on development in the Western United States as well as on 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 nearly 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 before 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. The concentration of finely ground ores by the flotation process, selective adherence of mineral particles to rising bubbles, was first used for gold ores around 1900 and came into general use in the 1930's. Heap leaching, essentially a form of cyanidation, has come into general practice for treatment of low-grade ores only during the past two decades.

Cumulative world production to date is estimated at about 105,000 metric tons (3.4 billion ounces), about two-thirds of it mined in the past 60 years. The total is equivalent 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 nearly 11,000 metric tons (353 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 so that scarce equipment, supplies, and skilled manpower could be focused on mining essential base metals. Because of increased cost and rehabilitation problems, only a few reopened after the war; however, 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

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 a wire more than 80 km (50 miles) long.

As an illustration of gold's high specific gravity or density, 1 cubic foot of pure gold weighs a little more than 1,200 pounds, one cubic inch of pure gold weighs about 311 grams (10 troy ounces), and a lump or nugget of gold the size of a navy bean weighs about 3 grams (0.1 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 requires the use of the metric system of measure. Thus, outside of the Government, either system may be encountered. 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; under this system, the weight of gold may be designated in standard metric terms; gram, kilogram, or metric ton. The metric ton is equivalent to 32,150.7 troy ounces.

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 milimeter (mm) to 0.76 mm (0.015 to 0.03 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.

Refined gold bullion bars destined for monetary, investment, and industrial usage are generally designated as "Good Delivery Bars." The unit of trading on the London Gold Market is a bar measuring about 17.8 centimeters (cm) by 9.2 cm by 4.1 cm (7 inches by 3⅝ inches by 1⅝ inches) thick weighing approximately 12.5 kg (400 troy ounces or about 27 pounds), having a minimum fineness of 995, and bearing a weight stamp, serial number, melt number, and the stamp of an acceptable melter or assayer. Smaller bars for use by investors as well as industrial users 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, to 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 "1/20 10-karat gold filled" means that one or more surfaces are covered with 10-karat gold and the coating constitutes at least 10% of the weight of the entire article covered. No article may be marked "gold filled" if its karat gold surface constitutes less than 1/20 of the total weight. Thinner coatings are marked "rolled gold plate.

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 bar, rod, sheet, foil, wire, powder, granule, and shot. 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 by governments.

Industry Structure

In the United States during 1989, 89% of domestic production came from gold ore, and most of the remainder was a byproduct of silver or copper and other base metal production. Placer gold production has declined to about 2% of the reported total production in recent years. Sixteen mines accounted for about 61% of domestic output in 1989; 80% came from mines in Nevada, California, Montana, and South Dakota. The leading producer in most recent years, Newmont Gold Co., provided about 17% of domestic output from its surface operations near Carlin, Nevada. The Homestake Mine, a deep underground mine in South Dakota, has been an alternate leading producer for many years. The Utah Copper Division 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. Freeport-McMoRan Gold Co.'s Enfield Bell (Jerritt Canyon) Mine, a large open pit operation in north-central Nevada that began production in 1981, was the fourth-largest producer in 1989.

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 room. These mines are owned or controlled by six corporations, which 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

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 iron, silver, arsenic, antimony, and copper.

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 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 tellurium, mercury, arsenic, and copper, 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.

An issue of continuing concern to domestic 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 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.

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 of South Africa, for example) because of high underground temperature, 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. 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. 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.

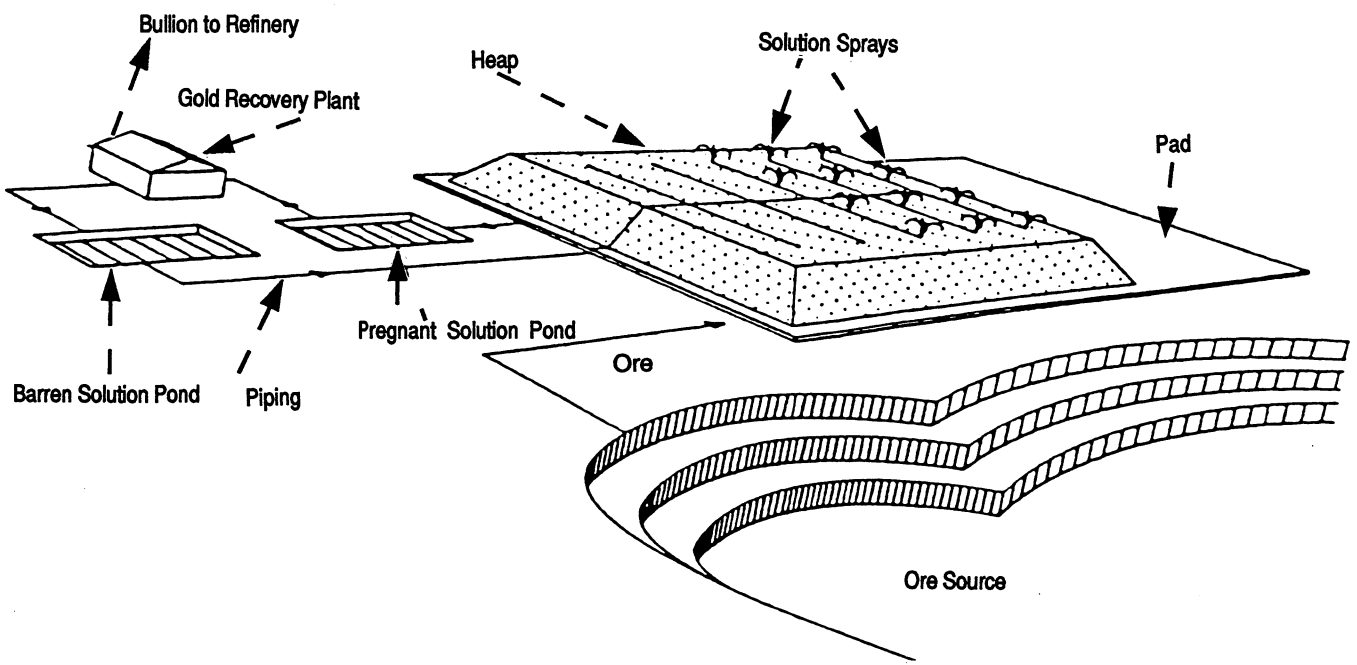
The South African mining industry, a leader in deepmining technology for many years, has evolved new methods of controlling problems relating to rock stress, dust, and stope temperature. Both large and small water-powered rock drills, large-diameter raiseboring machines, and new types of rubber tired 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 2100 meters (7,000 feet) by hydraulic pumps.

Beneficiation.—Milling technology for gold is highly developed, and normal mill recovery rates may range from 92% to 96%. Gold is recovered by cyanide leaching of gold ore contained in tanks or heaped on impervious leaching pads or by amalgamation, flotation, gravity concentration, and smelting, or by a combination of these processes. Heap-leach process components are shown in figures 1 and 2. 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.—Many gold mining operations recover 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

FIGURE 1

HEAP-LEACH PROCESS COMPONENTS



techniques. Some of these alternate techniques, unlike the long-established, well-understood cyanide process however, 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 4000 B.C. to barter for ingots of crude copper or other goods at a Mediterranean seaport.

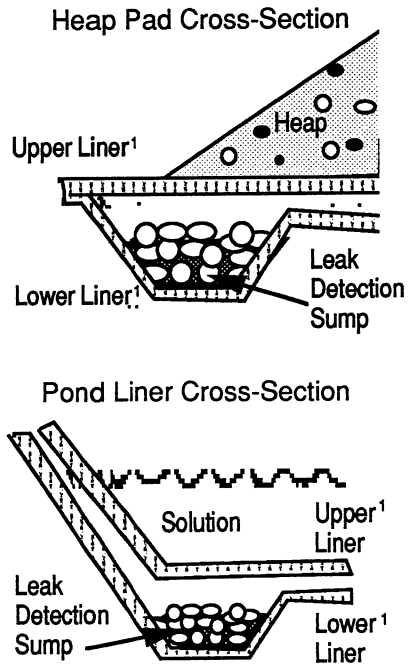
Precious metals refiners throughout the world recover gold from scrap. In the United States, about 60% of the scrap comes from current manufacturing operations, and the remainder comes from old scrap in the form of items such as discarded jewelry and dental materials, used plating solutions, junked electronic 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 located 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 semi-refiners may process the scrap and then ship the upgraded product elsewhere, including overseas, for further treatment and refining. Scrap is either purchased outright or treated on a toll basis.

A considerable quantity of scrap is generated in manufacturing operations, but because of tight security controls over waste materials in precious metals plants, nearly all of this "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.

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)

Economic Factors

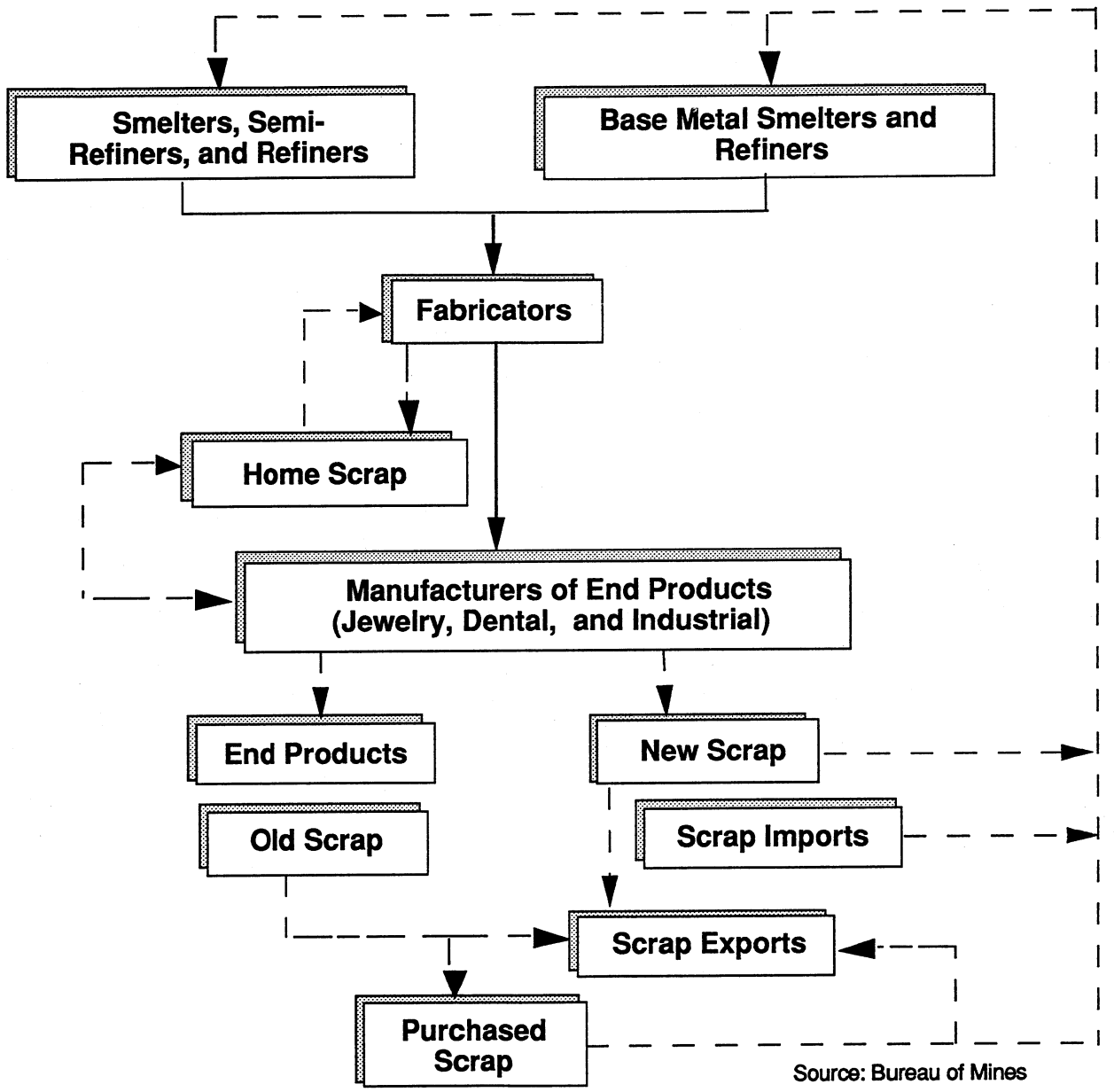
On January 31, 1934, following provisions of the Gold Reserve Act of that year, the official price of gold was raised by the U.S. Government from $20.67 per ounce to $35 per ounce. The value of $1 was thus established at 28.57 thousandths of a troy ounce, and gold flowed into the United States. By 1949, 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 Presidental order 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 1989, 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 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

FIGURE 3

SECONDARY GOLD CHART



Source: Bureau of Mines

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 nearly 43,000 metric tons (1,380 million ounces) in 1982; the volume in subsequent years has ranged from about 25,000 to nearly 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 consider a renewed role for gold in the U.S. economy, concluded that reintroduction of gold into the current monetary system would probably not serve to alleviate potential economic problems such as inflation. The prospects for a return to a gold standard in other countries would also seem to be uncertain. However, as a so-called "hard cur-

rency," 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.

An issue of increasing concern to the mining industry as well as Federal, State, and local 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.

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 U.S.,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 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 is likely to eventually 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 for 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 various 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 metric (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 of gold per metric ton (0.01 ounce per ton), depending on the stripping ratio, size and type of operation, the characteristics of the ore processed, and the mine's location with respect to the duration of the operational season and the infrastructural requirements. Underground mining for gold is the most expensive mining, but costs vary greatly from mine to mine; nevertheless, some underground mines are able to produce an ounce of gold at costs below those of some surface operation; for example, the average cost to produce an ounce of gold at the 2400-meter-deep (8,000 ft) Homestake Mine in South Dakota, including a small contribution from a new surface pit, during 1989 was $322. The cost was distributed as follows: mining and treatment, $287; administrative and general $16; and taxes $19.

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 Bureau of Mines to increase the flow rate of leaching solutions through crushed ore. Fine particles in the ore that would otherwise impede solution flow 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.

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 to 1966, while the other formula applies to newer mines. Many major gold-producing nations have also provided tax concessions, subsidies, and others 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 six-decade-old tax exemption for income derived from gold production, including byproduct production from 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 and monitoring procedures are employed to avoid contamination of the surrounding environment and to reduce the exposure of wildlife or humans to cyanide-laden process streams. 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. The amalgamation process continues, however, 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 control costs must be taken into account 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, more than doubled from nearly 7,000 in 1985 to 15,000 in 1989. 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. Citing employment studies for mining in Nevada and South Dakota, the Economics Institute of Boulder, CO.[16] derived an employment multiplier of 19.4 that, when applied to each $1 million of gold production, gave an estimate for total direct plus indirect employment attributable to gold production of about 51,000.

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[1] Ounce refers to troy ounce. One kilogram of gold weighs 32.1507 troy ounces.

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[12] Values have been converted from South African rands (R) to U.S. dollars at the rate of R1.00 = US$0.3822 for 1989, as shown in Int. Financial Stat., V. 43, No. 5, May 1990, p. 478.

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[15] Work cited in footnote 9.

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GRAPHITE

By Harold A. Taylor, Jr.

Physical scientist, Branch of Industrial Minerals. He has covered graphite for 10 years. Domestic survey data prepared by Joseph Daniels, mineral data assistant, Branch of Data Collection and Coordination. International data prepared by Audrey Wilkes, international data assistant, Geographic Data Section.

Amorphous graphite was mined domestically in 1989. Graphite supplies, particularly of fine crystalline flake, lagged behind industrial demand, which increased substantially from the previous year. Prices of the major imported graphites generally increased from those of 1988. Production of manufactured graphite and graphite fibers decreased slightly and increased by 21% respectively.

DOMESTIC DATA COVERAGE

Domestic production data for synthetic graphite are developed by the Bureau of Mines from a voluntary survey of domestic producers. Of the 33 operations polled, 100% responded. This represented 100% of the total production data shown in table 4.

LEGISLATION AND GOVERNMENT PROGRAMS

No acquisitions or disposal of graphite from the strategic and critical materials stockpile occurred in 1989. However, new and smaller goals were authorized but not implemented, as follows: 12,882 metric tons for Madagascar crystalline flake and 1,751 tons for crystalline graphite other than Madagascar and Sri Lanka. The following amounts of graphite were authorized for disposal: up to 3,298 tons of Madagascar crystalline flake and up to 792 tons of crystalline graphite other than Madagascar and Sri Lanka.

PRODUCTION

United Minerals Co. operated its Townsend, MT, mine in 1989. Output of manufactured graphite decreased slightly to about 270,000 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 21% to 2,915 tons. Union Carbide Corp. continued to operate its Puerto Rican graphite electrode plant in 1989, on an interim basis.

TABLE 1

SALIENT NATURAL GRAPHITE STATISTICS

		1985	1986	1987	1988	1989
United States:						
Production	metric tons	—	—	—	W	W
Apparent consumption	do.	40,261	31,784	31,634	42,799	50,867
Exports	do.	7,581	7,034	11,700	11,068	11,452
Value	thousands	$3,125	$3,416	$6,218	5,815	7,421
Imports for consumption	metric tons	47,842	38,818	43,334	53,867	62,319
Value	thousands	$16,186	$15,758	$17,654	$23,238	33,707
World: Production	metric tons	r583,779	r624,718	r648,156	p643,938	e634,050

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 2

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1989, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	18,144	16,171
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	2,540	1,754
Nonstockpile-grade, all types	—	846

Source: General Services Administration, Inventory of Stockpile Materials as of Dec. 31, 1989.

CONSUMPTION AND USES

Reported consumption of natural graphite increased 9% to about 37,400 tons. The three major uses of natural graphite were refractories, lubricants, and foundries, which together accounted for 59% of reported consumption.

Nonclay refractories represent two important use categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizeable 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. High-purity coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower value. The newest impor

TABLE 3

PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1989

Company	Plant location	Product [1]
Akzo-Enka America Inc., Fortafil Fiber Div.	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.		
Do.	Morganton, NC	Electrodes, unmachined shapes, motor brushes, other.
Do.	Niagara Falls, NY	
Do.	Ozark, AR	
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.
North American Carbon 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.
The Stackpole Corp., Carbon Div.	St. Mary's, PA	Motor brushes and unmachined shapes.
Standard Oil Co., Specialty Graphite Metallics Div.	Sanborn, NY	Motor brushes, unmachined shapes, cloth.
Superior Graphite Co.	Russellville, AR	Electrodes and other.
Do.	Hopkinsville, KY	
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	
Union Carbide Corp., Carbon Products Div.	Clarksburg, WV	
Do.	Clarksville, TN	Anodes, electrodes, unmachined shapes, crucibles and vessels, other.
Do.	Columbia, TN	
Do.	Yabucoa, PR	

[1] Cloth includes low-modulus fibers; motor brushes include machined shapes, crucibles include vessels.

tant 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 users 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 linings. 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.

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

TABLE 4

U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY USE

Use	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Products:				
Anodes	6,827	$17,399	6,196	$18,144
Cloth and fibers (low-modulus)	239	28,228	377	34,846
Crucibles, vessels, refractories	W	W	W	W
Electric motor brushes and machined shapes	W	W	W	W
Electrodes	r192,959	r382,538	188,264	379,196
Graphite articles[1]	—	35,656	—	32,492
High-modulus fibers	2,176	117,754	2,538	128,603
Unmachined graphite shapes	5,033	33,258	4,584	27,297
Other	6,542	47,881	6,201	57,516
Total	r213,776	r662,714	208,160	678,094
Synthetic graphite powder and scrap	r63,939	r34,648	62,259	28,574
Grand total	r277,715	r697,362	270,419	706,668

r Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1] Includes all items for which no quantity data is available.

TABLE 5

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)
1979	153	$10,089	176	$13,031	329	$23,120
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

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.

PRICES

Natural graphite prices are often negotiated between the buyer and seller and are based on purity and other criteria. Therefore, published price quotations such as those in Industrial Minerals are given as a range of prices. Another source of information for graphite prices is the average customs value per ton of the different imported classes. These mainly represent shipments of unprocessed graphite. A third source for natural graphite prices is the amount paid per ton at the point of consumption.

The price for crystalline graphite at the point of consumption—mostly crystalline flake, some crystalline dust, and a little lump graphite—rose by 27% to $1,540 per ton. The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) rose by 5% to $707 per ton.

FOREIGN TRADE

The United States changed its tariff classification to the Harmonized Code on January 1, 1989. This has rendered the 1988 and 1989 import and export statistics to be somewhat noncomparable. The statistics for imports of artificial graphite are completely noncomparable; actual activity is believed to be fairly similar in both years.

Total exports of natural graphite decreased slightly. Exports of graphite electrodes totaled 97,307 tons valued at $142.6 million, of which 32,966 tons ($20.3 million) went to Canada, 11,474 tons ($15.0 million) to Brazil, 11,161 tons ($22.4 million) to Japan, 7,051 tons ($15.6 million) to Venezuela, 3,542 tons ($9.2 million) to the Federal Republic of Germany, and the balance to other destinations.

Imports of natural graphite increased 16% from those of 1988. Imports of natural graphite from Canada, China, the Republic of Korea, and Madagascar rose substantially.

WORLD REVIEW

The current year has been interesting and murky, as we watched two major developments being played out. At yearend 1988, the Chinese announced some major price increases in crystalline flake coupled with a cutback in exports of 40,000 to 50,000 tons. They stated that this resulted from a drought which affected the water supply for beneficiation and transportation, greater internal consumption, and the closure of economically marginal mines. The higher prices continued to be posted throughout the year. A high Bureau official was told earlier by the Chinese

that industrial mineral prices at the October 1989 Canton Fair would be "very competitive." In spite of this supposed cutback, the actual Chinese graphite exports to major markets changed little from 1988. No drop off was observed towards the end of the year. The demand by actual consumers such as the steel industry held up well, and it was probably even stronger than 1988. Against this backdrop, a number of Canadian would-be graphite producers struggled to come on-stream to fill this perceived gap. New capacity came on-stream in Norway and Mexico which also offset the shortfall in production.

Australia

Gwalia Minerals NL entered into a joint venture with a London-based merchant banker to perform a feasibility study of the Munglinup graphite prospect. The prospect is 80 kilometers east of Ravensthorpe, Western Australia. Earlier diamond drilling showed graphite continuity over a strike length in excess of 600 meters. Total resources were stated to be 1.6 million tons averaging 18% carbon. Pilot plant testwork is also underway. If the feasibility study

TABLE 6

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)
1987:[3]	13,132	$14,795	16,046	$9,082	29,178	$23,876
1988:						
Batteries	W	W	W	W	804	1,340
Brake linings	r2,601	r1,948	r2,494	r3,107	5,095	5,055
Carbon products[4]	317	879	232	374	549	1,253
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	1,641	1,818
Foundries[5]	465	283	3,907	1,247	4,373	1,530
Lubricants[6]	r3,386	r4,895	r2,815	1,623	r6,201	r6,518
Pencils	r1,596	r1,947	303	174	r1,899	r2,121
Powdered metals	1,450	1,472	50	84	1,500	1,556
Refractories	W	W	W	W	7,382	4,352
Rubber	95	128	338	324	434	452
Steelmaking	188	116	1,153	1,405	1,341	1,521
Other[r 7]	2,533	5,655	455	677	2,988	6,332
Withheld uses	7,267	6,848	2,560	663	—	—
Total[r 2]	19,897	24,171	14,308	9,678	34,205	33,848
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	1,757	1,876	248	150	2,005	2,026
Powdered metals	1,401	2,551	58	111	1,459	2,662
Refractories	W	W	W	W	10,195	8,985
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	8,527	9,552	4,408	3,054	—	—
Total[2]	20,503	30,587	16,910	12,569	37,413	43,156

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 lubricant 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.

TABLE 7

REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1988	1989
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
Custom value, at foreign ports:		
Flake	742	951
Lump and chip, Sri Lankan	843	1,027
Amorphous, Mexican	53	114

Source: Industrial Minerals, No. 255, Dec. 1988, p. 82, and No. 267, Dec. 1989, p. 82.

TABLE 8

INDEXES OF UNIT VALUE OF GRAPHITE FIBER PRODUCED IN THE UNITED STATES[1]

(1973 = 100)

Year	Cloth and low-modulus fibers	High-modulus fibers
1978	117	66
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

[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 9

U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY

Country	Natural[1]		Artificial		Total	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
1988:						
Brazil	17	$5,524	284	$330,791	301	$336,315
Canada	5,989	2,093,978	12,170	638,990	18,159	2,732,968
Germany, Federal Republic of	15	3,735	2,027	737,953	2,042	741,688
Italy	20	23,518	167	197,891	187	221,409
Japan	1,500	1,314,394	4,037	3,201,325	5,537	4,515,719
Mexico	1,158	526,572	463	245,695	1,621	772,267
United Kingdom	328	276,731	1,694	1,195,560	2,022	1,472,291
Venezuela	504	382,071	224	140,754	728	522,825
Other	1,536	1,188,192	11,348	7,323,521	12,884	8,511,713
Total	11,068	5,814,715	32,414	14,012,480	43,480	19,827,195
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

[1] Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified.
Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake		Lump or chippy dust		Other natural crude and refined		Amorphous		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1987	5,964	$4,683	1,272	$1,137	17,771	$10,710	18,328	$1,123	43,334	$17,654
1988:										
Austria	34	25	—	—	—	—	61	39	95	64
Brazil	2,080	1,607	—	—	2,646	2,064	—	—	4,726	3,671
Canada	2,216	1,533	—	—	2,494	1,188	—	—	4,710	2,721
China	1,186	613	—	—	13,752	6,051	138	25	15,076	6,689
France	18	22	—	—	27	78	—	—	45	100
Germany, Federal Republic of	(2)	1	—	—	248	624	—	—	248	624
Hong Kong							131	53	131	53
India	—	—	—	—	220	207	—	—	220	207
Japan	19	83	—	—	224	635	—	—	243	718
Madagascar	2,615	2,169	—	—	1,332	1,032	—	—	3,946	3,201
Mexico	—	—	—	—	1,607	869	18,794	1,000	20,401	1,869
Netherlands	—	—	—	—	6	65	—	—	6	65
South Africa, Republic of	—	—	—	—	340	188	—	—	340	188
Sri Lanka	—	—	2,819	2,376	—	—	—	—	2,819	2,376
Sweden	—	—	—	—	1	1	—	—	1	1
Switzerland	—	—	—	—	119	108	—	—	119	108
Taiwan	—	—	—	—	14	3	—	—	14	3
United Kingdom	80	63	—	—	1	1	—	—	81	64
Zimbabwe	—	—	—	—	634	410	—	—	634	410
Other	1	4	—	—	11	101	—	—	12	105
Total[1]	8,249	6,120	2,819	2,376	23,676	13,625	19,123	1,117	53,867	23,238
1989:										
Belgium-Luxembourg	—	—	—	—	50	12	—	—	50	12
Brazil	2,613	2,937	—	—	2,935	3,018	—	—	5,548	5,955
Canada	2,144	2,235	—	—	3,261	2,684	—	—	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	294	322	—	—	4,368	3,318	—	—	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[1]	8,922	8,481	675	693	27,064	21,176	25,658	3,357	62,319	33,707

[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

is positive, the option on the property will be exercised.

Graphite Mines of Australia, a subsidiary of Solution Mining, announced that it would reopen its Uley Mine near Port Lincoln, South Australia. It will have an output of 2,500 tons per year of product. The firm plans to gradually double the mine's production and export about 75% of the product. It plans to spend around $3.8 million.

Brazil

Nacional de Grafite Ltda. is planning to increase its product capacity at Pedra Azul by building a new plant on the same site. The present capacity of 28,500 tons of product per year will increase by 18,000 tons per year in mid-1991 and by an additional 18,000 tons per year by 1992.

Canada

Stratmin Inc. was the only Canadian producer of graphite in 1989. It brought its second mine on-stream and was considering expanding its mill capacity to 30,000 tons per year of concentrate. Cal Graphite Corp. and Exploration Graphicor Inc. may come on-stream in 1990. Exploration Graphicor holds three deposits near those of Stratmin and is hoping to have a production capacity of 11,000 tons.

Societe d' Exploration Miniere Mazarin Inc. estimates that its heavily-drilled deposit near Fermont has over 8.5 million tons of an unusually rich ore averaging 17% graphite. This would be a 67 years supply at the proposed productive capacity of 20,000 tons per year. The deposit has good road access and is close to the iron ore towns of Labrador and Quebec. The firm tried to negotiate a partnership with Cassiar Mining Ltd., but was unsuccessful. The project cost was estimated to be $32 million.

Mexico

For $5.7 million, the Mexican Government sold all of Grafito de Mexico SA, its crystalline flake graphite operation. The buyer was Minerals No-Metalicos Mexicanos SA, a member of the Jose Valdes group. The capacity doubling now underway should be finished this year. The firm is planning to add an acid and pressure leaching stage that will allow it to make a 99.6% carbon final product.

Sri Lanka

Guerillas attacked the Kolongaha graphite mine towards the end of the year. They set fires that destroyed some vehicles and machinery, doing about $500,000 in damage.

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF ARTIFICIAL GRAPHITE AND GRAPHITE ELECTRODES, BY COUNTRY

Country	Artificial graphite		Graphite electrodes	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1988:				
Belgium	—	—	352	$676
Brazil	—	—	187	56
Canada	1,588	$599	9,916	12,606
China	—	—	258	376
France	769	3,326	1,495	1,983
Germany, Federal Republic of	641	2,997	5,138	7,906
Italy	203	411	4,827	7,477
Japan	1,002	8,418	21,839	33,245
Mexico	—	—	8,230	9,734
Spain	—	—	1,049	1,791
Sweden	—	—	1	75
Switzerland	4,579	9,852	499	905
Taiwan	—	—	234	267
United Kingdom	7	101	2,703	3,919
Other	4	48	212	293
Total[1]	8,793	25,751	56,940	81,309
1989:				
Belgium	—	—	306	542
Brazil	—	—	1,289	503
Canada	37	19	6,130	6,277
China	2	6	526	831
France	1	9	1,387	1,367
Germany, Federal Republic of	217	268	2,758	4,082
Italy	—	—	5,931	9,747
Japan	4	48	4,889	7,807
Mexico	190	6	11,333	14,122
Spain	—	—	525	985
Sweden	—	—	—	5
Switzerland	(2)	2	55	105
Taiwan	12	29	4	14
United Kingdom	124	810	588	928
Other	77	126	669	874
Total[1]	665	1,322	36,390	48,189

[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

The Bureau of Mines examined substitutes for the crystalline flake graphite used in dolomite-carbon refractories, and the use of graphite fiber in particular. Test samples were evaluated for modulus of rupture, deformation under load, and air-slag-metal resistance. Graphite

TABLE 12

GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	32	40	216	24	50
Austria	30,764	36,167	39,391	7,577	7,000
Brazil (marketable)[3]	27,239	28,586	31,404	32,000	30,000
Burma[4]	234	722	—	—	—
China[e]	185,000	185,000	185,000	200,000	200,000
Czechoslovakia[e]	[r]35,000	[5]25,254	[r]25,000	[r]25,000	25,000
Germany, Federal Republic of	12,798	13,233	9,891	[e]7,000	7,000
India (mine)[6]	27,337	38,412	42,589	52,134	55,000
Korea, North[e]	25,000	25,000	25,000	25,000	25,000
Korea, Republic of:					
Amorphous	69,877	96,577	106,507	107,767	98,000
Crystalline flake	1,602	641	838	678	1,000
Madagascar	13,971	16,187	13,169	14,106	14,000
Mexico:					
Amorphous	33,468	[r]36,018	36,674	42,096	45,000
Crystalline flake	1,910	1,838	1,787	1,735	2,000
Norway	2,684	—	—	—	—
Romania[e]	12,000	12,000	12,000	12,000	10,000
Sri Lanka	7,413	7,453	9,400	8,547	[5]4,163
Turkey (mine)	[e]5,000	3,586	11,760	12,833	13,000
U.S.S.R.[e]	82,000	83,000	84,000	84,000	84,000
United States	—	—	—	W	W
Zimbabwe	10,450	15,004	13,530	11,441	11,000
Total	[r]583,779	[r]624,718	[r]648,156	643,938	631,213

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

[1]Table includes data available through May 8, 1990.

[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 beneficiation, in metric tons: 1985—16,425; 1986—19,074; 1987—10,505; 1988—20,000 (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%-20% of mine production.

fiber at the 1.5% level was added to sample dolomite-carbon brick. The resulting physical properties were generally comparable to those obtained with natural flake graphite, but were below those obtained with 10% flake graphite additions. Therefore, graphite fiber was shown to be an unsatisfactory substitute for flake graphite.[1]

The U.S. Air Force sponsored a major conference on the occupational health aspects of advanced composite materials use in the aerospace industry in Dayton, OH in February.

OUTLOOK

Projected demand for crystalline flake graphite totaled 23,000 tons for 1995 and 25,000 tons for 2000. Demand for other graphite, mostly amorphous, totaled 12,000 tons for 1995 and 10,000 tons for 2000. This relatively slow rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick. The supply situation, previously described, is unusually cloudy and appears likely to stay that way for at least several years.

BACKGROUND

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 which can be sold only for low-value uses 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 be or has been separated therefrom by ordinary crushing, pulverizing, screening, or mechanical concentration process, such flake being made up of a number of parallel laminae, which may be separated by mechanical means."

Under the foregoing definition, finely divided particles of crystalline flake graphite would be classified as crystalline graphite. However, the Court of Customs Appeals has reportedly 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. Thus, quantities of fine crystalline flake graphite are imported under the other Natural Crude and Refined classification.

Sri Lankan lump graphite is classified as amorphous or crystalline. Each type is divided into a number of grades, depending upon the size (such as lump, ranging from the size of walnuts to that of peas; chip, from that of peas to about that of wheat grains; and dust, finer than 60 mesh), graphitic carbon content, and degree of consolidation.

Amorphous graphite is graded primarily on graphitic carbon content. Commercial ore contains about 75% to

93% carbon, depending on the source.

Crystalline flake graphite from Madagascar is divided into two main grades, "flake" (coarse flake) and "fines" (fine flake). Madagascan crucible flake must have a minimum of 85% graphitic carbon and be essentially all minus 8 plus 60 mesh in particle size. Other crystalline flake graphites are also graded according to graphitic carbon content and particle size.

Natural graphite is marketed in the form of crystalline graphite as flake, lump, chip, and dust and in the form of amorphous graphite in sizes from fine powder to lumps up to the size of walnuts. It is common practice to blend different graphites to obtain a product having certain desired physical and chemical properties. In many instances, the composition of these blends is retained as a trade secret.

GEOLOGY—RESOURCES

The three principal types of natural graphite—lump, amorphous, and crystalline flake—are based on physical characteristics that are the result of major differences in geologic origin and occurrence. A variety of silicate minerals are generally associated with graphite in the ore.

Lump graphite occurs as fissure-filled veins. It is typically massive, ranging in particle size from extremely fine grains (amorphous) to coarse, platy intergrowths of fibrous to acicular aggregates (crystalline). The origin of vein-type graphite deposits is believed to be hydrothermal and/or pneumatolytic.

Amorphous graphite is formed by metamorphism of coalbeds by nearby intrusives. Its purity depends on the purity of the original coalbeds. Amorphous graphite usually is associated with sandstones, shales, slates, and limestones.

Flake graphite commonly occurs disseminated in regionally metamorphosed sedimentary rocks, such as gneisses, schists, and marbles. It is believed that the graphite was formed under the same conditions that caused the metamorphism of the rocks—from carbon deposited with the sediments.

Although the flake graphite deposits of certain countries conform to this description, the commercial deposits that are exploited are alluvial, lateritic clays that have accumulated at the surface. Graphite, quartz, and other resistant minerals have been freed by kaolinization of the feldspars, lessening the amount of crushing necessary before beneficiation.

World graphite reserves totaled 21.0 million tonnes. Detailed breakouts are given in the 1988 Mineral 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. Air drills are used in development headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds also are usually mined underground, however, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, handloaded 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 graphites are refined by hand cobbing and 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.

Graphite floats readily and does not require a collector; hence, 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.

ECONOMIC FACTORS

The price structure of graphite is quite complex because of the wide variety of products and the lack of standard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller. These quotations are available in Industrial Minerals, Chemical Marketing Reporter, and the Bureau of Mines Minerals Yearbook. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from 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, chiefly because of high labor costs and the low graphite content of the ore.

Employment and Productivity

Production of 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. Since 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.

Taxes and Tariffs

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.

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.

TABLE 13

U.S. IMPORT DUTIES

Tariff item	No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Crystalline flake, (not including flake dust):	2504.10.10	0.7 cents per kilogram	3.6 cents per kilogram.
Other powder	2504.10.50	Free	10% ad valorem.
Other	2504.90.00	Free	Do.

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.

[1] Bennett, J. P. Effect of Natural Flake Graphite and Carbon Fiber Additions on High-Temperature Properties of Dolomite-Carbon Refractories. BuMines RI 9275, 1989, 16 pp.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications:

Graphite. Ch. in Mineral Commodity Summaries, annual.
Graphite. Ch. in Minerals Yearbook, annual.
Graphite. Reported annually in Mineral Industry Surveys.

Other Sources:

Industrial Minerals (London).
Wall Street Journal.
Materials Engineering.
Chemical Week.
European Chemical News.

GYPSUM

By Lawrence L. Davis

Mr. Davis, a physical scientist with 34 years of industry and Bureau of Mines experience, has been the commodity specialist for gypsum since 1985. Domestic survey data were prepared by Pamela Shorter, mineral data assistant; and international data tables were prepared by Peter J. Roetzel, international data assistant.

Although demand for gypsum products remained strong in 1989, new public and private housing unit starts, a major indicator of gypsum product demand, decreased 8% to 1.4 million units. The gypsum industry set new record-high levels for crude gypsum mined, calcined gypsum produced, and shipments of prefabricated wallboard products.

Sales of gypsum products increased 7% to 27 million short tons, and value decreased 8% to $1.9 billion. Increased competition caused lower prices for gypsum products. Imports for consumption of crude gypsum decreased 4% to about 9.3 million tons. Total value of gypsum product exports increased 41% to $60 million.

TABLE 1

SALIENT GYPSUM STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Active mines and plants[1]	116	113	109	112	112
Crude:					
Mined	14,414	15,403	15,612	16,390	17,624
Value	$111,785	$99,570	$106,977	$109,205	$128,448
Imports for consumption	9,922	9,559	9,717	9,679	9,304
Byproduct gypsum sales	779	653	688	733	725
Calcined:					
Produced	15,982	17,061	17,592	17,274	17,893
Value	$366,581	$310,353	$321,645	$313,251	$285,659
Products sold (value)	$2,418,296	$2,514,432	$2,278,822	$2,090,786	[2]$1,926,676
Exports (value)	$26,419	$28,805	$32,061	[r]$42,789	$60,311
Imports for consumption (value)	$155,422	$181,168	$163,581	$158,169	$111,012
World: Production	[r]95,908	[r]98,175	101,913	[p]105,776	[e]108,624

[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.

DOMESTIC DATA COVERAGE

Domestic production data for gypsum are developed by the Bureau of Mines from a survey of U.S. gypsum operations. Of the 120 operations to which the annual survey request was sent, 87 responded, representing 73% 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.

PRODUCTION

The United States remained the world's leading producer of gypsum, accounting for 16% of the total world output. Crude gypsum was mined by 36 companies at 65 mines in 21 States. Production increased 8%. Leading producing States, in descending order, were Oklahoma, Iowa, Michigan, Texas, California, Nevada, and Indiana. These seven States produced more than 1 million tons each and together accounted for 76% of total domestic production.

Leading companies were USG Corp., 11 mines; National Gypsum Co., 7 mines; Georgia-Pacific Corp., 7 mines; Celotex Corp., 3 mines; and Harrison Gypsum Inc., 2 mines. These 5 companies, operating 30 mines, produced 68% of the total crude gypsum.

Leading individual mines, in descending order of production, were USG's Plaster City Mine, Imperial County, CA; National Gypsum's Tawas Mine, Iosco County, MI; USG's Sweetwater Mine, Nolan County, TX; USG's Shoals Mine, Martin County, IN; USG's Alabaster Mine, Iosco County, MI; USG's Sperry Mine, Des Moines County, IA; National Gypsum's Sun City Mine, Barber County, KS; Harrison's Cement Mine, Caddo 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 41% of the national total. Average output for the 65 mines increased 6% to 271,000 tons.

Gypsum was calcined by 13 companies at 71 plants in 28 States, principally for the manufacture of gypsum wallboard and plaster. Calcined output increased 4% in tonnage and decreased 9% in value. Leading States, in descending order, were California, Texas, Iowa, 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; Briar Gypsum Co.'s Briar plant, Howard County, AR; National Gypsum's Tampa plant, Hillsborough County, FL; USG's Baltimore plant, Baltimore County, MD; USG's Shoals plant, Martin County, IN; USG's Sperry plant, Des Moines County, IA; USG's Stony Point plant, Rockland County, NY; and PABCO's Las Vegas Plant, Clark County, NV. These 10 plants accounted for 28% of the national production. Average calcine production for the 71 U.S. plants was 252,000 tons, a 7% increase.

A total of 725,000 tons of byproduct gypsum, valued at $2.9 million, was used, principally in agriculture, but some for gypsum wallboard manufacturing. Approximately 76% was of nonphosphogypsum origin compared with 67% in 1988.

According to the Gypsum Association, yearend gypsum wallboard plant capacity for producing 1/2-inch regular wallboard decreased slightly to 24.04 billion square feet per year. Total wallboard shipments were 21.9 billion square feet, 91% of capacity.

Improvements to existing plants and construction of new plants continued during the year. Centex-American's new plant in Bernalillo, NM, is expected to be fully operational in 1991.

Domtar continued construction of its $30 million wallboard plant at Newington, NH. The plant was expected to be operational in 1990, using crude gypsum imported from Domtar's Flat Bay quarry in Newfoundland. Annual capacity of the plant was to be 540 million square feet.

Eagle Gypsum Products was building a new wallboard plant in Eagle County, CO. The plant was expected to be completed in mid-1990. Another new entrant in the gypsum board industry, Highland-American Corp., was constructing a gypsum fiberboard plant in East Providence, RI. The plant was scheduled to begin production in mid-1990 with an annual capacity of 150 million square feet. National Gypsum was adding a new line to their Rensselaer, NY, plant and were modernizing their Portsmouth, NH, plant. South Florida Gypsum Co. continued construction of a wallboard plant in Miami, FL. The plant, scheduled to begin operating in 1990, will use crude gypsum imported from Spain. USG completed a $30 million expansion of its wallboard plant at Sperry, IA. The expansion doubled the capacity of the plant.

Weyerhaeuser Co. sold its gypsum mine, calcining plant, and wallboard plant at Nashville, AR, to Boral Ltd., an Australian building and construction materials company. The gypsum complex now operates as Briar Gypsum Co.

Atlantic Gypsum Co. Inc.'s new plant in Port Newark, NJ, opened in late 1988, but was closed for most of 1989.

Western Plains Materials operated three quarries in Oklahoma, mostly for the production of road aggregate. Rock for road construction was also produced by Winn Rock Inc. at its Winnfield Mine in Winn Parish, LA, the only anhydrite mine in the United States. Quad-Honstein Joint Venture's Woodham Mine in Larimer County, CO, and Cox Enterprises Inc.'s Levan Mine in Sanpete County, UT, both idle in 1988, were active during 1989.

CONSUMPTION AND USES

Apparent consumption, defined as production plus net imports plus industry stock changes, of crude gypsum, including byproduct gypsum, increased slightly to 26.8 million tons. Net imports provided 34% of the crude gypsum consumed. Apparent consumption of calcined gypsum increased 6% to 17.8 million tons.

Yearend stocks of crude gypsum at mines and calcining plants were 3.8 million tons. Of this, 53% was at calcining plants in coastal States.

Of the total gypsum products sold or used, 5.5 million tons, about 20%, were 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.

TABLE 2

CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1988			1989		
	Active mines	Quantity (thousand short tons)	Value (thousands)	Active mines	Quantity (thousand short tons)	Value (thousands)
Arizona, New Mexico	6	574	$2,956	6	561	$3,132
Arkansas, Kansas, Louisiana	5	1,654	9,951	5	1,836	13,097
California	7	1,490	11,222	6	1,734	13,066
Colorado, Montana, South Dakota, Washington, Wyoming	9	676	5,085	10	673	5,202
Indiana, New York, Ohio, Virginia	5	2,239	14,067	5	2,149	16,226
Iowa	6	2,047	13,710	6	2,273	16,884
Michigan	5	1,958	11,630	5	2,089	15,589
Nevada, Utah	7	1,637	11,400	8	1,792	13,839
Oklahoma	8	2,173	13,393	8	2,523	14,369
Texas	6	1,943	15,790	6	1,993	17,044
Total[1]	64	16,390	109,205	65	17,624	128,448

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

TABLE 3

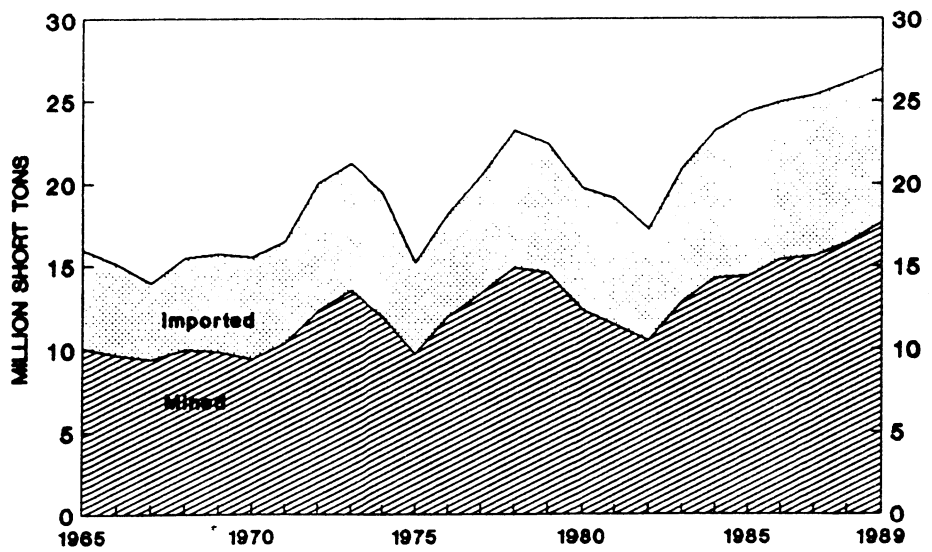
CALCINED GYPSUM PRODUCED IN THE UNITED STATES BY STATE

State	1988			1989		
	Active plants	Quantity (thousand short tons)	Value (thousands)	Active plants	Quantity (thousand short tons)	Value (thousands)
Arizona, Colorado, New Mexico, Utah	5	673	$10,001	5	651	$7,831
Arkansas, Louisiana, Oklahoma	7	1,729	29,371	7	1,982	25,741
California	6	1,950	39,767	6	1,958	32,401
Delaware, Maryland, North Carolina, Virginia	6	1,681	30,538	6	1,708	28,155
Florida	3	1,309	27,001	3	1,303	21,066
Georgia	3	782	14,070	3	724	12,022
Illinois, Indiana, Kansas	6	1,524	25,143	6	1,513	24,721
Iowa	5	1,271	20,979	5	1,490	24,575
Massachusetts, New Hampshire, New Jersey	4	825	16,451	4	832	14,410
Michigan	4	675	11,332	4	650	10,677
Washington, Wyoming	4	729	17,592	4	761	18,016
Nevada	4	1,228	20,590	4	1,186	19,075
New York	4	1,101	19,289	4	1,093	15,646
Ohio	3	485	11,194	3	458	7,405
Texas	7	1,312	19,932	7	1,584	23,918
Total[1]	72	17,274	313,251	71	17,893	285,659

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

FIGURE 1

SUPPLY OF CRUDE GYPSUM IN THE UNITED STATES



In 1989, 62% of the uncalcined gypsum products were 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, 83% was 1/2 inch and 10% was 5/8 inch.

In descending order, the leading sales regions for prefabricated products were the South Atlantic, Pacific, East North-Central, and Middle Atlantic. Together they accounted for 69% of the total.

PRICES

On an average value-per-ton basis, f.o.b. mine or plant, crude gypsum increased 9% to $7.29, calcined gypsum decreased 12% to $15.96, and byproduct gypsum decreased to $4.03, 20% lower than in 1988. Prefabricated products were valued at $85.96 per ton, plasters at $128.29 per ton, and uncalcined products at $13.44 per ton.

According to the Department of Commerce, the average producer price of regular 1/2-inch wallboard was 4% lower in 1989 than in 1988, and type X board was 3% lower.[1]

FOREIGN TRADE

Imports for consumption of crude gypsum decreased 4% to 9.3 million tons and represented 34% 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 44% to 355 million square feet. The sharp decrease is believed to be caused by fewer housing starts in the United States and strengthening of the Canadian dollar against the U.S. dollar.

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	1988		1989	
	Quantity	Value	Quantity	Value
Uncalcined:				
Portland cement	3,987	47,622	3,422	41,834
Agriculture and miscellaneous[1]	1,388	27,851	2,094	32,310
Total[2]	5,375	75,473	5,516	74,145
Calcined:				
Plasters	792	98,411	W	W
Prefabricated products[3]	19,155	1,916,901	21,552	1,852,531
Total calcined[2 4]	19,948	2,015,313	21,552	1,852,531
Grand total[2 4]	25,323	2,090,786	27,068	1,926,676

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 not include plasters in 1989.

TABLE 5

PREFABRICATED GYPSUM PRODUCTS SOLD OR USED IN THE UNITED STATES

Product	1988			1989		
	Thousand square feet	Thousand short tons[1]	Value (thousands)	Thousand square feet	Thousand short tons[1]	Value (thousands)
Lath:						
3/8 inch	18,447	14	$3,145	15,319	11	$2,747
1/2 inch	376	(2)	65	460	(2)	61
Other	2,322	2	383	3,480	3	532
Total[3]	21,145	16	3,593	19,259	15	3,339
Veneer base	472,127	473	47,931	476,330	478	40,810
Sheathing	311,264	299	43,008	310,880	301	36,543
Regular gypsumboard:						
3/8 inch	438,430	330	41,850	891,365	819	100,335
1/2 inch	11,503,724	10,184	935,825	11,187,062	9,830	802,976
5/8 inch	1,605,138	1,495	163,910	1,303,673	2,244	101,706
1 inch	30,597	37	6,495	76,604	94	16,712
Other[4]	309,780	202	32,490	80,820	62	8,834
Total[3]	13,887,669	12,247	1,180,570	13,539,524	13,050	1,030,564
Type X gypsumboard	4,583,338	4,922	445,572	6,027,090	6,398	537,116
Predecorated wallboard	132,008	125	43,582	129,341	122	41,427
5/16-inch mobile home board	604,988	474	55,208	725,283	549	67,049
Water/moisture-resistant board	549,814	504	76,325	587,830	557	77,385
Other	96,486	95	21,112	83,561	83	18,297
Grand total[3]	20,658,842	19,155	1,916,901	21,899,098	21,552	1,852,531

[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.

WORLD REVIEW

Estimated world production of crude gypsum increased slightly to 109 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 16% of the world total.

Australia

The French company Lafarge-Coppee announced a planned joint venture with Pioneer Concrete to manufacture gypsum wallboard products at plants in Sydney and Melbourne.[2]

Canada

Louisiana-Pacific Panel Products Ltd., a subsidiary of U.S.-based Louisiana-Pacific Corp., broke ground in early May for a new fiber gypsum board plant in Sydney, Nova Scotia. The $64.5 million facility will have an annual capacity of 240 million square feet. The company plans to market its products in the northeastern United States.[3]

Eastern Gypsum Inc. announced plans for construction of a $40 million gypsum wallboard facility in McAdam, New Brunswick. The plant is scheduled to start production in the summer of 1990.[4]

The Gypsum Association in the United States, of which all Canadian wallboard producers were members, reported that yearend wallboard capacity in Canada was 3.72 billion square feet, about the same as in the previous year.

France

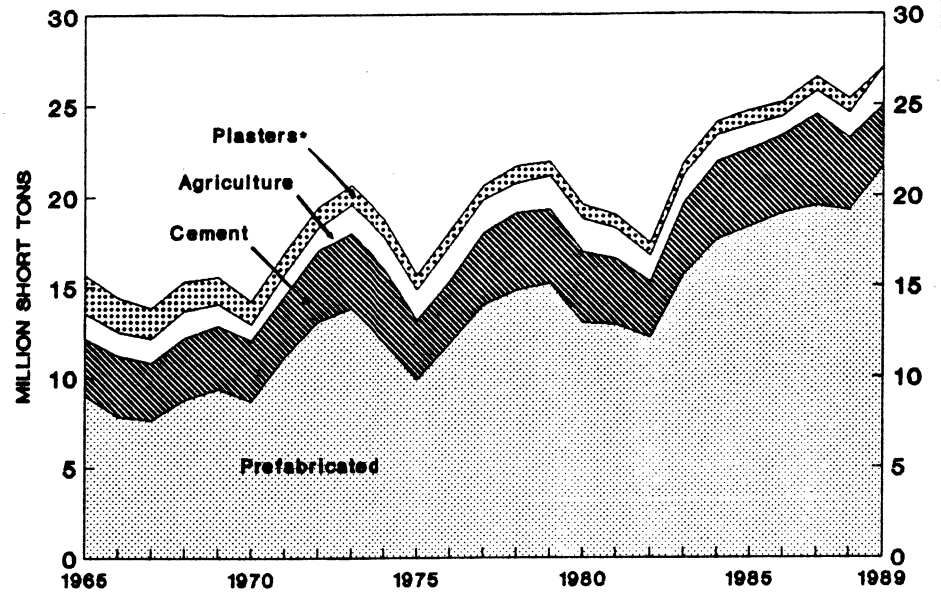
Escogypse SA, a small wallboard producer with a single-line plant at Valenciennes, was in the process of being purchased by Redland Plasterboard Ltd. Redland is a joint venture of Redland PLC of the United Kingdom and CSR Ltd. of Australia.[5]

Italy

BPB Industries PLC of the United Kingdom was planning to build Italy's first wallboard plant. The country was one of the few in Western Europe that relied totally on imported board.

FIGURE 2

SALES OF GYPSUM PRODUCTS, BY USE



•Data withheld in 1989

TABLE 6

IMPORTS FOR CONSUMPTION OF CRUDE GYPSUM, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Australia	23	178	23	201
Canada[1]	6,229	39,256	6,285	41,964
China	232	1,235	13	95
Dominican Republic	14	113	(2)	3
Germany, Federal Republic of	12	48	(2)	23
Mexico	2,177	11,170	2,353	11,606
Morocco	51	711	12	60
Spain	936	6,221	618	5,142
Other	4	233	(2)	14
Total[3]	9,679	59,166	9,304	59,107

[1]Includes anhydrite.
[2]Less than 1/2 unit.
[3]Data do not add to totals shown because of independent rounding.
Source: Bureau of the Census.

Spain

A German company, G. Siempelkamp GmbH & Co., has been contracted to build a gypsum fiberboard plant at Carboneras, Almeria, for Internacional de Paneles SA. The plant is expected to open in early 1991 with an annual capacity of about 160 million square feet.[6]

OUTLOOK

More than 90% of the gypsum consumed annually in the United States is used in construction, mainly to produce prefabricated wallboard products, with lesser amounts used in the manufacture of portland cement. Therefore, gypsum demand correlates well with construction activity. Using the macroeconomic indicator, New Construction Activities, annual gypsum use in prefabricated wallboard products is expected to remain about 21 million tons through 1995. Using the same macroeconomic indicator, annual gypsum use in the manufacture of portland cement is expected to reach 4.8 million tons by 1995, an average annual increase of about 3%.

Despite a decline in new housing starts in each of the past 3 years, the gypsum industry has been at record or near-record levels of production. The industry has been able to maintain these high levels by increasing markets in commercial construction, remodeling, and exports. However, increased competition, caused by increased capacity and the slowdown in new housing starts, has driven prices down and lowered profitability. A problem for the immediate future is that several new wallboard plants are supposed to begin operations in 1990. The added capacity will lead to more competition, even lower prices, and lower profits. In the short term, some companies will have difficulties remaining profitable, even though gypsum demand should continue at high levels.

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,

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:								
1985	4	447	78	12,574	NA	9,332	4,066	26,419
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	r42,789
1989	108	2,286	106	15,914	97	25,140	16,972	60,311
Imports for consumption:								
1985	9,922	64,089	2	242	694	80,119	10,972	155,422
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

rRevised. NA Not available.

[1]Import and export data for 1989 are for "Gypsum; anhydrite," Harmonized Tariff Schedule 2520.10. Data for 1985–88 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 are for "Plasters," Harmonized Tariff Schedule 2520.20. Data for 1985–88 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 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 1985–88 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 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 1985–88 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 might not be comparable that of previous years.

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

Source: Bureau of the Census.

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; and Spain, which exports to the United States, Scandinavia, and other countries. In the United States and other industrialized nations, the major use of gypsum is in the manufacture of gypsum wallboard products. Most crude gypsum is mined in rural areas and shipped to urban areas for manufacture into wallboard and ultimate consumption. In developing countries, most gypsum is consumed by local cement plants.

Geology-Resources

Gypsum deposits may be found in any geologic era, but they are most common in the Permian. They are 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, and climate, because these factors affect the depth of ground water and surface water penetration.

Domestic and foreign reserves of gypsum are adequate for the foreseeable future. World reserves are conservatively estimated at 2.6 billion tons, of which the United States has 800 million tons. In the United States, gypsum resources are centered near five main areas: the Great Lakes, including the Silurian Basin and the Michigan Basin; the gulf coast embayment of Louisiana, Mississippi, and south Texas; the Permian Basin of New Mexico, Kansas, Oklahoma, and north Texas; several basins in the Rocky Mountain area, including those in Colorado, Montana, New Mexico, Utah, and Wyoming, Utah; and southern California and southern Nevada.

Gypsum reserves and resources are common throughout the world. More than 80 countries produce gypsum, and very few are without any resources.

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

TABLE 8

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1985	1986	1987	1988[p]	1989[e]
Afghanistan[e]	3	3	3	3	3
Algeria[e 2]	275	303	303	303	303
Angola[e]	22	22	22	22	22
Argentina	508	509	682	565	330
Australia	1,923	1,842	1,742	1,825	1,980
Austria[3]	765	[r]774	732	796	[4]689
Bolivia[e]	[r]2	[r]2	[r]2	[r]2	[r]2
Brazil (direct sales plus beneficiated)	[r]584	[r]693	727	715	720
Bulgaria	428	435	337	442	440
Burma	43	43	26	35	[4]3
Canada (shipments)[3]	9,311	9,704	9,980	10,485	[4]9,590
Chile	216	213	259	348	330
China[e]	6,300	7,200	7,900	8,900	8,900
Colombia	276	325	333	338	342
Cuba[e]	145	145	145	145	145
Cyprus	18	33	50	36	[4]12
Czechoslovakia	851	819	851	853	854
Dominican Republic	342	146	65	73	77
Ecuador	349	320	281	[e]289	287
Egypt	927	998	1,200	[e]1,200	1,200
El Salvador[e]	5	5	5	5	5
Ethiopia[5]	[re]1	[re]1	2	2	2
France[3]	5,827	5,797	5,962	6,204	[4]6,266
German Democratic Republic[e]	397	375	353	353	342
Germany, Federal Republic of (marketable)[3]	2,609	2,090	1,882	1,599	2,040
Greece	516	613	[re]550	[re]550	550
Guatemala	19	31	26	38	[4]31
Honduras[e]	25	25	25	25	25
Hungary[e 3]	[r]22	[r]22	[r]111	[4]130	127
India	1,389	1,707	1,900	1,571	[4]1,558
Iran[e]	[4]9,242	9,300	9,300	9,300	9,300
Iraq[e]	330	330	390	390	500
Ireland	335	318	313	359	[4]347
Israel	[e]50	51	39	34	33
Italy	1,390	[r]1,372	1,339	[e]1,430	1,380
Jamaica	197	129	194	161	160
Japan[e]	6,900	7,000	6,600	6,900	6,900
Jordan	101	77	[e]77	94	[4]146
Kenya[3]	[e]2	12	43	42	40
Korea, Republic of	873	—	—	—	—
Laos[e]	120	140	[r]77	88	95
Lebanon[e]	3	3	[r]2	[r]2	2
Libya[e]	200	200	200	200	200

See footnotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country	1985	1986	1987	1988[p]	1989[e]
Luxembourg[e]	(6)	(6)	(6)	(6)	(6)
Mauritania	6	20	21	7	[4]11
Mexico	5,074	4,666	5,044	4,548	[4]5,305
Mongolia[e]	35	35	35	35	35
Morocco[e]	500	500	500	500	500
Nicaragua	9	[e]9	8	[e]8	8
Niger[e]	3	3	—	3	3
Pakistan	451	411	495	413	[4]515
Paraguay	3	3	3	4	[4]4
Peru	32	[r]189	252	[re]165	176
Philippines	124	138	138	[e]141	132
Poland[3]	1,073	1,220	1,242	1,224	1,220
Portugal	267	292	356	373	330
Romania[e]	1,790	1,760	1,650	1,760	1,760
Saudi Arabia	451	411	[e]411	[e]413	413
Sierra Leone[e]	4	4	4	4	4
South Africa, Republic of	505	446	385	410	[4]448
Spain[e]	[4]6,090	6,060	6,100	6,060	6,060
Sudan[3]	7	[e]8	[e]8	6	[4]11
Switzerland[e]	240	220	250	250	240
Syria	177	[e]176	273	197	198
Taiwan	2	2	2	3	3
Tanzania[3]	16	16	27	22	22
Thailand	1,404	1,836	3,341	5,014	[4]6,038
Tunisia[e]	100	110	110	110	110
Turkey	86	141	333	275	276
U.S.S.R.	4,655	5,070	5,270	[e]5,300	5,300
United Kingdom[3]	3,515	3,765	[re]3,860	[re]4,080	4,400
United States[7]	14,414	15,403	15,612	16,390	[4]17,624
Uruguay[e]	110	110	110	110	110
Venezuela	[r]208	[e]275	272	277	276
Vietnam[e]	30	30	30	30	30
Yemen Arab Republic	27	58	165	176	175
Yugoslavia	662	656	610	612	605
Total	[r]95,908	[r]98,175	101,913	105,776	108,624

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Table includes data available through June 27, 1990.
[2]Includes approximately 55,000 short tons of plaster a year.
[3]Includes anhydrite.
[4]Reported figure.
[5]Data are for years ending July 7 of that stated. Reported in cubic meters and estimated at 2.2 short tons per cubic yard.
[6]Less than 1/2 unit.
[7]Excludes byproduct gypsum.

depth of hydration is important in mining because the presence of only a few percent anhydrite is sufficient to render gypsum unusable for making plaster. Adequate samples may be obtained from outcrops or drill cores.

Deposits near the surface are developed by stripping the overburden, developing either single- or multiple-bench open pits, and constructing access and transportation routes. Underground ore bodies are developed by sinking shafts or driving adits, with mining development and production by the room-and-pillar system.

Most domestic gypsum is produced from surface mines using standard open pit mining methods. In a typical domestic mine, the gypsum is drilled and blasted as needed, probably every week or two. Broken gypsum rock, loaded with hydraulic shovel or front-end loader, is hauled to the primary crusher by a fleet of three or four 35-ton haultrucks. All material removed from the mines is crude gypsum. All waste is left in the mine.

The processing of crude gypsum depends on the end use. Gypsum for use in cement is crushed to minus 1½ inch plus 3/8 inch. For agricultural or filler use, the gypsum is pulverized to 100 mesh or finer.

To produce plaster and wallboard products, minus 100-mesh gypsum is heated in batch kettles to remove three-quarters of the water of crystallization, converting gypsum, $CaSO_4 \cdot 2H_2O$, to the hemihydrate product, $CaSO_4 \cdot \frac{1}{2}H_2O$. 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 boards 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.

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[1]International Trade Administration (Dep. of Commerce). Construction Review. V. 36, No. 2, Mar.-Apr. 1990, p. 41.

[2]Dickson, T. Gypsum. Min. Annu. Rev., June 1989, pp. C113-C114.

[3]Rock Products. V. 92, No. 5, May 1989, p. 22.

[4]St. Croix Courier (St. Stephen, ME). February—Gypsum, Milk Prices and Truck Route. Dec. 27, 1989.

[5]Industrial Minerals (London). No. 262, July 1989, p. 10.

[6] ———. No. 268, Jan. 1990, p. 11.

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HELIUM

By William D. Leachman

Mr. Leachman, chemical engineer, Helium Field Operations, has covered helium for 7 years. He also prepared the domestic survey data and the international data.

Grade-A helium (99.995% or better) sales volume in the United States by private industry and the Bureau of Mines was 2,083 million cubic feet (MMcf) in 1989.[1] Grade-A helium exports by private producers were 796 MMcf, for total sales of 2,879 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 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 production shown in table 2.

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 1989, 12 privately owned domestic helium plants were operated by 9 companies. Seven of these and one 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 increased 5% in 1989 because most crude helium plants remained operational throughout the year. One plant shut down for about 1 month because of a legal dispute over its feedgas. In addition, Exxon increased the helium production at their Riley Ridge plant by eliminating "bottlenecks." All natural gas processed for helium recovery came from gasfields in Kansas, New Mexico, Oklahoma, Texas, and Wyoming. Pressure-swing adsorption is used for helium purification at four of the private helium plants and at the Bureau's plant. Cryogenic purification is used by the other producers. The Bureau and all seven private plants that produce Grade-A helium also liquefy helium. The plant operators and locations are Air Products and Chemicals Inc., Hansford County, TX; Navajo Refined Helium Co., Shiprock, NM;

TABLE 1

OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS IN THE UNITED STATES IN 1989

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]
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	Grade-A helium.[1]
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)

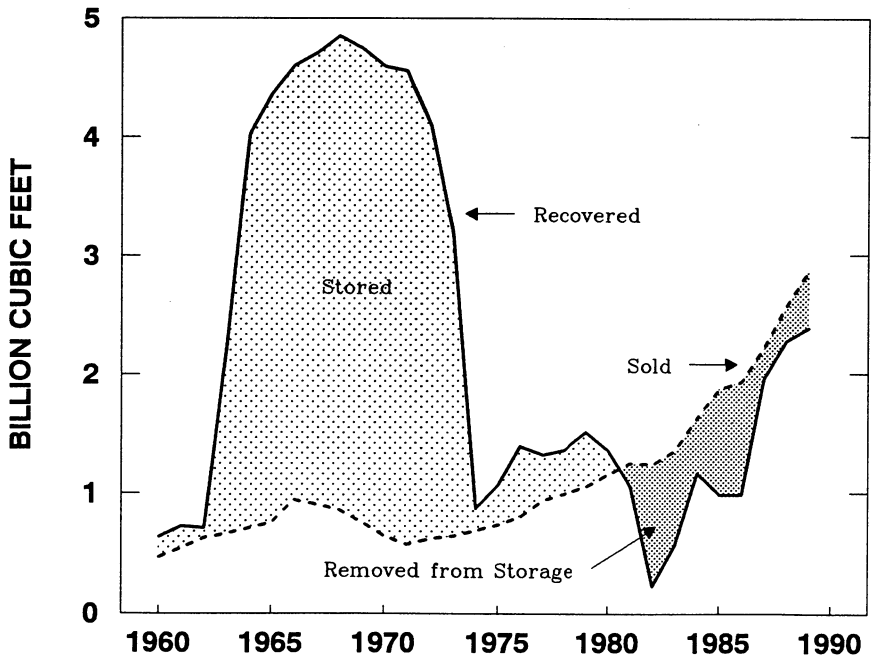
	1985	1986	1987	1988	1989
Crude helium:					
Bureau of Mines total storage	−411,681	−379,827	−289,085	−359,409	−377,508
Private industry:					
Stored by Bureau of Mines	487,576	431,917	730,360	630,748	547,158
Withdrawn	−956,462	−980,209	r−697,266	−551,997	−653,263
Total private industry storage	−468,886	−548,292	r33,094	78,751	−106,105
Total crude helium	−880,567	−928,119	r−255,991	−280,658	−483,613
Stored private crude helium withdrawn from storage and purified by the Bureau of Mines for redelivery to industry	−5,339	−18,658	−6,765	−11,920	−5,482
Grade-A helium:					
Bureau of Mines sold	397,446	333,447	266,594	316,954	350,154
Private industry sold	1,485,662	1,607,963	1,963,750	2,256,997	2,529,226
Total sold	1,883,108	1,941,410	2,230,344	2,573,951	2,879,380
Total stored	−885,906	−946,777	r−262,756	−292,578	−489,095
Grant total recovery	997,202	994,633	r1,967,588	2,281,373	2,390,285

r Revised.

[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



Kansas Refined Helium Co., Otis, KS; Exxon Company, U.S.A., Shute Creek, WY; and Union Carbide Corp., Linde Div., Bushton, Elkhart, and Ulysses, KS. Linde's helium plant at Elkhart, KS, was shut down in 1988 after modifications at their Ulysses, KS, plant were completed and it was restarted.

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 350 MMcf in 1989, an increase of about 10% when compared with last year's sales. This increase was due largely to the U.S. Department of Defense Strategic Defense Initiative projects and the National Aeronautics and Space Administration's (NASA) resumption of space shuttle flights, which include associated projects that use large volumes of helium. Sales to the U.S. Department of Energy continue to decline.

The Federal agencies purchase their major helium requirements from the Bureau of Mines. Direct helium purchases by Defense, NASA, Energy, 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

FIGURE 2

MAJOR U.S. HELIUM-BEARING NATURAL GAS FIELDS

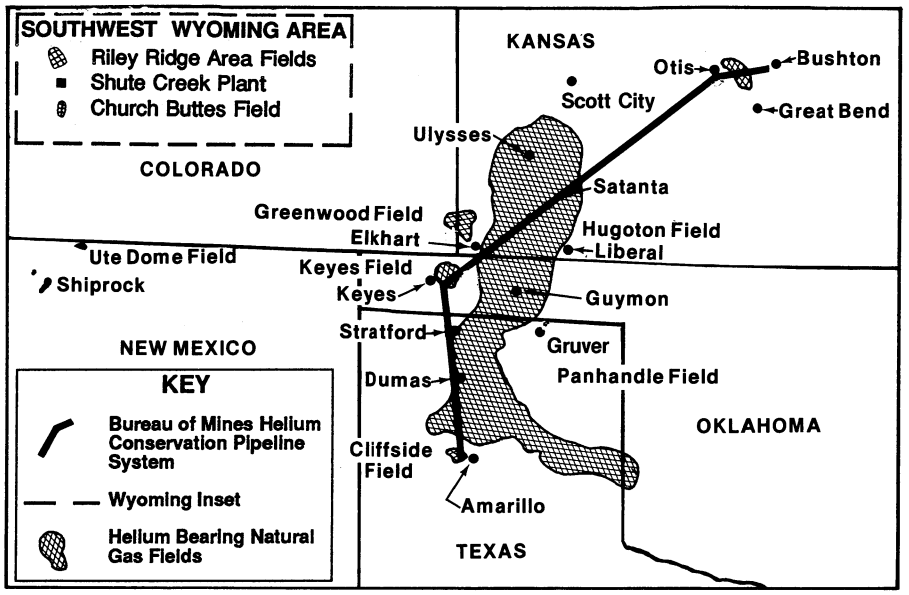


TABLE 3

SUMMARY OF BUREAU OF MINES HELIUM PLANT OPERATIONS

(Thousand cubic feet)

	1987	1988	1989
Grade-A supply			
Inventory at beginning of period[1]	17,784	38,899	35,937
Helium recovered: Exell plant[2]	294,474	325,912	355,581
Total	312,258	364,811	391,518
Grade-A disposal:			
Sales	266,594	316,954	350,154
Redelivered to private producers	6,765	11,920	5,482
Inventory at end of period[1]	38,899	35,937	35,882
Total	312,258	364,811	391,518

[1] At Amarillo and Exell helium plants.
[2] Includes 6,765 Mcf purified for private industry in 1987, 11,920 Mcf in 1988, and 5,482 Mcf in 1989.

TABLE 4

TOTAL SALES OF GRADE-A HELIUM IN THE UNITED STATES

(Million cubic feet)

Year	Volume
1985	1,444
1986	1,509
1987	1,736
1988	1,911
1989	2,083

future use in the Bureau of Mines helium conservation storage system, which includes the conservation pipeline network and the Cliffside Field near Amarillo, TX, totaled 35.1 billion cubic feet (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 1989, 547 MMcf of private helium was delivered to the Bureau's helium conservation storage system and 659 MMcf was withdrawn, for a net decrease of 112 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 semitrailers. Small gas cylinders are filled at the Amarillo plant, and railway tankcars are filled at the Exell plant. Other shipping containers for gaseous helium may be filled at either plant. Bureau liquid helium was shipped in dewars and semitrailers from the Exell plant exclusively. Private industrial gas 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 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 1989 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 20% in 1989 to 796 MMcf (table 7). About 53% of the exported helium was shipped to Europe. Belgium-Luxembourg, France, and the United Kingdom, collectively,

TABLE 5

BUREAU OF MINES SALES OF GRADE-A HELIUM BY PURCHASER[1]

(Thousand cubic feet)

	1987	1988	1989
Federal agencies:			
Department of Defense	95,386	96,934	121,913
Department of Energy	27,497	23,088	20,416
National Aeronautics and Space Administration	17,504	49,654	63,322
National Weather Service	766	841	711
Other	7,223	4,557	3,440
Total	148,376	175,074	209,802
Federal agency sales supplied by private contract helium distributors[2]	117,052	140,944	139,333
Commercial sales	1,166	936	1,019
Grand total	266,594	316,954	350,154

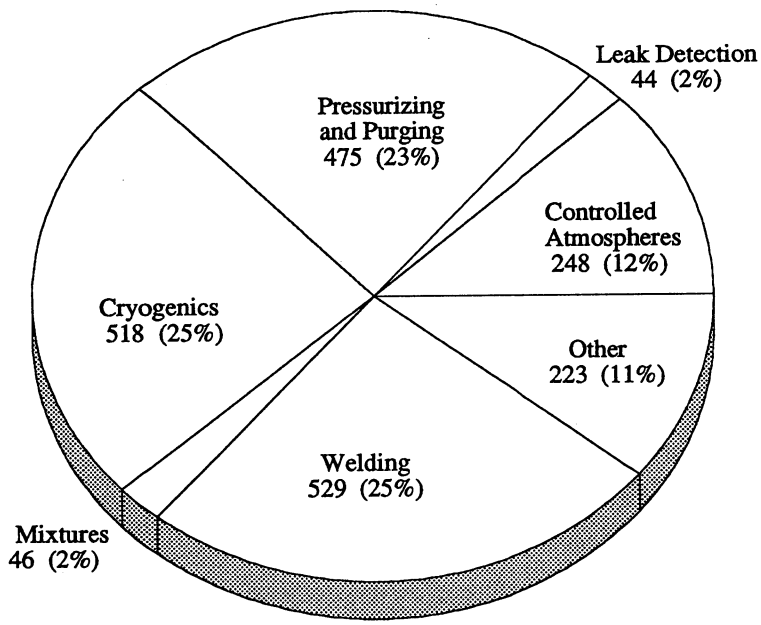
[1] Table identifies Federal purchaser, who might redistribute the helium to another Federal helium user.

[2] Purchased from the Bureau of Mines by commercial firms and redistributed to Federal installations under contract authority of 30 CFR 602.

FIGURE 3

ESTIMATED HELIUM CONSUMPTION BY END USE IN THE UNITED STATES IN 1989

(Million cubic feet)



Estimated Total Helium Used
(2,083 million cubic feet)

received about 88% of the European helium imports. About 34% of the U.S. helium exports went to Asia, with Japan taking about 85% of this helium. Other exports were as follows: 3% each to North and South America; over 2% each to Australia-New Zealand, the Middle East, and Central America; and less than 1% each to Africa and the Caribbean. The shipments of large volumes of helium to Western Europe were attributed to helium 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 1989, import tariffs on helium remained at the 3.7% rate established on January 1, 1987. No further decreases in import tariffs are currently scheduled.

WORLD REVIEW

World production of helium, excluding the United States, was estimated to be 250 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.

BACKGROUND

The 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, because of its natural gas expertise, for assistance. 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 Oklahoma 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

TABLE 6

SUMMARY OF BUREAU OF MINES HELIUM CONSERVATION STORAGE SYSTEM OPERATIONS[1]

(Thousand cubic feet)

	1987	1988	1989
Helium in conservation storage system at beginning of period:			
Stored under Bureau of Mines conservation program	34,405,169	34,116,084	33,756,675
Stored for private producers under contract	1,773,445	1,799,774	1,866,605
Total	36,178,614	35,915,858	35,623,280
Input to system:			
Net deliveries from Bureau of Mines plants[1]	-289,085	-359,409	-377,508
Stored for private producers under contract	730,360	630,748	547,158
Total	441,275	271,339	169,650
Redelivery of helium stored for private producers under contract[2]	-704,031	-563,917	-658,745
Net addition to system[2]	-262,756	-292,578	-489,095
Helium in conservation storage system at end 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

[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.

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, NASA, and the U.S. Department of Energy, 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 as all other Government plants have been dismantled or "mothballed."

In the mid-1970's, the Bureau began accepting privately owned crude helium for storage in Cliffside under long-term contracts. Private industry has a 1-year supply of helium in Government storage, assuming all market requirements would come from storage.

TABLE 7

U.S. EXPORTS OF GRADE-A HELIUM

(Million cubic feet)

Year	Volume
1985	439
1986	432
1987	494
1988	663
1989	796

Source: Bureau of the Census.

TABLE 8

WORLD GRADE-A HELIUM PRODUCTION CAPACITY, DECEMBER 31, 1989

(Million cubic feet)

	1989
United States	[1] 3,000
Rest of World[e]	250
Total[e]	3,250

[e] Estimated.
[1] Includes capacity of operating plants, as well as plants on standby.

Resources

Domestic measured and indicated helium resources as of January 1, 1989, the latest figures available, are estimated to be 535 Bcf. The total identified helium resources are about 1 Bcf more than reported in 1988. The increase is attributed to the reevaluation of the helium reserves of several fields in the midcontinent and southwest areas of the United States. The resources include measured reserves and indicated resources estimated at 257 and 32 Bcf, respectively, in natural gas with a minimum helium content of 0.3%. The measured reserves included 36 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 36 Bcf. Indicated helium resources in natural gas with a helium content of less than 0.3% are estimated to be 210 Bcf. Approximately 165 Bcf, or 93%, 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 located in the midcontinent and Rocky Mountain regions of the United States. The measured helium reserves are located in approximately 92 gasfields in 11 States. About 87% 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 Bureau of Mines analyzed a total of

174 natural gas samples from 18 States during 1989 in conjunction with its program to survey and identify possible new sources of helium.

TECHNOLOGY

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 that have limited their use in various superconducting applications. If these problems are solved, the new materials could replace liquid helium-cooled superconductors and adversely affect the liquid helium market. Most researchers seem to think it will be at least 5 to 10 years before the new materials affect liquid helium demand.

Meanwhile, 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 Department of Energy 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 Energy in January 1989.

Testing of the six liquid helium-cooled electromagnets supplied for the Large Coil Task was completed at Oak Ridge National Laboratory. These six magnets each incorporated slightly different designs, which were being tested to determine the best configuration for the confinement of fusion systems for 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 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 using 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.

Lifting gas applications are increasing. Many companies besides Goodyear are now using "blimps" for advertising. 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 Agency has installed six radar balloons 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 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.

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. Easing of tensions with the U.S.S.R. and Eastern Bloc nations might slow development of SDI weapons.

Superconducting magnetic energy storage (SMES) is also being investigated to provide power for Department of 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.

[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 is a physical scientist with the Branch of Nonferrous Metals. He has covered indium for 2 years. Domestic survey data were prepared by Lura Nightlinger, Nonferrous Data Section.

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 1989 were unavailable. The U.S. producer price for indium dropped throughout the year because of lower demand and increased world supply. The main uses were for indium tin oxide (ITO) and indium coatings, alloys, plating, and semiconductor compounds.

LEGISLATION AND GOVERNMENT PROGRAMS

On June 1, 1989, the Assistant Secretary of Defense announced the inclusion of indium in the National Defense Stockpile with a goal of 41,990 kilograms. Purchases were scheduled to begin at 2,488 kilograms annually for fiscal years 1990 and 1991.[1]

CONSUMPTION AND USES

Domestic consumption was about 25,000 kilograms in 1989. Thin coatings of indium on glass, used in applications such as liquid crystal displays (LCD) and heat-reflecting window coatings, were the largest use in 1989, accounting for 45% of consumption. Other uses were for electrical and electronic components, 25%; solder and alloys, 20%; 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 manufacturing semiconductors and solar cells.

Thin film coatings on glass, which use indium oxide and ITO, have been the largest area of growth for indium usage in the past 3 years. Solar cells, computers, digital displays, and infrared reflective window coatings to reduce energy costs were some major applications. Another area of increasing importance during this period was the use of high-purity indium as a constituent in semiconductors, which are used mainly for infrared and radiation detectors, fiber optics, and other optoelectronic devices.

Applications involving thin coatings on glass can be divided into two categories, electrically conductive and infrared reflecting. Electrically conductive coatings, which comprise the largest group, were used primarily in LCD's for watches, television screens, portable computer screens, video monitors, and other related display devices. An LCD consists of a liquid crystal material bonded between two sheets of glass that are coated on the inside with a transparent indium oxide or ITO film, which acts as an electrode. A polarizing filter is placed on the outside of the glass, and the entire display is sealed in plastic. A small change in voltage applied to the electrode causes the crystal to become oriented in a distinct pattern and blocks polarized light emitted from the back of the display, thus producing the display.[2]

Some aircraft and locomotive windshields used a transparent ITO film as a demister or defogger. In this application, electric current heats the film to clear the glass. Indium coatings are more effective than other types of materials, but its use is limited because of the higher cost. Many automobile manufacturers have also experimented with this use but, because of the higher cost, most of them used a zinc-silver oxide coating for quick defrost of 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 transparent, infrared reflecting coatings on window glass to control energy losses by reflecting heat inward during the winter and out in the summer. For residential windows, the coating was 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 retrofitting a commercial building remains high, other less expensive metals, such as silver, were used as a replacement for indium on new 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 higher temperature for improved efficiency.

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 and illuminates the area when electricity is applied. E-L lighting penetrates 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 used in infrared detectors and optoelectronic photonic devices such as fiber optics, laser diodes, optical computers, and signal processing. Indium phosphide was the leading substrate material for optical integrated circuits and laser diodes.[3] Indium antimonide and indium arsenide were used in infrared detectors for missile-guidance systems, night-vision instruments, and medical devices.

Copper-indium-diselenide (CIS) was a promising material for high-efficiency solar cells. CIS has demonstrated energy-conversion efficiency ratings of at least 9.7% for large panel units and 14.1% for small cells, with a goal of 15% to 20% efficiency by 2000. CIS cells were also more durable than other materials, such as amorphous silicon. For the cells to become economically viable, two other goals have to be achieved. They must have a 30-year lifespan, and the cost of production must drop from the current range of $100 to $240 per square meter ($m^2$) to near $50 per m^2. Other indium solar-cell materials, such as copper-indium-gallium-diselenide were more expensive to manufacture than CIS, but had higher energy conversion ratios.[4]

A major domestic use for indium has been as an alloying addition to bismuth, cadmium, lead, mercury, or tin to lower the melting point. These alloys can be used in such applications as a heat fuse material for fire-protection systems, or a holding material for the grinding of optical glass. Indium was used in combination with tin for glass-to-metal and glass-to-glass seals.

Low-temperature, indium-base solder was used as a replacement for tin-lead solder, because advanced electronic components can be damaged by the temperature of tin-lead solder. Indium-base solders melt at a much lower temperature and remain flexible over a greater temperature range. Unlike tin-lead solder, which can leach gold or other precious metals and cause a defective solder joint, indium does not react with those metals. The DOD was studying the inclusion of indium-base solders for military specifications.

Several manufacturers of pressurized water reactors used an alloy consisting of 80% silver, 15% indium, and 5% cadmium for nuclear control rods. This use 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.

Because of its softness and ability to cold-weld to itself, certain breath-analyzer units used an indium tube as a containment device. To obtain a specimen, the person exhales into the unit and a breath sample is crimped inside the tube and sent to a laboratory for analysis. This method, however, was losing its share of the market to electronic methods of detecting intoxicants.

Minor uses included indium-palladium and indium-gold alloys in dentistry, 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 neurons easily induce radioactivity in indium.

PRICES

A slight increase in world stocks of indium and reduced demand resulted in lower prices. The price of standard-grade, 99.97%-purity indium in the United States gradually decreased from $9.65 per troy ounce in January to $7.80 per troy ounce in December.

WORLD REVIEW

World refinery production in 1989 was about 115 metric tons. Belgium, France, Italy, and Japan were the largest producers. World consumption was about 110 tons. Japan and the United States were the largest consumers.

Canada

Cominco Ltd. commenced operations at its new indium refinery at Trail, British Columbia. The company planned to adjust the output to prevailing market conditions. Production capacity of the new facility was 30 tons per year. Problems with the startup of the plant caused production to be less than planned in 1989.

In January, Johnson Matthey Plc., United Kingdom, purchased facilities for producing high-purity metals, including indium, in Spokane, WA, and Trail, British Columbia, from Cominco Ltd. Cominco Electronic Materials (CEM) produced high-purity indium and other metals for semiconductors and a variety of indium solders, wire, and sputtering targets at the two production facilities. The purchase included Crystal Research Inc., another subsidiary of Cominco that conducted research on high-purity metals at Vancouver, British Columbia. Johnson Matthey continued operations at the existing plants using source material from Cominco. The new company, Johnson Matthey Electronics, was headquartered in Spokane.

Falconbridge Ltd. and Indium Corp. of America planned to complete a new indium recovery plant at Falconbridge's Kidd Creek Mine at Timmons, Ontario, in late 1990. Indium Corp. planned to refine the material at its plant in Utica, NY, and to gradually increase its production to about 30 tons per year. Canada would become the world's largest producer of refined indium upon completion of these projects.

Japan

Nippon Mining Co. Ltd., the largest producer of indium in the world, began developing a new lead-zinc deposit on Hokkaido, which according to the company contained an estimated 3 million tons of ore. Indium, silver, and copper were expected to be produced as byproducts.[5]

Japan increased its reported output of refined indium from 27 tons in 1987 to 49 tons in 1989, thereby becoming the largest producer in the world. The reported figure included indium produced from lower purity metal imported from Europe and North America. Therefore, actual production was estimated at 31 tons in 1989. Consumption in Japan was estimated at 60 tons in 1989 and was expected to increase substantially over the next 5 years. The leading uses of indium in Japan were for transparent, electrically conductive coatings on glass, electroluminescent lamps, and semiconductors.

CURRENT RESEARCH

In May 1989, space shuttle mission

STS-30 conducted experiments on producing high-grade indium in a weightless environment. Indium Corp. of America supplied several indium rods for use in the Fluids Experiment Apparatus. In the process, an indium rod was slowly moved through a heat source, which caused the impurities to concentrate at one end of the rod, resulting in a high-purity metal. The results of the study were being analyzed. A similar experiment was expected to be performed on STS-32 in January 1990.[6]

Several companies developed high-speed indium phosphide computer chips for data transmission. The chips operate at speeds up to 250 billion oscillations per second (GHz), compared to silicon materials, which usually operate below 2 GHz. The chips use High-Electron-Mobility-Transistors (HEMT), in which the impurities are not in the regions in which the charge-carrying electrons travel, resulting in faster speeds.[7] The chips were expected to be used to send data via optical fibers and for satellite transmission. Other HEMT applications under development included collision-avoidance radar for cars and radar systems for smart weapons, which can discern a target's shape though fog or smoke.[8]

OUTLOOK

World reserves and anticipated increases in production capacity are sufficient to meet expected demand for indium through 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.

BACKGROUND

Definition, Grades, and Specifications

Indium is silvery-white in color and has a brilliant metallic luster. It is softer than lead, very ductile and malleable; hence, it is well suited for use in solders and low-melting alloys. It retains these plastic-like properties to temperatures near absolute zero. Indium does not work harden, 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, 2080° 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, Provi-

TABLE 1

U.S. IMPORTS FOR CONSUMPTION OF INDIUM,[1] BY CLASS AND COUNTRY

Class and country	1987		1988		1989[2]	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Unwrought and waste and scrap:						
Belgium	10,421	$1,994	8,957	$2,855	6,035	$2,544
Bulgaria	—	—	17	76	—	—
Canada	1,344	286	1,685	619	357	105
China	4,596	933	3,378	542	2,444	629
France	10,600	1,614	4,729	1,576	4,629	1,324
Germany, Federal Republic of	273	102	439	111	2,931	485
Hong Kong	466	144	—	—	44	12
Italy	5,745	1,121	7,490	2,553	2,150	604
Japan	907	478	351	416	659	500
Netherlands	1,442	219	1,771	182	1,109	313
Peru	3,177	643	1,698	487	914	492
U.S.S.R.	—	—	—	—	529	135
United Kingdom	8,141	1,887	6,460	3,452	5,012	1,801
Total	47,112	9,421	36,975	[3]12,870	26,813	8,944
Wrought:						
China	11	17	3	11	—	—
Japan	43	61	79	34	—	—
United Kingdom	166	297	171	401	—	—
Other	—	—	822	69	—	—
Total	220	375	1,075	[3]516	—	—

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable to those in 1987 and 1988.
[2] Beginning in 1989, only data for unwrought and waste and scrap are available.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 2

ESTIMATED WORLD INDIUM REFINERY PRODUCTION AND CAPACITY, DECEMBER 31, 1989

(Metric tons)

	Production	Capacity
North America:		
Canada	NA	30.0
United States	NA	30.0
Total	15.0	60.0
South America:		
Peru	2.0	6.0
Europe:		
Belgium	18.0	25.0
France	15.0	15.5
German Democratic Republic	—	3.0
Germany, Federal Republic of	5.0	15.5
Italy	10.0	12.0
Netherlands	1.0	3.0
U.S.S.R.	6.0	15.0
United Kingdom	3.0	6.0
Total	58.0	95.0
Asia:		
China	9.0	12.0
Japan	31.0	50.0
Total	40.0	62.0
World total	115.0	223.0

NA Not available.

dence, RI, and Indium Corp. of America, 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 produce high-purity indium shapes, ingots, and foil. Metalspecialties Inc., Fairfield, CT, and Powmet Inc., Rockford, IL, occasionally recover indium from old scrap.

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 was believed to contain the largest quantity of indium.

Refining capacity was historically based in Europe. However, in recent years refining capacity shifted to Asia and North America because of increased production in Japan and planned expansions in the United States and Canada. The major world refiners were:

Company	Location
Billiton Metaalundustrie NV	Netherlands
Cominco Ltd.	Canada
Capper Pass Ltd.	United Kingdom
Empresa Minera del Centro del Perú S.A. (Centromin-Peru)	Peru
Metaleurop	Federal Republic of Germany
Do.	France and Italy
Metallurgie Hoboken-Overpelt	Belgium
Mining and Chemical Products Ltd.	United Kingdom
Nippon Mining Co. Ltd.	Japan

Geology-Resources

Indium occurs predominantly in solid solution in sphalerite, but has been reported in other base-metal ores of copper, lead, and tin. It is not known to occur in the native state. The average indium content of the Earth's crust was estimated at 0.1 parts per million (ppm).[9] The indium content of mined zinc deposits ranged from 0 to 100 ppm. The highest known indium occurrences 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 ppm. Deposits include the Central City District, CO, the Argentine Andes, the Cornwall tin district in England, and the Mount Pleasant tin deposit in New Brunswick, Canada.[10] Because indium was frequently recovered as a byproduct of zinc, world indium reserves were based on estimates of the average indium content of zinc ore for a particular region.

Technology

Processing.—A variety of methods were employed to recover indium, depending on the source material and indium content. Indium was primarily recovered as a byproduct of zinc processing. Among the more common methods of recovery were 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 was used to recover indium from dilute solutions. Another method involved 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 concentrates, 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.[11]

Byproducts and Coproducts

Domestically refined indium was a minor byproduct of processing base metal ores or zinc residues. The value of recovered indium was negligible in relation to the value of zinc production. Coproducts include tungsten, molybdenum, silver, and tin.

[1] Federal Register. Office of the Secretary of Defense. V. 54, No. 109, June 8, 1989, p. 24587.

[2] Roskill Information Services Ltd. The Economics of Indium. 4th ed., 1987, 100 pp.

[3] Lasers and Optronics. At RADC Hanscom, A Two-Pronged Approach. V. 8, No. 5, May 1989, pp. 26-28.

[4] Zweibel, K., H. S. Ullal, and R. L. Mitchell. Polycrystalline Thin Film Photo Voltaics, Proc. of the 21st IEEE PV Specialists Conf., Kissimmee, FL, May 21-25, 1990, 9 pp.

[5] Mining Journal (London). New Mine for Nippon. V. 312. No. 8009, Mar. 3, 1989, p. 167.

[6] Materials Engineering. V. 106, June 1989, p. 14.

[7] Journal of Metals. V. 42, No. 1, Jan. 1990, p. 4.

[8] The Wall Street Journal (New York). Speeding Flow of Data with Indium Phosphide. Apr. 9, 1990, p. B1.

[9] Hurlbut, C. S., Jr., and C. Klein. Manual of Mineralogy. Wiley, 19th ed., 1977, pp. 123-124.

[10] Work cited in footnote 2.

[11] White, C. E. T. Indium: High Technology Metal. Advanced Mater. and Processes Inc. Metal Progress, Dec. 1986, pp. 69-72.

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Metal Bulletin (London).
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IODINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the Bureau of Mines, has been the commodity specialist for iodine for 11 years. Domestic survey data were prepared by Blanche Hughes, mineral data assistant, and international data tables were prepared by Peter Roetzel, international data assistant.

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 Bureau of Mines from a voluntary survey of U.S. operations. Of the four operations to which a survey request was sent, three responded, representing an estimated 55% of the total production shown in table 5.

LEGISLATION AND GOVERNMENT PROGRAMS

The Food and Drug Administration extended the provisional listing for Red Dye No. 3, erythrosine containing 58% iodine by weight, until January 29, 1990, for cosmetic uses.[1]

STRATEGIC CONSIDERATIONS

The National Defense Stockpile (NDS) contained 6.1 million pounds of crude iodine valued at $54 million in inventory at yearend. The stockpile goal remained at 2.6 million kilograms (kg) (5.8 million pounds). Responsibility for the NDS was transferred from the Federal Emergency Management Agency and the General Services Administration to the Department of Defense (DOD) (Public Law 100–180). Within DOD, the Defense Logistics Agency (DLA) was to handle the buying, selling, and storing of NDS materials. Executive Order 12626 designated the Secretary of Defense as the National Defense Stockpile Manager.

The National Defense Authorization Act of 1989 (Public Law 100–456) authorized the stockpile manager to dispose of 19 materials, including iodine, determined to be in excess of stockpile requirements. DLA announced that offers for the purchase of iodine would be considered during fiscal year 1989. At yearend 1988, 200,000 pounds was disposed of, leaving 137,657 kgs (303,482 pounds) in excess of the goal at yearend 1989 that was valued at $2.4 million or $17.24 per kg ($7.82 per pound).

PRODUCTION

IoChem Corp., located 2 miles east of Vici, OK, produced iodine by the blowing-out process. IoChem expanded capacity from about 1 million pounds per year to about 4 million pounds per year. North American Brine Resources operated two miniplants at Dover and Hennessey in Kingfisher County, OK. The plants were at oil field reinjection disposal sites where iodine concentrations ranged up to 1,200 parts per million (ppm). The company completed a new $5 million plant in Harper County. Woodward Iodine Corp., a subsidiary of Asahi Glass Co. of Japan, produced iodine from brines using the blowing-out process.

CONSUMPTION AND USES

Iodine was used in animal feed supplements, catalysts, inks and colorants, pharmaceutics, photographic equipment, sanitary and industrial disinfectants, stabilizers, and radiopaque medium. Other uses included production of high-purity metals, motor fuels, iodized salt, and lubricants.

A major use of iodine is as a catalyst in the production of acetic acid by the Monsanto process. BP Chemicals Inc. modified the process to coproduce acetic acid and acetic anhydride. BP is the second largest acetic acid producer with a capacity of 870,000 tons.[2]

Uniroyal Chemical Inc. is a major consumer of iodine for use as an oxidizer in the production of rubber chemicals and elastomers with joint ventures in Brazil, India, Korea, and Mexico. Uniroyal Chemical Co. was purchased with $240 million cash and $560 million as assumed debt in a leverage buyout by a management led team.[3]

Ecolab Inc., a major consumer of iodine for use in cleaning products, sold Henkel KGaA, its West German counterpart, an 11.8% voting interest in preferred stock for $110 million.[4]

GAF Corp. is a major consumer of pyrrolidone-base chemicals that can be used as an environmentally safe cleaning solvent replacing chlorofluorocarbons.[5]

Eastman Kodak Co., a major consumer of iodine in photographic uses, formed a new business unit, Eastman Fine Chemicals, that included Sterling Organic external chemical sales business and sections of Eastman Chemicals specialty organic operations.[6]

Mallinckrodt Inc., a subsidiary of International Minerals & Chemical Corp., began marketing a nonionic contrast medium for radiology and cardiology X-ray procedures. The United States market for X-ray contrast media

is about $500 million annually. The worldwide market was more than twice the U.S. market.[7]

Ceralure, an iodine-containing lure for the Mediterranean fruit flies, developed by the U.S. Department of Agriculture, may replace the use of helicopter sprays.[8]

PRICES

The average declared c.i.f. value for imported crude iodine was $17.68 per kg ($8.05 per pound). The average declared c.i.f. value for imported crude iodine from Japan averaged $17.64 per kg ($8.00 per pound). The average declared c.i.f. value for iodine imported from Chile was $18.01 per kg ($8.17 per pound.

Quoted yearend U.S. prices for iodine and its primary compounds are shown in table 2.

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.

WORLD REVIEW

The World Health Organization, headquartered in Geneva, Switzerland, published "Guidelines for Iodine Prophylaxis following Nuclear Accidents" (EH-35). The guidelines were a result of experience gained from the Chernobyl nuclear accident that exposed population groups to radioactive iodine.

Capacity

The data in table 4 are rated capacity for plants 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 iodine is based on rated capacity as reported by the company, by 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 produced iodine, sodium nitrate, potassium nitrate, and sodium sulfate. SOQUIMICH continued to operate a plant at Puelma. SOQUIMICH had a joint venture with Israel Chemicals

TABLE 1

U.S. CONSUMPTION OF CRUDE IODINE, BY PRODUCT

Product	1988 Number of plants	1988 Consumption (thousand kilograms)	1989 Number of plants	1989 Consumption (thousand kilograms)
Reported consumption:				
Resublimed iodine	7	86	7	143
Hydriodic acid	4	42	3	49
Calcium iodate	(1)	(1)	(2)	(2)
Calcium iodide	(1)	(1)	3	119
Cuprous iodide	(1)	(1)	3	15
Potassium iodide	7	886	6	829
Potassium iodate	(1)	(1)	5	56
Sodium iodide	5	177	4	46
Other inorganic compounds	13	1,027	14	821
Ethylenediamine dihydroiodide	5	390	4	398
Other organic compounds	10	245	8	426
Total	[3]29	2,853	[3]31	2,902
Apparent consumption	XX	4.3	XX	4.8

XX Not applicable.
[1] Included in "Other organic compounds."
[2] Included with calcium iodide for 1989.
[3] Nonadditive total because some plants produce more than one product.

TABLE 2

YEAREND 1989 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	$7.44
Calcium iodide, 50-kilogram drums, f.o.b. works	23.65- 25.65	12.07- 11.62
Iodine, crude, drums	19.00- 20.00	8.61- 9.06
Iodoform, N.F., 300-pound drums, f.o.b. works	24.00	10.82
Potassium iodide, U.S.P., drums, 5,000-pound lots, delivered	9.15	4.14
Iodine, U.S.P.	17.00	7.70
Sodium iodide, U.S.P., crystals, 5,000-pound lots drums, freight equalized	10.15	4.60

[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. 237, No. 1, Dec. 29, 1989, pp. 32-39.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1988		1989	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude:				
Belgium	11	256	30	545
Canada	(2)	5	(2)	9
Chile	792	13,828	1,014	18,298
Germany, Federal Republic of	—	—	(2)	1
Japan	450	7,812	2,251	39,751
Mexico	—	—	13	178
Sweden	—	—	(2)	13
United Kingdom	2	43	—	—
Total	[3]1,255	21,944	3,309	58,795
Iodide, potassium:				
Germany, Federal Republic of	(2)	6	1	28
India	28	478	7	121
Italy	3	11	9	31
Japan	(2)	10	—	—
Sweden	(2)	3	—	—
Switzerland	—	—	(2)	5
United Kingdom	2	138	—	—
Total	[3]34	646	17	185
Iodine, resublimed:				
Canada	(2)	2	NA	NA
Finland	(2)	3	NA	NA
Germany, Federal Republic of	(2)	1	NA	NA
Japan	1,969	33,326	NA	NA
Total	[3]1,969	33,332	NA	NA
Grand total	3,258	55,912	3,326	58,980

NA Not avaliable because a change in reporting format; crude and resublimed iodine are now one category.
[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.

Ltd. named Compania Quimica Internacional de Desarrollo (IDC Co.) dedicated to research and development in the inorganic chemicals and fertilizers.[9]

North Lily Mining Co. of the United States formed a joint venture, named Taltal Joint Venture, with Zurfund International Ltd., Canada, to mine iodine. North Lily will operate the deposit known as the Yolanda Project through Minera Northern Resources, a wholly owned subsidiary. Davey McKee Corp. was retained by the Taltal Joint Venture to undertake a feasibility study of the Yolanda Project.[10]

Other companies active in iodine production in Chile included 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 was operating a plant originally built by Minera Lagunas. The plant had been expanded with a $3 million investment. The crude product was shipped to the Netherlands for use by the producing company rather than for an open market.[11] Cia Minera Chilbras, a Chilean-Brazilian joint venture, produced iodine from nitrate deposits in the Salar de Bellavista.[12] The Merck Pharmaceutical Co. of the Federal Republic of Germany was involved in a project to produce between 4 to 5 tons per year of iodine from nitrate tailings near Huara in the Iquiqui region.[13] Compania Minera Sierras de Tarapaca began production of iodine at the San Pedro plant 37 kilometers east of Pozo Almonte, Tarapaca. The plant cost $2 million and had a 360 tons per year of capacity.[14] Banco Bilbao Vizcaya S.A., Spain, announced a $19.2 million iodine recovery facility to be built on 1,184 hectares of land purchased for $14 million from Cia Minera Gran Tamarugal S.A. The plant planned to produce 4,750 tons of iodine the first 10 years with production destined for markets in Europe.[15] Compania Minera del Alba operated a small plant at Salar de Lagunas.

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 20 million pounds per year.

United Kingdom

Thornton Processing Ltd., Bradford, reported that during 1988 more

TABLE 4

WORLD IODINE ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989 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 standby basis.
[3] Data do not add total shown because of independent rounding.

than $2 million worth of iodine was recovered at the Caledonia plant from industrial residues, principally those generated from growing sodium iodide crystals.

CURRENT RESEARCH

Because of their reaction with metals in the presence of water, alkyl halides may find use in metal recovery and refining and methyl iodide in metallurgical processing. Because algae serve as a major source of environmentally occurring methyl iodide, a microorganism approach in the metallurgical process could be possible in the future.[16]

When natural rubber, a polymer, is treated with iodine, it becomes 10 orders of magnitude more highly conducting than native rubber. If further research can improve the conductivity, then commercial applications could be possible.[17]

A researcher with Nippon Steel Corp., Japan, used a catalyst of cadmium and cesium iodides to make liquid crystalline polyesters that could be used in magnetic recording tapes, dielectrics in capacitors, and thermal printer ribbons.[18]

Three experiments to grow lead iodine crystals were completed during a National Aeronautics and Space Administration's *Discovery* space shuttle flight of September 1988. Lead iodide crystals are used as image intensifiers for X-ray and gamma-ray films. Larger crystals would produce better films. Crystals grown in space are superior to Earth-grown crystals for some applications.[19]

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. New processes have decreased the amount of iodine while demand has increased. For example, a patent was obtained that required less iodine to provide the same sanitizing ability.

BACKGROUND

Definitions, Grades, and Specifications

Commercial crude iodine normally has a minimum purity of 99.5%. Resublimed iodine is usually 99.9% purity. Most iodine is converted for industrial use to potassium iodide, sodium iodide, and other inorganic compounds, as well as numerous organic compounds.[20]

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.

TABLE 5

CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Chile	3,020,000	3,076,000	3,115,000	4,035,000	4,000,000
China[e]	500,000	500,000	500,000	500,000	500,000
Indonesia	13,000	6,000	8,000	10,000	[3]14,000
Japan	7,251,000	7,389,000	7,014,000	7,451,000	7,600,000
U.S.S.R.[e]	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
United States	W	W	W	998,000	[3]1,508,000
Total	[4]12,784,000	[4]12,971,000	[4]12,637,000	14,994,000	15,622,000

[e] Estimated. [p] Preliminary. W Withheld to avoid disclosing company proprietary data.
[1] Table includes data available through May 30, 1990.
[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.

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

In the United States and Japan, iodine is removed from brines by processes that separate the brines from any associated oil or gas. In the blowing-out process, brine is acidified and iodine is liberated by reducing the pH to about 3. A countercurrent stream of air transports the liberated iodine to a second tower in which the iodine is absorbed by a solution of hydriodic acid. The iodine settles, is filtered, and melted under concentrated acid. Brine stripped of iodine is treated and then reinjected into its subsurface formation of origin.

In the absorption process, brine is passed through an absorber and the waste brine is neutralized and sent to a disposal well. The absorbent laden with iodine is treated with an alkaline solution to regenerate the absorbent and eludes iodine as sodium iodide. Iodide is precipitated under acid.

Japanese plants also use an ion-exchange resin. Upon saturation, the iodine is eluted using a caustic solution that regenerates the resin. Iodine is then processed with a sodium chloride solution and melted under acid.

Chilean caliche deposits are mined by open pit methods. The ore is leached with an alkaline solution to dissolve the iodine as sodium iodate, which is converted to sodium iodide. Iodine is precipitated by reacting with additional alkaline solution. The precipitated iodine is filtered in bag filters and the iodine free-leach solution is returned to the nitrate-leaching cycle.

Economic Factors

Prices.—Changes in the official price of crude iodine have in the past been initiated during shortages. Because iodine cannot be substituted in radiopaque, animal feeds, catalysts, and stabilizers readily, shortages tend to cause the accumulation of inventories. An adequate supply tends to 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.

Taxes.—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 iodine are 14% of gross income, and they may not exceed 50% of net income without the depletion deduction.

TABLE 6

TIME-PRICE RELATIONSHIPS FOR CRUDE IODINE

Year	Average annual c.i.f.[1] value, dollars per pound		Average annual c.i.f.[1] value, dollars per kilogram	
	Actual price	Based on constant 1988 dollars	Actual price	Based on constant 1988 dollars
1970	1.15	3.32	5.59	3.32
1971	1.58	4.32	3.48	4.32
1972	1.64	4.28	3.62	4.28
1973	1.72	4.21	3.79	4.21
1974	1.86	4.18	4.10	4.18
1975	2.21	4.52	4.87	4.52
1976	2.13	4.09	4.70	4.09
1977	1.05	3.69	2.31	3.69
1978	2.21	3.71	4.87	3.71
1979	3.37	5.20	7.43	5.20
1980	4.72	6.68	10.41	6.68
1981	6.03	7.78	13.29	7.78
1982	5.97	7.24	13.16	7.24
1983	5.57	6.50	12.28	6.50
1984	4.90	5.50	10.80	5.50
1985	5.38	5.88	11.86	5.88
1986	5.68	6.05	12.52	6.05
1987	6.92	7.15	15.26	7.15
1988	7.92	7.92	17.46	7.92
1989	7.70	7.70	16.98	7.70

[1] Cost, insurance, and freight charges for imported iodine.

Source: Bureau of the Census.

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 mg of iodine per year, which is usually consumed as iodized salt that contains 1 part sodium or potassium iodide to 100,000 parts of sodium chloride. Iodine deficiency is a major cause of goiter.[21]

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. Ingestion of potassium iodide, KI, can reduce the amount of radiation absorbed by the thyroid gland.[22]

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IRON ORE

By Peter H. Kuck and Cheryl M. Cvetic

Dr. Kuck has been the commodity specialist for iron ore since 1986. Ms. Cvetic joined the Bureau of Mines in 1988 and has a background in geology and international business. The domestic survey data were compiled and analyzed by Sarah P. Guerrino, Chief of the Ferrous Data Section. The world production table was prepared by Peter J. Roetzel in the International Data Section.

A cursory glance at the salient statistics in table 1 suggests that the domestic iron ore industry made little headway in 1989. In actuality, dramatic technological changes occurred that will have far-reaching effects on the entire iron and steel sector in both North America and the rest of the world.

The United States produced 59.03 million metric tons (Mmt) of usable iron ore during the year. Although the tonnage was only slightly more than that of 1988, significant improvements were made in pellet quality. For the first time, fluxed pellets accounted for more than one-third of production. Fluxed or partially fluxed pellets were being made at six of the Nation's nine active taconite plants. A 10th plant, the E.W. Davis Works at Silver Bay, MN, was reactivated in December, but did not begin producing pellets until January 27, 1990.

Mine shipments of pellets, concentrates, and direct shipping ore totaled 58.30 Mmt, again an amount only slightly higher than that of 1988. Combined U.S. imports of ore, concentrates, and agglomerates decreased 3% to 19.60 Mmt, with Brazil and Venezuela gaining market share at the expense of Australia and Canada. Exports, in contrast, have been slowly creeping upward since 1985. Virtually all of the 5.37 Mmt exported in 1989 went to Canadian steel companies that hold equities in U.S. taconite projects. Consumption of iron ore by the iron and steel industry rose slightly between 1988 and 1989 to 73.06 Mmt. Pig iron production was 50.69 Mmt, virtually the same as in 1988, for an average output of 4.22 Mmt per month. On December 31, 48 blast furnaces were in operation, 2 less than at the end of 1988.

DOMESTIC DATA COVERAGE

U.S. production data for iron ore are developed by the 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 31 addressees to whom the 1066-A form was sent, 30 responded, representing 99.99% of total production shown in tables 1 through 4. Production for nonrespondents to the annual survey can be estimated from monthly surveys (1066-M), from railroad reports, or from reported production levels in prior years. This information may be supplemented by employment data, mine-inspection reports, and information from consumers.

Data on consumption and stocks of iron ore and agglomerates at iron and steel plants were provided by the American Iron Ore Association (AIOA). AIOA also provided data on ore shipments from loading docks on the upper Great Lakes as well as receipts at transfer docks and furnace yards nationwide. The dock and steel plant data were compiled jointly by AIOA and the American Iron and Steel Institute (AISI). Data on consumption of iron ore for nonsteel end uses were compiled from information gathered from other Bureau surveys.

LEGISLATION AND GOVERNMENT PROGRAMS

Congress enacted the Omnibus Trade and Competitiveness Act (Public Law 100-418) on August 23, 1988, to enhance the competitiveness of the Nation's industries and to improve the management of U.S. trade strategy. This comprehensive act, included among other items, provisions modifying U.S. customs laws and tariff schedules. Subtitle B of the new law requires that all tariff schedules after January 1, 1989, conform to the nomenclature of the internationally established Harmonized System—a global system of classifying products for tariff purposes that had been adopted earlier by many major trading countries.

The new law restructured both the import and export classification systems. The new schedule B classification is now based on the organizational framework of the Harmonized Tariff Schedule of the United States (HTSUS). That is, equivalent import and export items are assigned the same 10-digit classification code. In the case of iron ore, seven subheadings replaced the two less definitive ones in use since September 1963.

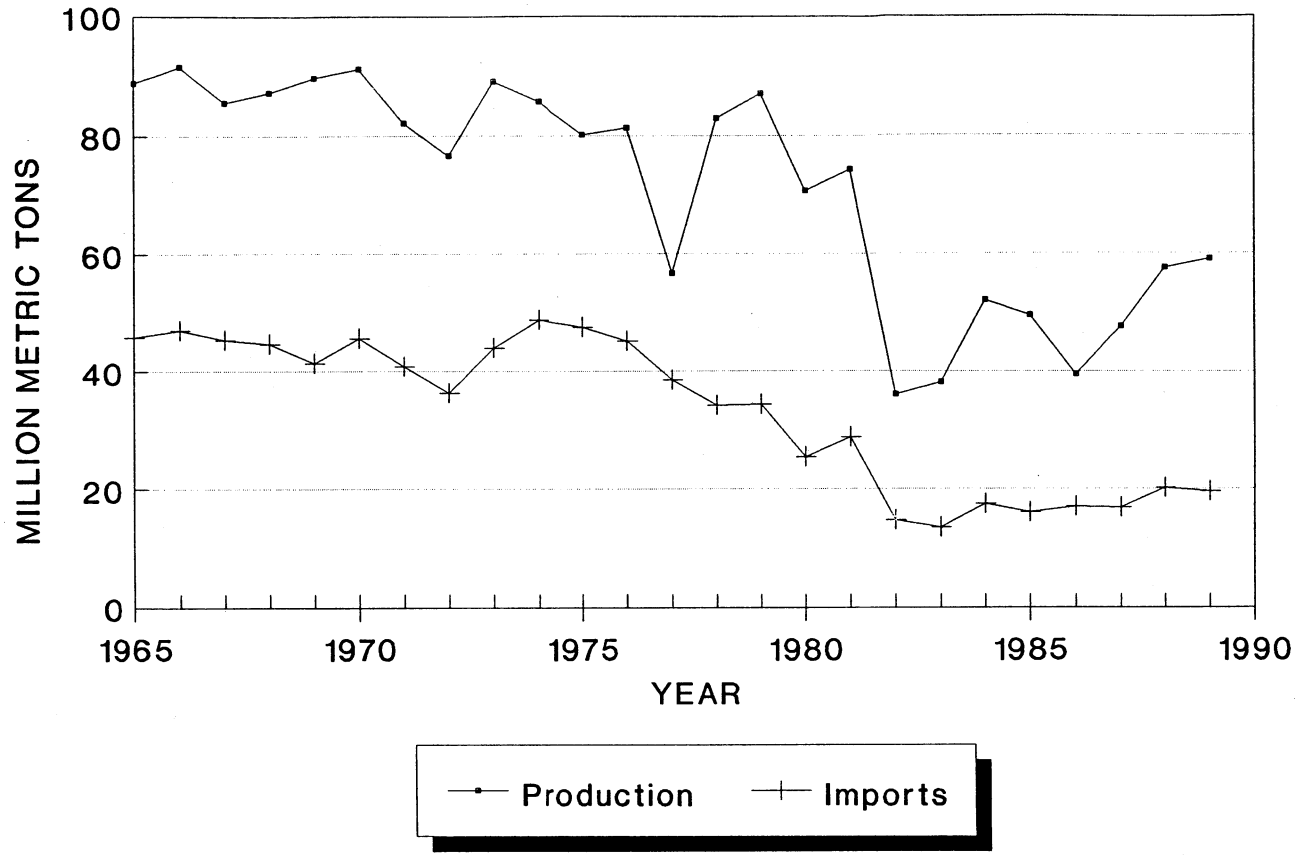
Various Executive and Congressional mandates have directed that all Federal Agencies convert their statistics to the International System of Units in a timely manner. The principal regulations governing the conversion are contained in the Metric Conversion Act of 1975 (Public Law 94-168), as amended in 1988 (Public Law 100-418). All of the iron ore trade statistics collected by the Bureau of the Census are now being compiled and published in *metric* units. The Bureau of Mines also has begun publishing its statistics on iron ore production and consumption in *metric* units. To convert from metric tons to long tons, multiply by 0.984207.

EMPLOYMENT

Statistics on employment and productivity in the U.S. iron ore industry in

FIGURE 1

U.S. IRON ORE PRODUCTION AND IMPORTS FOR CONSUMPTION



1989, shown in table 2, were derived from quarterly employment data supplied by the Mine Safety and Health Adminstration (MSHA) and from production data derived from 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 798 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 140 individuals were engaged in the secondary beneficiation of iron ore for heavy media and other nonsteel uses.

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 10% more than that of 1988, with at least two mine operators calling back laid off workers to meet increased pellet demand from domestic steel producers and start up idled capacity. The additional personnel enabled the iron ore industry to boost its output of usable ore by 3%. The relatively small gain 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.

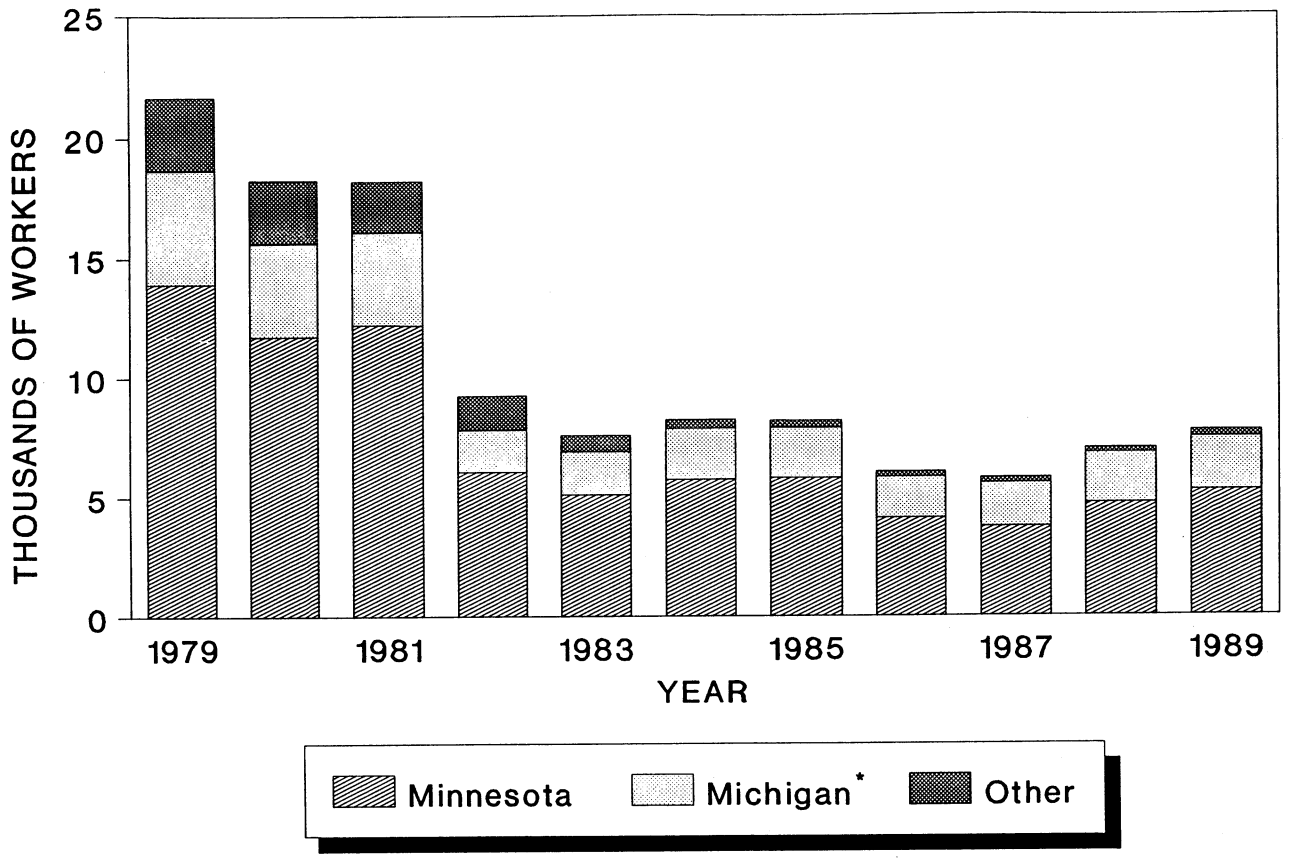
Total hours worked rose 10% because of the renovation project, the recalls, and increased level of production. The increase in demand came at a time when at least three operations in the Lake Superior District had begun switching over to fluxed pellet production or making other major technological improvements. 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 7.4% lower than that of 1988. Because the district accounts for the bulk of U.S. output, the average productivity for the entire industry dropped 6.9%.

PRODUCTION

The outlook for the domestic iron ore industry has changed dramatically since the disastrous summer of 1986 when

FIGURE 2

EMPLOYMENT AT IRON MINES AND BENEFICIATING PLANTS



*Includes workers in Wisconsin for years prior to 1984.

monthly pellet production dropped below the 3.5-Mmt level. At that time, USX Corp. was shut down by a nationwide work stoppage, and LTV Corp. had just filed for reorganization under chapter 11 of the Federal Bankruptcy Code. However, by reducing costs, recapitalizing, adopting new technologies, and improving pellet quality, the iron ore industry extricated itself from a difficult situation that skirted total economic collapse. A strengthening of demand for finished steel products in the wake of these improvements caused domestic iron ore shipments to jump 36% between 1986 and 1988. Ore sales continued to improve in 1989, with shipments reaching 58.30 Mmt, the highest level since 1981. Two taconite operations, the Empire and Minorca Mines, set new records for pellet production in 1989. Total output of usable ore was equivalent to about 71% of installed production capacity on January 1, 1989. This percentage was a considerable improvement over that of 1987 and 1986, when the utilization factors were 55% and 46%, respectively. 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; increased demand for steel worldwide; and the Federal Voluntary Restraint Arrangements program, which reduced steel imports to a little more than 20% of the U.S. market.

Iron ore was produced by 20 open pit mines and 1 underground mine. Fourteen mines produced ore for the iron and steel industry, while the remainder shipped ore mainly to cement plants. Installed production capacity for usable ore at yearend was estimated at 83 Mmt per year, including 79 Mmt of capacity for pellets. Effective production capacity for pellets was at least 12 Mmt less than installed capacity. Only five of the nine operational pelletizing plants utilized more than 85% of their installed capacities, despite the upswing in demand since 1987.

An average of 3.2 tons of crude ore was mined in 1989 for each ton 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 almost 57 Mmt, 97% of usable ore output. The average iron content of usable ore produced was 63.4%.

The iron ore industry of the United States and Canada had finally begun to untangle itself from the web of financial problems created by the collapse of steel demand in 1985 and 1986. This collapse accelerated the reduction of U.S.

steelmaking capacity, which started in 1978, and triggered a major restructuring of the iron ore and steel industries on both sides of the border. Since 1986, the two industries have introduced major changes aimed at lowering operating costs and improving competitiveness.

The first phase of the restructuring of the iron ore industry occurred in the summer of 1986, when the industry was experiencing one of its worst years since the Great Depression. However, some of the organizational changes introduced then were still being implemented in 1990. The second phase of the restructuring took place in the summer of 1989, and mainly affected Canadian mines. This second phase culminated with the transfer of the Quebec Cartier Mining Co. from USX Corp. to a partnership formed between Dofasco Inc., Cia. Auxiliar de Empresas de Mineracao (CAEMI), and Mitsui & Co. Ltd. (See "Canada.")

LTV Corp., Wheeling-Pittsburgh Steel Corp., and Sharon Steel Corp. were all forced to file for bankruptcy at the time of the 1986 collapse, but continue to operate under the protection of chapter 11 of the Federal Bankruptcy Code. The bankruptcy problems of the three integrated steel producers immediately 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. The mining partners of the bankrupt steel companies have continued, for the most part, to ship pellets to the three companies' blast furnaces and have relied patiently on the courts and lengthy legal negotiations to resolve their financial claims. Several claims were settled in 1989, pending court approval.

In April 1989, Cleveland-Cliffs Inc. (CCI) tentatively settled its 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 per year 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.

A large part of CCI's claims against Wheeling-Pittsburgh were settled earlier in September 1988. As part of the 1988 settlement, Wheeling-Pittsburgh assumed its 10% interest in the Empire Mining Partnership on January 1, 1989, but surrendered its 4% interest in the Tilden Mining Co. In exchange, CCI was allowed an unsecured claim of $100 million for damages resulting from the steel producer's rejection of its Tilden obligations. Wabush Mines of Labrador and Quebec was allowed a similar claim of $59 million, but two lesser claims by Wabush were being disputed. An exchange of equities in Wabush was proposed toward the end of 1989, but a number of details were still under negotiation. LTV and Wheeling-Pittsburgh had interests in Wabush of 15.6% and 10.2%, respectively.

Minnesota

Minnesota produced 70% of the national output of usable ore in 1989. Production of pellets totaled 40.76 Mmt, equivalent to about 72% of installed production capacity of the State's six active taconite plants. Utilization of active pelletizing capacity by the six, though, was 91%. The remainder of the output consisted of hematite concentrates produced by LTV Steel from natural ores. A seventh taconite plant, the E.W. Davis Works at Silver Bay, was being refurbished by Cyprus.

National Steel Pellet Co. (NSPC) produced 4.76 Mmt of standard acid pellets at its Keewatin complex in 1989.[1] The pellets averaged 65.10% iron (Fe), 4.92% silica (SiO_2), and 0.010% phosphorus (P) on a wet basis. The complex, situated at the southwestern end of the Mesabi Range, operated at full capacity for most of the year. About 70% 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 30% was hauled in 160-car unit trains to NSC's smaller steelworks at Granite City, IL.

NSPC was a wholly owned subsidiary of NSC. NSC was controlled in turn by NKK Corp., the second largest steel producer in Japan. In May 1990, NKK increased its equity in NSC from 50% to 70% and took steps to acquire an additional 20% from its partner, National Intergroup Inc.

All of LTV Steel's natural ore production came from its McKinley Extension Mine, 4 kilometers (km) north of Aurora. The mine, operated by LTV Steel's Northwest Ore Div. under a lease from USX, shipped 592,000 metric tons (mt) of beneficiated sinter fines and 20,000 mt of 1- by 4-inch coarse ore in 1989.[2] 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. Excessive capacity and large stocks of pellets continued to be a problem for LTV Steel Mining. In January 1989, LTV Steel Mining laid off 92 hourly employees at its Hoyt Lakes operation, 32 km east of the city of Virginia. In recent years, normal seasonal layoffs in response to the end of the shipping season had been about 64 employees, but the company laid off more employees than usual in anticipation of projected cutbacks in production later in the year.

On November 5, LTV Steel Mining laid off one-third of the 1,400 hourly and salaried employees at Hoyt Lakes for 2 weeks. During the 2-week period, production was cut back about 50% to trim pellet stocks. According to mine officials, the temporary cutback was part of a broader action taken by the parent company, LTV Steel, to reduce excessive inventories in its production system. During the fourth quarter of 1989 and the first quarter of 1990, the domestic steel industry experienced a modest drop-off in orders, especially from manufacturers of automobiles and appliances. LTV was a major supplier of finished steel to both consuming industries.

The Hoyt Lakes operation had a rated annual capacity of 8.1 Mmt of standard

acid pellets and shipped 7.68 Mmt in 1989. The design capacity of the mining complex, though, was 11 Mmt per year.

In January 1990, representatives of LTV Steel Mining met with Minnesota Pollution Control Agency (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 square kilometers (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.

LTV Steel Mining has been closely monitoring seepage from the Dunka stockpiles as part of a 1986 agreement with the State. Water samples taken from the Bob Bay area of Birch Lake, 800 meters (m) northeast of the pit, also had elevated levels of the three metals. Partly because of the elevated levels in Bob Bay, the MPCA issued a notice of violation to the company, charging that the seepage exceeded water quality standards. Citizen groups were concerned because the 31-km^2 (7,600-acre) lake drained into the environmentally sensitive Boundary Waters Canoe Area Wilderness. The situation was further complicated because there were at least five inactive copper-nickel workings on the southeastern side of the string-bean-shaped pit. The old workings are in an area where the Biwabik Iron Formation has been metamorphosed and truncated by gabbros of the younger Duluth Complex. LTV Steel Mining submitted a preliminary plan to deal with the seepage problem in the fall of 1989 and was taking steps to change the configuration of some of the stockpiles.

The Hibbing Taconite Co. (Hibtac) produced 8.24 Mmt of acid pellets, falling somewhat short of the record 8.79 Mmt set in 1988.[3] The pelletizing plant, which was expanded in 1979 to 8.2 Mmt, had an effective capacity of 9.0 Mmt at the end of 1989. Hibtac's biggest customer was Bethlehem Steel Corp., which owned 70.3% of the joint venture. The remaining equity was divided between CCI (15.0%), which managed the complex, and Stelco Inc. (14.7%). In December, Hibtac began developing a new mining area southwest of its existing section 36 pit. The new area was to encompass parts of the former Mahoning natural ore pit, worked by Pickands Mather & Co. from 1923 to 1973.

Minntac, the largest iron mine in the United States, produced 9.9 Mmt of fluxed pellets and 2.3 Mmt of standard acid pellets.[4] The output from the complex at Mountain Iron matched the 12.2 Mmt produced in 1988, but fell far short of its installed capacity of almost 19 Mmt. Minntac was owned and operated by the USS steel segment of USX, the largest integrated steel producer in the country.

The bulk of the beneficiation facilities at Mountain Iron were switched from acid to fluxed pellet production in July 1988 at a cost of more than $8 million. A number of improvements were made to the concentrator at that time, including the installation of a flotation circuit to reduce silica levels in the new fluxed pellet. Refinements were made to the circuit in 1989 that raised the iron content of the new pellet while further reducing its silica. The limestone-dolomite fluxed pellet produced during the 1989 campaign contained 62.22% Fe, 3.96% SiO_2, and 0.0147% P on a wet basis. For comparison, the acid pellet produced in 1986 averaged 5.40% SiO_2. The 50-50 blend of limestone and dolomite was being shipped from Michigan to Duluth in self-unloaders and then transferred to Duluth Missabe and Iron Range Railway Co. (DM&IR) ore cars that would normally return empty to the pelletizing plant.

An additional 2-Mmt-per-year 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. Both fluxed and acid pellets were shipped to the company's integrated steelworks at Lorain, OH, which was placed in mid-1989 under the operational control of a joint partnership with Kobe Steel Ltd. Limited amounts of acid pellets also went to the Weirton Steel Corp. in West Virginia. About 1.44 Mmt of 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 grew for the fourth consecutive year and was the highest since 1981. The joint venture produced 5.03 Mmt of partially fluxed pellets, 17% more than in 1988. The magnetite concentrate from the taconite was mixed with Peridur and a 1% limestone additive to make a pellet averaging 64.56% Fe, 4.97% SiO_2, 0.016% P, and 0.67% lime (CaO) on a wet basis. 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%). In June 1988, Eveleth reactivated the second of two pelletizing lines at its Fairlane plant, 11 km south of the city of Eveleth. This older line, which had been idle since July 1982, gave Fairlane a total effective capacity of 6.2 Mmt per year. At yearend, Eveleth employed about 670 hourly and 130 salaried personnel.

In late 1987, Oglebay Norton filed an environmental assessment plan with the Minnesota Department of Natural Resources seeking approval to expand the north pit of the Thunderbird Mine toward the city of Virginia. Under the long-term plan, Eveleth would expand the pit by 400 acres and create three new stockpiles. One of these stockpiles would be in the old Rouchleau pit on the southeastern edge of the city of Virginia.

More than two-thirds of the 15.8 Mmt of crude taconite mined in 1989 came from the north pit. The south pit provided about 3.5 Mmt, with the remainder coming from the new Spruce Hill reserve. Stripping of the Spruce Hill reserve began in 1986, but mining did not actually start until November 1988. The highway between Leonidas and West Eveleth had to be relocated because of the Spruce Hill Project. The reserve is near the old Spruce Mine on the northwestern edge of the south Thunderbird pit.

In the spring of 1989, Inland Steel Mining Co. obtained the rights to mine a large taconite reserve in the central part of the Mesabi Range. The new property, the Biwabik-West Taconite reserve, was near the city of Gilbert, about 10 km southeast of Inland's Minorca mining and pelletizing complex. Shortly after acquisition, company officials drafted a plan calling for immediate development of the property. The ores would be used to supplant Minorca's dwindling reserves and would be recovered using the same surface mining techniques employed elsewhere on the range. The new pit would be known as the Laurentian Mine because of its proximity to the Laurentian Divide.

In late November, the board of directors of Inland Steel Industries Inc. formally approved development of the Laurentian Project. Inland Steel Mining, a wholly owned subsidiary of the Inland Steel Co., expected to spend $20 million on the mine, which would provide iron units for the parent company's integrated steelworks at Indiana Harbor, IN. The Laurentian ore would be trucked 10 km to Inland's existing beneficiation plant on the northeastern edge of the city of Virginia. Minorca produced a record high 2.50 Mmt of fluxed pellets in 1989 and was still operating at almost full capacity. If the present rate of production were maintained, the existing pit at Minorca could be exhausted as early as 1992. The new ore body would provide the plant with more than 15 years of reserves. Inland also hoped to negotiate leases on adjoining properties that could supply an additional 25 years of reserves.

The current plan calls for the Laurentian ore to be blended with Minorca ore beginning in 1991. Blending would extend the life of the Minorca pit until 1995, when mining would be shifted entirely to the new ore body. A dedicated haul road would be constructed from the pelletizing plant through the Pike River Basin to the proposed mine site. Inland planned to build a series of berms to reduce nuisance noise from the operation. Overburden and waste rock would be used to construct a 12-m high sound barrier along the section of haul road that would border Gilbert. The company was experimenting with several new methods of blasting designed to minimize ground shock to homeowners.

The Laurentian Project would be the first entirely new taconite mine to come on-line in Minnesota in more than a decade. However, environmental permits still had to be obtained from the U.S. Army Corps of Engineers, the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, and three local governments. The required environmental impact statement was released in final form in August 1990. Inland also considered mining two other sites, the Ordean Reserve west of Minorca and the East Rouchleau pit on the outskirts of Virginia, but temporarily shelved both of these projects.

In August 1988, the Governor of Minnesota met in Denver with Cyprus executives to explore new ways of reopening Reserve's mining complex at the extreme northeastern end of the Mesabi Range. At that time, CCI and Northfield Mining Inc. also expressed an interest in acquiring or managing the defunct operation. Reserve's principal assets consisted of the Peter Mitchell Mine near Babbitt and the E.W. Davis pelletizing plant 65 km to the southeast at Silver Bay. State officials had become increasingly concerned because key machinery at both sites had begun to deteriorate from the harsh Minnesota winters and lack of maintenance. The bankruptcy trustee had also sold half of the flotation cells in the concentrator to pay expenses. Potential buyers were discouraged by several additional obstacles, including liabilities for the sprawling Milepost 7 tailings basin and the questionable viability of the reactivated operation if demand for pellets dropped back to 1986 levels. In short, the chances of finding a suitable buyer were diminishing daily.

The Denver talks led to the drawing up of a maintenance agreement between the State, Cyprus, and the bankruptcy trustee in October 1988. Under the terms of the agreement, Cyprus began stabilizing the situation at the two sites, but was not obligated to buy the operation.

By the spring of 1989, the outlook for Babbitt and Silver Bay had improved considerably. On April 21, Cyprus tentatively agreed to pay $40 million in cash for the bankrupt company's assets. The acquisition agreement was filed with the U.S. Bankruptcy Court for the Southern District of New York, and a hearing was scheduled for June 12. CCI and Northfield were given until June 5 to better the offer from Cyprus. On June 5, CCI bid $44.5 million. On the day of the hearing, both companies increased their bids substantially. Although CCI's final bid was $54 million, the bankruptcy judge awarded Reserve's assets to Cyprus for $52 million, after weighing recommendations from Reserve's bondholders, the trustee, and the State of Minnesota. According to a spokesperson for the State of Minnesota, one of the principal reasons for the judge's ruling in favor of Cyprus was that Cyprus had sufficient cash on hand, while CCI did not. Another reason was that Cyprus had already negotiated agreements with the Mesabi Trust Co. (which held the mineral rights to the Peter Mitchell Mine) and some other involved parties. The sale to Cyprus was expected to provide Reserve's bondholders with $45 million after expenses.

The final details of the sale and bankruptcy settlement were completed on August 25, 1989. The operation was renamed Cyprus Northshore Mining Corp. The sale included the company railroad that runs from the mine to Silver Bay. The environmentally sensitive Milepost 7 tailings basin was leased to Cyprus by the bankruptcy trustee for a minimum of 5 years. Cyprus was expecting to spend at least an additional $30 million refurbishing the mining complex and improving pellet quality to meet current industry standards. New equipment was to allow Cyprus to produce fluxed pellets and use different organic binders in place of the traditional bentonite.

After settlement, Cyprus moved quickly to reopen both the mine and plant. The coal-fired electric generating station at Silver Bay, which provided power for the processing facilities, was restarted on November 16. Drilling was resumed that same week at the mine. Contracts, totaling more than $5 million, were let to upgrade the pelletizing plant and the Milepost 7 tailing disposal system. The installation of a hearth layer for the two largest pelletizing furnaces and related retrofitting alone cost $2.6 million. The hearth layer work on the two 1964-vintage furnaces was completed on December 20. Four of the six smaller furnaces installed when the processing plant was commissioned in 1955 may be upgraded at a later date.

On December 27, Cyprus formally reopened the mine at Babbitt. The Governor of Minnesota attended the ceremonies and was given the honor of detonating the first blast since the 1986 closure. The Chief Executive was one of the individuals instrumental in convincing Cyprus to acquire the idled complex. On January 5, 1990, 150-car unit trains began hauling crushed ore on the 76-km long railroad extending from Babbitt to the concentrator at Silver Bay.[5] 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.

Cyprus was planning to produce 1.7 Mmt of standard acid pellets in 1990 and started shipping after the Soo Locks opened in late March. Armco Inc. had agreed to buy 1.5 Mmt per year for the next 7 years. If all goes well, the Northshore operation could be producing 4.0 Mmt per year by 1994. On January 12, 1990, a fire broke out in the pelletizing

plant and completely destroyed two electrostatic dust collectors. No one was injured, but the fire caused an estimated $1 million damage to the fluid ionics section of the plant. Startup of the No. 12 furnace, which was to have begun on January 15, was delayed about 2 weeks. The No. 11 furnace was not brought on-line until mid-March.

At the time of the fire, Cyprus had 88 employees at Babbitt and 238 at Silver Bay. About 90% of those hired between June 1989 and March 1990 were former employees of Reserve and had an average age of more than 50. Additional details on the startup of Cyprus Northshore are given in reference 5.

Michigan

Michigan produced about 26% of the national output of usable ore in 1989. More than 98% of the production consisted of pellets produced from ores mined at the Empire and Tilden Mines near Ishpeming in Marquette County. Both mining ventures were managed and partially owned by CCI's Cleveland Cliffs Iron subsidiary. The company's wholly owned Republic Mine remained idle throughout the year. Production of pellets totaled 15.41 Mmt, of which 8.24 Mmt was produced at the Empire plant and 7.17 Mmt was produced at Tilden.[6] The Empire plant operated beyond its rated capacity, setting a new production record and surging past the 95% mark reached in 1987 when it made 7.75 Mmt of pellets. The output of the Tilden plant was up 4% from that of 1988, despite delays associated with the startup of the new magnetite operation.

From 1982 to 1987, Tilden was used as a swing producer because it had higher operating costs than Empire. The economics of the Tilden operation was hobbled by the mineralogy of the taconite. The ores of fine-grained martite and common hematite were much more difficult to beneficiate than the magnetite-rich varieties of taconite found elsewhere in the Lake Superior District. In March 1988, Tilden's three solvent partners—the Algoma Steel Corp. Ltd., CCI, and Stelco Inc.—decided to make the mining complex more competitive by upgrading the Tilden concentrator so that it could process both magnetite and hematite. The magnetite-rich taconite would come from the Cliffs Drive III ore body at Schoolhouse Lake, about 1 km north of the existing pit. Conversion of the pelletizing plant would cost $7.5 million; development of the new pit, about $6 million. An additional $15 million was required to buy new equipment and upgrade existing facilities. In November 1988, CCI and its two Canadian partners decided to completely underwrite the $30 million project with equity funds instead of using outside sources for funding and ordered Tilden's engineering staff to immediately begin modifying the concentrator. Preproduction stripping at the new pit, which had already begun in July 1988, was accelerated. Equity interests in the new Tilden Magnetite Partnership were divided as follows: Algoma, 50%; CCI, 33.3%; and Stelco, 16.7%.

The beneficiation part of the refurbished plant had been scheduled to begin producing magnetite in early August 1989, but startup had to be postponed 2 weeks because of engineering problems with the 54 new magnetic cobbers. Development of the ore body also took longer than anticipated. Despite these problems, the converted operation reached 88% of designed concentrating capacity in December 1989 and, by yearend, had produced 1.8 Mmt of the new pellets. An additional $1.7 million had been set aside for eliminating production bottlenecks, perfecting the beneficiation process, and improving pellet quality. As a result of the capital improvements, Tilden was able to make both magnetite and hematite pellets in either standard or fluxed grades. The operation became more flexible and cost competitive, but had to sacrifice capacity, at least for 1989 and 1990. Tilden was currently able to produce 4.1 Mmt per year of magnetite pellets, but only 2.7 Mmt of hematite pellets. Hematite pellet capacity could be quickly raised to 4.1 Mmt with additional capital expenditures if pellet demand in North America improved dramatically.

The Republic Mine in the western half of Marquette County was shut down in October 1981 at the beginning of the 1982-84 recession and has been maintained since then in a standby status. On June 27, 1989, CCI formally appealed the 1989 tax assessment on the inactive mining and pelletizing complex to the Michigan Tax Tribunal. In Michigan, mining companies are required to pay a specific ore tax to the local township in lieu of property taxes. In this case, the ore tax was determined and paid to the township of Republic. CCI claimed that the specific ore tax should have been only $206,000, instead of the $527,000 billed by the township. Republic Township quickly filed a response to the company's appeal. At the end of the year, both sides were still waiting for the tribunal to set a prehearing date. The outcome of the appeal was important to the mining communities of the Upper Peninsula because CCI is challenging the way in which the specific ore tax was computed. A ruling in the township's favor could lead to increased ore taxes on the much larger Empire and Tilden Mines. Six of the thirteen local units of government agreed to pay part of the legal fees incurred by Republic Township.

CCI's appeal disputed two items used to compute the ore tax on the Republic Mine: (1) the township's use of a published price to determine the value of Michigan ore, and (2) the rated capacity of the idled pelletizing plant. The company claimed that fundamental changes in the North American iron ore market, such as the increased number of spot sales, had made the published price inaccurate and that the lower prevailing market price should have been used instead. Because the Republic Mine was inactive, its rated capacity was used in the tax formula in place of a 5-year average of production. When the mining complex was shut down in 1981, the pelletizing plant had two lines and was able to produce 2.7 Mmt per year of pellets averaging 63.3% Fe on a wet basis. This was the figure that the township supervisor used in his 1989 tax determination. CCI, though, moved some of its equipment to other mines several years ago and argued that Republic had only one operational pelletizing line at the end of 1988, limiting production to 1.3 Mmt per year.

Later in the summer, CCI announced that it would not reopen Republic in 1990, as had been rumored. The company decided not to make any decision about the idled complex until corporate staff could better define near-term production costs and evaluate adverse forecasts put forth by some industry analysts. At the time of the 1981 shutdown, Republic was owned by the Marquette Iron Mining Partnership, a joint venture between Jones and Laughlin Steel Corp. (which later became part of LTV Steel), Cleveland-Cliffs Iron, Wheeling-Pittsburgh, and the International Harvester Co. CCI acquired full ownership of Republic after the other

three filed for chapter 11 bankruptcy protection.

At the beginning of 1989, the M.A. Hanna Co. donated 22.81 km^2 (5,637 acres) of mining properties in the Menominee Range to the State of Michigan. The land was part of the former Groveland Mine, 21 km northeast of Iron Mountain and 6 km east of Randville. About one-fourth of the land was covered by tailings ponds and other impoundments. An additional 8.90 km^2 (2,200 acres) that included the old pit was acquired in late December by a real estate company based in the Bahamas. Between 1959 and 1962, the Groveland operation produced 2 Mmt of concentrates from a jasper-type ore. In 1963, Hanna built a 2-Mmt-per-year pelletizing plant at Groveland to process a 60% magnetite-40% hematite blend made from ore averaging 35% Fe.[7] The plant operated until December 1982, supplying a pellet that contained 63.1% Fe and 6.95% Si. The Michigan Natural Resources Commission incorporated the land into the Copper Country State Forest, making future development of the remaining 100 Mmt of taconite less likely.

Missouri

The Pea Ridge Iron Ore Co. operated the smallest of the 10 active mining and pelletizing complexes in the United States. The Pea Ridge Mine is on the northeast flank of the Ozark uplift in Washington County near Sullivan, MO. The operation produced slightly more than 1 Mmt of iron ore products in 1989 and was the only active underground iron mine in the country. More than 90% of the production consisted of olivine-enriched pellets made from magnetite concentrate containing 70% Fe and less than 1% SiO_2. The addition of 5% olivine increased the reducibility of the pellet while improving its high-temperature properties in the blast furnace and increasing its resistance to low-temperature breakdown. The complex also produced heavy-medium magnetite for coal cleaning, as well as a variety of iron oxides for ferrites, pigments, and ceramic magnets.

During the first quarter of 1990, Pea Ridge received increased attention because of the uniqueness of the deposit and the novel steps taken by the engineering staff to solve problems shared by the entire North American iron ore industry. After a decade of work, the company had made significant progress in lowering the phosphorus content of the magnetite concentrate used as pellet feed. The phosphorus came from apatite and several rare-earth minerals that form inclusions in the fine-grained massive magnetite. Control of phosphorus is critical in the making of quality steels. The ideal situation is to keep the phosphorus level as low as possible in the pellets, coke, and fluxes so that even minor amounts of the element cannot accompany the iron into the steel. 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%.[8]

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.

In April 1988, the Missouri Division of Geology and Land Survey (DGLS) entered into a cooperative agreement with Pea Ridge to map in detail selected levels of the mine. The U.S. Geological Survey (USGS) agreed to provide financial and technical support for the underground mapping project. The Pea Ridge Project had been incorporated into DGLS' larger "Operation Basement" study, which also involved surface mapping of exposed Precambrian rocks in the St. Francois Mountains. Preliminary data indicate that many similarities exist between the basement rocks of southern Missouri and those of South Australia, especially in terms of age, composition, and apparent origin. The striking resemblance between the two basements excited exploration geologists because South Australia is the host for the world-class Olympic Dam deposit discovered in 1975. The Olympic Dam ore body averages 1.6% copper and 0.06% uranium oxide (U_3O_8) and also contains economically significant amounts of gold, silver, and rare earths.

Some geologists speculated that Pea Ridge could be an outlier of a much larger Olympic Dam-type deposit. To help test the Olympic Dam model, Cominco American Inc. drilled two holes on the undeveloped Boss-Bixby Precambrian copper-iron deposit. Like Pea Ridge, Boss-Bixby was discovered in the 1950's by drilling a prominent magnetic anomaly. This second Precambrian deposit was in Dent County, about 65 km southwest of Pea Ridge, and bordered on the western edge of the Viburnum Trend. The Viburnum Trend was the largest lead producing district in the United States in 1989. Cominco was planning to drill into Boss-Bixby from new underground workings in its neighboring lead mine.

DGLS and USGS were extremely interested in mapping the Pea Ridge Mine because it was one of only a few sites in the midcontinent region where geologists could examine the buried Precambrian basement in three dimensions. Pea Ridge is referred to as a "blind" ore body because none of it is exposed at the ground surface. The dike-like mass of magnetite is covered by 400 m of relatively flat-lying, barren sedimentary rocks and extends almost vertically from the unconformity to an unknown depth greater than 1,000 m. The deepest working and development levels were at 754 m and 815 m, respectively, in mid-1990. The underground mapping project has already revealed that the deposit is far more complex than originally thought in terms of both structure and mineralization. The volcanic host rocks consist of at least four different types of brecciated rhyolite porphyries, which are believed to be remnants of a Precambrian collapse caldera.[9] Veins and carbonate pods exist that are rich in monazite, allanite (a cerium-yttrium epidote), and at least five other rare-earth minerals. The Rolla Research Center of the Bureau of Mines was working with the company to determine if it would be economically feasible to recover the rare earths as a byproduct of the iron ore operations.

New York

On November 23, 1989, NL Chemicals Inc. shut down its magnetite concentrating operation at Tahawus in Essex County, NY. The company and its predecessor, NL Industries Inc., had been producing heavy-medium quality concentrate from crude magnetite stockpiled at the MacIntyre Mine. There had been no

mining at the site since 1982. The bulk of the concentrate was being railed to eastern coal mines for coal washing.

The MacIntyre Mine was opened by the National Lead Co., the grandparent of NL Chemicals, in July 1942 to provide ilmenite ($FeTiO_3$) for the titanium dioxide (TiO_2) pigment industry. At the time, the ilmenite was desperately needed to replace supplies of beach sands from India, which had been cut off at the beginning of World War II. Crude magnetite was recovered as a byproduct of the ilmenite operation. During the 40-year period, National Lead recovered 12 Mmt of ilmenite and 18 Mmt of magnetite from 60 Mmt of crude ore.[10] The ilmenite was shipped to National Lead's TiO_2 plants in Sayreville, NJ, and St. Louis, MO. National Lead dominated the titanium pigment market for many years, accounting for as much as 60% of the country's output of TiO_2, but lost ground when its sulfate process became uncompetitive with the newer, more economical chloride process. Officials of NL Chemicals estimated that 31 Mmt of ilmenite and 21 Mmt of magnetite remain in the deposit.

The MacIntyre and other ore bodies in the Sanford Lake District are part of a large Precambrian anorthosite massif that forms the central part of the Adirondack Mountains. The ore bodies of ilmenite and vanadiferous-titaniferous magnetite occur as massive lenses in the anorthosite or as bands in gabbro associated with the anorthosite. Iron mining in the district dates back to 1832, when a forge was built near Sanford Lake by a group of entrepreneurs led by Archibald McIntyre.

NL Chemicals was to maintain an active presence at the mine and had initiated a voluntary reclamation program going beyond requirements set by the New York State Department of Environmental Conservation. The company kept its State mining permit in force, continued to ship concentrate from existing stockpiles, and planned to sell crushed stone to contractors. In August 1989, NL Chemicals acquired a 72-year lease on the 53-km long railroad line extending from the mine to the trunk line of the Delaware & Hudson Railway at North Creek. The lease was obtained at a public auction from the General Services Administration for $950,000. The branch line was built by the Federal Government between 1942 and 1944 to eliminate truck haulage of the concentrates. At the end of 1989, the company deeded the branch line to the Essex County Industrial Development Agency (IDA), but subleased it back for 5 years. The purchase and subsequent subleasing agreement prevented the rail line from being torn up for scrap and gave NL Industries an option to reopen the mine in the distant future. Deeding the rail line to the county reduced carrying costs because the IDA is a tax exempt organization. The rail line was critical to future mine development because of Tahawus' isolated location.

Other States

Geneva Steel of Utah continued to expand production at its 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 75-car unit trains. The 100-ton railcars were originally built to carry pellets from USX's former Atlantic City Mine in Wyoming to Geneva. The actual mining was contracted out to the Gilbert Development Corp. Run-of-mine ore averaging 55.1% Fe, 6.7% SiO_2, and 0.27% P was crushed and screened at the Comstock-Mountain Lion Mine, two adjoining properties leased by Geneva from CF&I Steel Corp. of Pueblo, CO. Gilbert Development also produced wet screened and magnetically cobbed material from old stockpiles of lean ore at the former Iron Mountain Mine, 8 km to the southwest. Mining was also underway at the new Excellsior and Chesapeak, two smaller ore bodies on the northeastern edge of Iron Mountain. The Excellsior and Chesapeak material was averaging 58.7% Fe, 5.2% SiO_2, and 0.30% P on a wet basis. A total of 776,000 mt was shipped from the district in 1989.[11] More than 50% of the material consisted of fines, which could not be charged directly into Geneva's three blast furnaces and had to be sintered.

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. The company produced direct-shipping ore averaging 32.0% 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.

CONSUMPTION AND USES

Consumption of iron ore rose less than 2% owing to a leveling off of demand from the iron and steel industry. Consumption for ironmaking and steelmaking totaled 73.55 Mmt, including 65.60 Mmt in blast furnaces, 7.12 Mmt in sintering plants, 0.49 Mmt for production of direct-reduced iron (DRI), and 0.34 Mmt in steelmaking furnaces. An additional 10,000 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 6.09 Mmt, compared with 5.99 Mmt in 1988. Reported consumption of iron ore for manufacture of cement, heavy-medium materials, animal feed, ballast, ferrites, pigments, and other nonsteel products was 1.21 Mmt.

The near-term outlook for the iron and steel industry had improved considerably since the 1986 collapse. U.S. production of hot metal and pig iron totaled 50.69 Mmt in 1989, only a fraction more than in 1988, but still the largest tonnage since 1981. Hot metal and pig iron production was extremely stable throughout the year, averaging 4,224 mt per month. The deviation from the mean was never more than 10% for any one month. Monthly iron ore consumption statistics reflected this stability, which developed after overall demand for steel mill products had strengthened in the fall of 1987.

Consumption of pellets, direct-shipping ore, and merchant sinter for the first 6 months was 38.45 Mmt, a 9% increase from the same period in 1988. The situation reversed in the second half of the year, with blast furnace output dropping below corresponding 1988 levels. During 1989, the number of blast furnaces in operation ranged from 48 to 52. At year-end, 48 of the 83 blast furnaces available were on-line. The monthly blast furnace data show how pig iron production has 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. Twenty-nine 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 78.75 Mmt. This included 61.74 Mmt of pellets; 13.66 Mmt of sinter, briquettes, etc; and 3.35 Mmt of natural coarse ore. Of the primary ore consumed, 73% was of domestic origin, 10% came from Canada, and 17% 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.

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 continued downward in 1989. At yearend, total industry stocks were 21.70 Mmt, only 3% more than the record low set in 1987. The renewed decline was caused primarily by a cutback in domestic ore stocks at furnace yards. As a result of the cutback, furnace yard stocks stood at only 15.73 Mmt, a 61% drop from the 39.93 Mmt reported at yearend 1978. Combined stocks at furnace yards and receiving docks included 13.03 Mmt of domestic ores, 2.45 Mmt of Canadian ores, and 2.43 Mmt of other foreign ores. Mine stocks at yearend were 29% more than those of 1988 because of unusually cold weather in November and the early shutdown of loading ports on the Upper Great Lakes in mid-December.

End-of-month stocks reported at mines peaked at 12.12 Mmt in March and continuously declined to 4.11 Mmt in November. Stocks of ore at consuming plants were 180° out of phase with those at the mines, ranging from a low of 9.31 Mmt in April to a high of 15.73 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 0.56 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

Vessel shipments of iron ore from U.S. ports on the Upper Great Lakes totaled 51.04 Mmt, about 3% less than those of 1988. Nearly 90% 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 4.88 Mmt and accounted for almost 25% of U.S. imports. The balance of imports, 14.71 Mmt, was shipped primarily through ports on the east and gulf coasts.

Ore shipments from three of the seven U.S. ports on the Upper Great Lakes decreased from the levels of 1988, with the largest decrease at Two Harbors, MN. Tonnage shipped from each port in 1989 is shown in the text table.

Port	Date of first shipment	Date of last shipment	Total tonnage (thousand metric tons)
Duluth, MN	Apr. 1	Dec. 19	7,408
Two Harbors, MN	Mar. 14	Dec. 25	9,503
Silver Bay, MN[1]	—	—	—
Taconite Harbor, MN	Mar. 26	Dec. 19	8,217
Superior, WI	Mar. 25	Dec. 22	11,052
Marquette, MI	Mar. 24	Jan. 2	9,117
Escanaba, MI	Mar. 23	Jan. 19	5,742
Total[2]			51,038

[1]No pellets have been shipped since Nov. 1987. However, Cyprus Minerals Co. acquired all of the facilities of the defunct Reserve Mining Co. in Aug. 1989 and was in the process of refurbishing the beneficiating and pelletizing complex at Silver Bay. The port was reopened in Oct. 1989 so that coal could be delivered to the complex's idled electric generating station. The generating station was restarted on Nov. 16.
[2]Covers the 1989 navigation season, which extended from Mar. 14, 1989, to Jan. 19, 1990.

Source: Lake Carriers' Association, 1989 Annual Report.

The decline in overall shipments was primarily the result of adverse winter weather. At the end of October, cumulative shipments were slightly ahead of those of 1988. However, an inordinate number of storms delayed sailings in November. The storms were followed by a record-breaking cold spell in mid-December. Early ice formation in the St. Marys River forced the Corps of Engineers to close the locks at Sault Ste. Marie, MI, on December 28, 2 weeks ahead of schedule. The early closing of the locks left 1.5 Mmt of pellets undelivered at Lake Superior loading docks.

No iron ore shipments were made from the dock at Silver Bay in 1989. However, coal was unloaded for the reopened powerplant beginning in October. The number of vessel shipments from the other six ports totaled 1,506, indicating an average cargo of 33,890 mt. Individual cargoes of 60,000 mt or more were loaded at five of the ports during the year, although the average shipment from individual ports ranged from 23,679 mt at Marquette to 46,421 mt at Taconite Harbor, MN.

On September 25, The Interlake Steamship Co. and other lake carriers raised freight rates between 6% and 13% to offset increased labor costs and shipyard expenses. 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 the text table.

From	To	Dollars per long ton[1]			
		Oct. 13, 1988		Sept. 25, 1989	
		Class X	Other	Class X	Other
Head of the Lakes	Lower lake ports	4.95	5.60	5.60	6.00
Marquette	do.	—	4.69	—	4.98
Escanaba	Lake Erie ports	3.74	4.20	4.20	4.50
Do.	Lower Lake Michigan ports	2.97	3.19	3.36	3.60

[1]Excludes winter surcharges for shipments after Dec. 15 and before Apr. 15.

Sources: Cleveland-Cliffs Inc., Interlake Steamship Co., and Skillings' Mining Review.

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 1989 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 vessels.[12] The latter issue was rejuvenated 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 1985–89 are compared in the text table.

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 28,700 mt. Of the 69 vessels, 64 are self-unloaders. Only 65 vessels were in actual operation in 1989. However, these 65 represented 97.7% of available carrying capacity.

Construction of a second Poe-sized lock at Sault Ste. Marie continued to be stymied by funding problems.[13] 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.[14] The Water Resources Development Act of 1986 (Public Law 99-662) authorized construction of the new lock, but required 35% of the funding to come from non-Federal sources. New estimates made by the Corps of Engineers in October 1989 indicate that the lock will cost $256 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. The 101st Congress was considering legislation that could end the funding impasse.

All-rail shipments of iron ore and agglomerates in the United States and Canada totaled 9.48 Mmt, compared with 7.14 Mmt in 1988. This was the highest tonnage ever reported for the two countries, breaking the record just set in 1988. Separate statistics for the United States are not published to protect proprietary company information. All-rail shipments of pellets from Minnesota by the Duluth, Missabe and Iron Range Railway Co. and connecting lines amounted to 2.31 Mmt, substantially more than the 1.32 Mmt hauled in 1988.[15] Shipments from USX's Minntac Mine at Mountain Iron to the reactivated Geneva works in Utah accounted for 1.44 Mmt, or 63% of the all-rail total. An additional 169,000 mt of Minntac pellets was railed to USX's Edgar Thomson steelworks at Braddock, PA. About 696,000 mt of Eveleth pellets went to USX's Fairfield works near Birmingham, AL, on a trial basis. Shipments of pellets and small quantities of natural ore to the Ports of Duluth and Two Harbors totaled 17.15 Mmt for a total ore movement on the railway of 19.42 Mmt during the 1989-90 shipping season. More than 1 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 1989. The volume rate for pellets from the western Mesabi Range to the Allouez docks at Superior remained at $5.01 per long ton. In the third quarter of 1989, the rate for pellets from the Marquette Range of Michigan to Presque Isle was raised from $2.15 per long ton to $2.35. The rate to Escanaba remained at $3.03. Escanaba also had a handling charge of 3.5 cents per long ton since 1980.

Rail rates from lower lake ports to a number of consuming points were raised between 4% and 12% on January 16, 1989. Most ore transfer charges were unchanged. At Lake Erie ports, ore transfer charges from rail-of-vessel or dock-receiving areas direct into railway cars ranged from $1.00 to $1.20 per long ton. Key rail rates for 1986–89 are compared in the text table.

Published nominal ocean freight rates for iron ore from eastern Canada to U.S. mid-Atlantic ports were $3.50 to $3.75 per deadweight ton (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.

United States and Canadian ore shipments on the Great Lakes (thousand metric tons)

Loading district	1985	1986	1987	1988	1989
Lake Superior	37,962	31,677	41,835	46,098	45,296
Lake Michigan	7,503	7,497	6,032	6,660	5,742
Eastern Canada	7,542	7,108	8,109	9,209	9,480
Total[1]	53,008	46,282	55,976	61,966	60,518
U.S. flag fleet shipments[2]	44,027	39,457	48,952	55,028	51,799
Percent carried by U.S. fleet	83	85	87	89	86

[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.

PRICES

Very few published prices for domestically produced pellets changed in 1989. CCI and Oglebay Norton were both still quoting a price of 72.45 cents per *long ton unit* of iron, natural, for their standard

From	To	Type of rate[1]	Dollars per long ton			
			Nov. 17, 1986	Jan. 1, 1988	Jan. 16, 1989	Jan. 1, 1990
Lake Erie ports	Pittsburgh district	Multiple car	10.62	11.07	12.42	11.53
Do.	Steubenville, OH, and Weirton, WV	do.	9.60	10.00	10.37	10.47
Baltimore, MD	Pittsburgh district	do.	11.49	12.51	12.98	13.11
Do.	do.	Single car	15.77	16.82	16.82	16.82
Philadelphia, PA	do.	do.	16.48	17.57	17.57	17.57
Mesabi Range	Granite City, IL	Multiple car	19.07	19.69	19.69	19.69
Mobile, AL	Birmingham district	do.	9.91	10.33	10.33	(2)
Pea Ridge, MO	do.	do.	6.41	6.41	6.41	6.41

[1]As a result of the Staggers Rail Act of 1980, which partially deregulated the railroads, it has become difficult to obtain accurate freight rate data. Published tariff rates are only suggested rates and may be significantly higher than the actual contract rates.
[2]Quotation discontinued.

Sources: Cleveland-Cliffs Inc., Minnesota Mining Directory, and Skillings' Mining Review.

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 1989. USX also decided to retain its 1987–88 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 $23.83 per long ton of undried pellets containing 63.82% Fe and 2.51% moisture. The range of all of the above prices was approximately equivalent to $34.50 to $46.37 per long ton of pellets containing 64% Fe, delivered rail of vessel at lower lake ports.

Prices for most Canadian and other foreign ores marketed in the United States are normally not published. The one exception was CCI's quotation for Wabush pellets, which remained at 63.5 cents per ltu f.o.b. Pointe Noire, Quebec. 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 $34.30 per metric ton (mt). This value was slightly higher than the average Canadian pellet value of $33.37 because Canada also sold limited quantities of high valued, 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 the text table.

Type of product	Country of origin	Average unit value (dollars per metric ton)
Coarse ores	Venezuela	23.69
Fine ores	Brazil	16.50
Do.	Canada	35.03
Do.	Mauritania	17.04
Do.	Venezuela	23.64
Pellets	Brazil	28.21
Do.	Canada	33.37
Do.	Peru	24.64
Do.	Venezuela	29.25

Source: Bureau of the Census.

Published f.o.b. prices for DRI were also unchanged from those quoted in 1988, 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 1989, the customs value of DRI imported from Venezuela ranged from $114 to $118 per mt.

FOREIGN TRADE

U.S. exports of iron ore were slightly higher than those of 1988 because of improved demand from the Canadian steel industry. 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 Minnesota and Michigan. Consumption of iron ore at Canadian blast furnaces totaled 13.98 Mmt, almost 6% more than that of 1988. U.S. material accounted for 5.44 Mmt, or 39% of the blast furnace total. An additional 147,000 mt of U.S. material was consumed at Canadian sintering plants.

U.S. imports of iron ore dipped slightly to 19.60 Mmt, despite the pickup in blast furnace activity. Total tonnage for 1989 was 12% greater than the mean of the previous 5 years, 17.51 Mmt, and was equivalent to about 26% of ore consumption. Sharp drops of imports into the Baltimore and Philadelphia customs districts (22% and 21%, respectively) offset small increases at lower lake and gulf ports. Canadian ores accounted for 44% of total U.S. imports; however, since 1982,

Canada has had to struggle to maintain its share of the increasingly competitive U.S. market. In 1989, Canada's share slipped to 11%, the lowest level in more than 10 years. Brazil, the second largest supplier, increased its share slightly to 6.9% from 6.7% in 1988. Venezuela was close behind with a 5.7% share and was more competitive in 1989 because it had a transfer vessel anchored at the mouth of the Orinoco River.

As a result of the Omnibus Trade and Competitiveness Act of 1988, much more detail became available on iron ore entering the United States after January 1, 1989. The eight new classification categories and their accompanying HTSUS numbers are listed in the text table.

HTSUS No.	Description
OXIDES	
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.
SULFIDES	
2502.00.0000	Unroasted pyrites.
2601.20.0000	Roasted pyrites.
PRIMARY CHEMICALS	
2827.33.0000	Iron chlorides.
2833.29.2000	Iron sulfates.

WORLD REVIEW

At least 47 countries mined iron ore during the year, producing a total of 922 Mmt. The U.S.S.R. was the largest producer, with an output of about 172 Mmt of concentrate or direct-shipping ore plus 67.0 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, increased slightly to 539 Mmt.

The world ore trade was estimated at 424 Mmt, of which about 87% was oceanborne.[16] Brazil, the leading exporter, shipped 113.7 Mmt to world markets in 1989, an increase of 8%. The top three customers of the Latin American giant were the European Community (EC), Japan, and the Republic of Korea. Australian shipments, in second place, rose from 98.2 to 107.6 Mmt, primarily because of increased imports by Japanese steelmakers who produced 80.2 Mmt of hot metal in their blast furnaces. Australian exports to Europe stood at 21.09 Mmt (on a dry weight basis) and were down slightly from the record 22.19 Mmt of 1988. The recently expanded EC received a total of 140.3 Mmt of ore and agglomerates, again edging out Japan as the world's principal importer. Japanese imports increased 4% from 123.4 Mmt to 127.7 Mmt.

World production of pellets was estimated at 233 Mmt, about 91% of rated capacity. Preliminary data suggest that pelletizing plant output was only slightly higher than the 227.8 Mmt reported for 1988. Most plants in Brazil, Canada, Sweden, and the U.S.S.R. were operating close to capacity. Producers in India, Peru, and the United States began reopening facilities idled in the wake of the 1981 downturn. 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 Australia, Canada, Japan, and the United States.

World output of DRI was estimated by Midrex Corp. at 15.94 Mmt, about 63% of installed capacity.[17] The low utilization rate was owing more to startup delays at new plants and other technical problems than to market factors. A breakdown by country is given in the "Iron and Steel" chapter. At eight gas-based plants, production actually exceeded rated capacity. Hot-briquetted iron (HBI), an enhanced form of DRI, was in considerable demand throughout 1989. 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 first of two Midrex modules was started up at the new Misurata plant in Libya. New units were also brought online in India and the Republic of South Africa, raising global DRI capacity from 24.39 Mmt to 25.11 Mmt. The improved utilization of existing gas-based facilities in Indonesia, Mexico, and Venezuela was largely responsible for the 13% increase in world DRI production between 1988 and 1989. About 47% of the total output for 1989 was produced in Latin America. The four-module, 1.67-Mmt-per-year Soviet complex at Stary Oskol was operating at 102% of rated capacity and accounted for an additional 11% of the 15.94 Mmt.

In the past, iron ore exporters normally completed their annual price negotiations in Europe before fixing prices in Japan. The tradition arose because European contracts are based on the calendar year, while Japanese contracts are on an April-to-March fiscal year. However, for the third consecutive year, Japanese ore buyers completed key price negotiations before their European counterparts.

For the fifth year in a row, excess stocks of sinter fines overshadowed the negotiations. Ore producers, though, were determined to win price hikes and end the discouraging price descent that had plagued them for 7 years. Formal negotiations between Cia. Vale do Rio Doce (CVRD) and purchasing agents of the West German steel industry began on November 21, 1988, but stalled when CVRD insisted on a 20% price hike. Japanese steelmakers, realizing that some form of price hikes was inevitable, quickly settled with Hamersley Iron Pty. Ltd. on December 14, 1988. Hamersley, the largest producer in Australia, won price hikes of 13.0% for fines and 17.3% for lump. The speedy Hamersley accord forced CVRD to settle for similar price increases from Rohstoffhandel GmbH and Erzkontor Ruhr GmbH, breaking the impasse in Europe. The two agreements set the tone for all of the other negotiations. By the end of the negotiation period, every major producer had won price hikes ranging from 12.2% to 27.8%. As in past years, premiums were paid on pellets and lump. Prices negotiated under Japanese contracts for fiscal year 1989 were reported as shown in the text table (f.o.b., in U.S. cents per dry ltu of iron).

On an f.o.b. (shipping port) basis, most 1989 prices apparently ranged from about $9.25 to $21.60 per dry metric ton (dmt) for fines, $16.95 to $21.70 per dmt for lump, and $26.35 to $35.70 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 was at its highest level in more

Country and producer	Ore type	Prices (April 1 to March 31)	
		Fiscal year 1988	Fiscal year 1989
Australia:			
Hamersley Iron Pty. Ltd. and Mount Newman Mining Co. Pty. Ltd.	Lump ore	28.78	33.76
Do.	Fines	23.68	26.76
Robe River Iron Associates	do.	20.51	23.18
Savage River Mines Ltd.	Pellets	36.46	42.77
Brazil:			
Cia. Nipo-Brasileira de Pelotizaçâo (Nibrasco)	do.	38.54	45.20
Cia. Vale do Rio Doce (Carajás)	Fines	21.23	23.99
Do.	Lump ore	24.92	30.99
Cia. Vale do Rio Doce (Itabira)	do.	22.24	25.60
Minerações Brasileiras Reunidas S.A	do.	21.77	25.05
Do.	Fines	21.73	24.46
Samarco Mineracâo S.A	Pellet feed	17.46	19.73
Canada: Iron Ore Co. of Canada (Carol Lake)	Concentrates	20.25	22.88
Chile:			
Minera del Pacífico S.A. (El Algarrobo)	Pellets	32.98	40.73
Minera del Pacífico S.A. (El Romeral)	Fines	16.44	18.58
India:			
Minerals and Metals Trading Corp. (Bailadila)	Lump ore	27.75	32.55
Do.	Fines	22.75	25.71
Liberia: LAMCO Joint Venture Operating Co.	do.	18.58	21.00
Peru: Empresa Minera del Hierro del Perú S.A.	Pellets	27.59	[1]
South Africa, Republic of:			
South African Iron and Steel Industrial Corp. Ltd.	Lump ore	[2]22.21	[2]26.05
Do.	Fines	[2]18.03	[2]20.37

[1]No quotation published.
[2]Price per dry metric ton unit.

Source: The TEX Report (Tokyo), v. 22, No. 5185, June 21, 1990, p. 7.

than 8 years.[18] The high shipping level was brought on by the continuing worldwide upswing in pig iron production. World production of pig iron was estimated to be 539 Mmt, an alltime high, with blast furnaces in the market economy countries operating at rates not seen since the peak year of 1979. The increase in iron ore trade came at a time when shipments of coking coal, grain, and several other major dry bulk commodities were also elevated. Shipowners were both delighted and wary because the increase came on the heels of 2 years of strong growth. Ocean freight rates for iron ore resumed their upward climb during the second half of 1988. Rates plateaued in the spring of 1989, dropped somewhat during the summer, but bounced back again in the fall. The recovery in freight rates helped make short-haul suppliers like Sweden and Mauritania more competitive. Published rates for spot charterings to the EC from Western Australia ranged from $7.90 to $12.50 per dwt for cargoes of 120,000 to 140,000 dwt, compared with $6.75 to $9.70 in 1988. The 1989 rate ranges for other shipments to the EC are shown in the text table.

Rates for cargoes of 120,000 to 150,000 dwt to Japan from Western Australia ranged from $4.85 to $6.75. Higher rates applied to Port Latta in Tasmania because it cannot accomodate vessels greater than 95,000 dwt and is farther from Japan. Rates to Japan from the

Country	Loading port	Cargo size (thousand deadweight tons)	Rate (dollars per deadweight ton)
Brazil	South Atlantic ports	100–150	6.10– 9.50
Do.	do.	200–240	5.65– 7.50
Canada	Sept-Iles or Port Cartier	100–140	5.00– 9.75
Liberia	Buchanan or Monrovia	60– 80	5.75– 8.75
Mauritania	Nouadhibou	80–130	4.30– 5.25
South Africa, Republic of	Saldanha Bay	100–200	6.40–10.00
Sweden	Narvik (Norway)	80–130	2.90– 5.00
Venezuela	Puerto Ordáz or Orinoco Delta	40–120	7.75–10.50

Sources: Drewry Shipping Consultants Ltd. (London), Maritime Data Network Ltd. (London), Simpson Spence & Young Shipbrokers Ltd. (London), and The TEX Report (Tokyo).

Brazilian port of Tubarão for cargoes of similar size were $11.65 to $14.75.

Capacity

Integrated iron ore operations have become extremely complex and resemble medium-sized towns in some cases. The production capacity of an operation of this magnitude is determined by equipment limitations at several stages of recovery. To simplify analysis and make comparisons of individual mines easier, data were collected that represent the rated or design capacity at three key points in the recovery process: crusher-screen output, concentrator output, and 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 18 shows world pelletizing capability at the close of 1989. The data represent the rated capacities of 82 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 18 also excludes all of the world sintering plants. Similar tables were being developed by the Bureau of Mines that list world crude ore production capability and world concentrating capability.

Australia

The Australian iron ore industry produced 108.7 Mmt of marketable material in 1989, breaking its previous record of 105.3 Mmt set in 1987. The major producers were trying to operate at full capacity to meet growing world demand for lump ore, but were hampered by labor disputes and work stoppages. Pellet production increased slightly to 3.6 Mmt. There were two pellet producers: Savage River Mines Ltd. and a subsidiary of the Broken Hill Pty. Co. Ltd. (BHP), the BHP Steel International Group. Shipments of ore and pellets reported by individual companies were as follows, in Mmt: Hamersley Iron Pty. Ltd., 49.91; Mount Newman Mining Co. Pty. Ltd., 27.01; Robe River Iron Associates, 22.34; Goldsworthy Mining Ltd. (GML), 6.20 (dry); BHP-Yampi Sound, 3.50; BHP-Middleback Ranges, 2.62; and Savage River Mines Ltd., 2.29. Exports of ore and pellets rose 10% between 1988 and 1989 because of increased sales to China, Japan, the Republic of Korea, and Taiwan. Exports totaled 108.1 Mmt, with 53% of the tonnage going to Japan.

In May 1989, Hamersley, Mount Newman, and Robe River concluded negotiations on a second generation of long-term contracts with the Japanese steel industry. The new contracts required annual price negotiations and were much shorter in duration than in the past—extending for only 7 years instead of 15 to 30 years. The base annual tonnage specified by the contracts was equivalent to about 30% of Australian capacity.

Hamersley, the largest iron mining company in Australia, reported record shipments and earnings in 1989. Shipments were 22% more than those of 1988 and consisted of 29.55 Mmt of sinter fines (-6 millimeters [mm]) and 20.33 Mmt of lump ore (-30 + 6 mm). The hematite ore came from two open pit mining complexes in the Pilbara region of Western Australia. Together, the two mines, Mount Tom Price and Paraburdoo, had an installed annual capacity of 46 Mmt of marketable product. The productivity of the entire Hamersley operation jumped dramatically following the reorganization of the company in 1987. Hamersley was a wholly owned subsidiary of CRA Ltd. and had more than 3,700 employees in Western Australia.

Development of the Channar Mine, 20 km east of Paraburdoo, was well underway with production scheduled to begin in January 1990 at the rate of 3 Mmt per year.[19] The mine was to be managed by Hamersley, with all of the output going initially to integrated steelworks in China under long-term contracts. The operation was a joint venture between CRA (60% equity) and China Metallurgical Import & Export Corp. (40%). Channar consists of five ore bodies having combined proven reserves of 290 Mmt averaging 63.0% Fe and 0.006% P. The 64 East and Channar ore bodies were being developed first. The ore was to be crushed on-site and then transported 20 km by overland conveyor to Hamersley's neighboring Paraburdoo Mine. The overland conveyor consisted of two flights, each approximately 10 km long. The first flight was built in a curve to avoid adverse topography between the mine and the midpoint transfer station. At Paraburdoo, the ore was to be run through the existing tertiary crusher, screened, and then blended with Paraburdoo material. From Paraburdoo, the ore blend was to be railed to Hamersley's porthead at Dampier on the Indian Ocean.

Mount Newman, the second largest iron ore operation in Australia, moved to increase production after a series of work stoppages in late 1988. The managing partners, led by BHP Minerals Ltd., were involved in lengthy labor negotiations with the unions. The negotiations were expected to lead to significant changes in work practices. If adopted, these changes could improve productivity by as much as 20%.

By mid-1989, development of Orebody 25 (Ferro Gully) was well underway, and production from Orebody 29 (Marra Mamba) had significantly increased. However, on August 30, part of the south wall of the Mount Whaleback pit collapsed.[20] The collapse severely hampered the company's efforts to increase production because it isolated a large deposit of high-grade ore and cut Mount Whaleback's production rate by one-third. The collapse was attributed to the oxidation of pyrite in a black shale unit that weakened the entire section. No one was injured, but rock bolts had to be installed to prevent further slippage. New haul roads also had to be constructed and substantial amounts of overburden removed. Mount Newman engineers began increasing production from the central and western ore bodies to compensate for the lost output from the eastern ore body. The pit was eventually redesigned with the 20 Mmt-per-year in-pit crusher being relocated further east.

Robe River's shipments rose dramatically between 1988 and 1989 because of increased sales to Kawasaki Steel Corp. Kawasaki raised its purchases from about 750,000 mt to 2,500,000 mt after Mount Newman was forced to limit deliveries.

Robe River was in the midst of a major expansion and was scheduled to expand capacity to more than 25 Mmt per year by 1992. The company's stockpiling, shiploading, and rail terminal facilities are at Cape Lambert at the eastern end of the Dampier Archipelago. The railroad from the East Deepdale Mine to Port Walcott and Cape Lambert was being upgraded to handle 200-car unit trains capable of hauling 15,000 to 20,000 mt of ore. The ore stockyards and loading facilities at Cape Lambert were also being modernized. The port modernization will increase Robe River's loading capability from 110,000 mt per day to 150,000 mt per day.

During the first quarter of 1989, Goldsworthy commissioned its new 3.0-Mmt-per-year beneficiation plant at Port Hedland. The plant was using jigs and spirals to recover the concentrate by gravity separation. BHP-Utah Minerals International, the minor partner in Mount Goldsworthy Mining Associates, was considering buying out CFG-Iron Holdings Pty. Ltd. (a 100% subsidiary of Hanson PLC. and Consolidated Gold Fields PLC). The purchase of Hanson's 70% would allow BHP to integrate the Goldsworthy operation into BHP's Mount Newman venture and consolidate the Finucane Island and Nelson Point loading facilities in Port Hedland.

In South Australia, the Long Products Division of BHP began developing a new area in the South Middleback Ranges.[21] The new area encompassed three separate deposits: the Iron Duke, the Iron Duchess, and the Iron Knight. The three deposits would supply high-grade ore to BHP's Whyalla steelworks over the next 25 years and would replace depleted reserves at BHP's Iron Baron Mine. The $50 million project was being managed by Baulderstone Hornibrook Group, with Kinhill Engineers Pty. Ltd. responsible for design of the ore-handling plant. The new Iron Duke pit was turned over to BHP in September 1989. The existing rail line was being extended, together with powerlines and a water pipeline, from the Iron Baron Mine to the new area. The ore-handling plant and railroad were to be jointly commissioned in February 1990.

Pickands Mather & Co. International and its five Japanese partners were in the process of restructuring the ownership and operation of Savage River Mines. Under the restructuring, Pickands Mather would acquire all of the other interests on October 1, 1990. At the same time, capacity would be drastically cut back from 2.5 Mmt to 1.3 Mmt. The Tasmanian mining and pelletizing complex, in operation since 1986, had been experiencing financial difficulties. Savage River had been scheduled to close in September 1990, but the restructuring would extend the life of the complex to 1995.

Canada

The Canadian iron ore industry was in the midst of a major restructuring. Six mining complexes operated during the year, but the two smallest, Adams and Sherman, were permanently closed on March 31, 1990. Both MacLeod and Mount Wright had new owners by the end of 1989. The solvent partners of the complexes at Carol Lake and Wabush were discussing how to adjust equities to compensate for the defaults of Wheeling-Pittsburgh and LTV.

Most of the industry operated near capacity throughout 1989, despite these changes. The supply and demand picture was almost identical to that of 1988. The six complexes shipped a total of 40.9 Mmt of iron ore products on a wet basis.[22] Production was estimated to be 40.6 Mmt, about 81% of active capacity. Canadian iron and steel plants consumed 15.5 Mmt of ore and agglomerates, about 4% more than the tonnage reported for 1988. Preliminary data indicated that exports were about 30.2 Mmt on a wet basis, down slightly from the previous year. The main market for Canadian ore continued to be Western Europe. In 1988, Canada's three largest customers were the EC (53.9%), the United States (33.4%), and Japan (7.2%). Pellets made up 57.6% of the tonnage exported that year; concentrates, 42.4%.

The Iron Ore Co. of Canada (IOC) shipped 15.14 Mmt of iron ore products from its docks at Sept-Iles, Quebec. The total included 8.11 Mmt of standard acid pellets (including 391,000 mt of pellet chips), 1.73 Mmt of fluxed pellets, 5.13 Mmt of concentrates, and 177,000 mt of Schefferville red ore. All of the material, except the red ore, was produced at the company's Carol Lake complex in Labrador. The beneficiating part of the Carol Lake operation is designed to produce 10 Mmt per year of concentrate for direct sale and 10 Mmt per year of pellet feed. The agglomerating part of the operation set a new production record of 10.72 Mmt, despite some loss in capacity owing to the production of fluxed pellets. The two Carol Lake pelletizing plants have a total of six traveling-grate furnaces with a combined design capacity of 10.5 Mmt per year. Furnace operating rates were at an alltime high, while fuel oil consumption rates were at the lowest levels on record. The shipment of red ore exhausted the stockpile of blended Schefferville ores that had been maintained at the Sept-Iles yards since 1983. IOC closed its Knob Lake mines near Schefferville at the nadir of the 1982–84 recession because of declining demand in the United States for direct-shipping ores and problems in developing a viable market for a Schefferville sinter feed.

Quebec Cartier Mining Co. (QCM) was the largest producer in North America in 1989, edging out IOC by less than 1 Mmt. QCM shipped 7.95 Mmt of concentrate, 6.58 Mmt of acid pellets, and 1.59 Mmt of fluxed pellets from its terminal at Port Cartier. All of the marketable concentrate and pellet feed came from the company's Mount Wright mining complex near Fermont. The Mount Wright ore had been averaging 32.1% Fe and was typically a fine-grained specularite with less than 5% magnetite. Proven in situ reserves exceed 2.5 billion tons. In 1989, the beneficiating plant at Mount Wright processed about 16.5 Mmt of concentrate containing 64.0% Fe and 4.7% SiO_2. The concentrate was being shipped 415 km on the company-owned Cartier Railway to Port Cartier in unit trains of about 19,000 mt.

For the third year in a row, the Port Cartier pelletizing plant operated above the 8.0 Mmt level, far exceeding its original design capacity of 6.0 Mmt per year. In late 1989, the company purchased 10 new pelletizing disks that effectively raised the plant's capacity to 8.4 Mmt per year. The Port Cartier plant, completed in 1979, had two traveling grate furnaces with a combined design output of 7.50 Mmt per year. The older of the two furnaces, which started up in November 1977, was set up to produce low-silica pellets for direct reduction plants. Concentrate for the low-silica line was routed through an upgrading plant employing wet high-intensity magnetic separators. Both fluxed and acid varieties have been produced. The low-silica fluxed pellet, introduced in 1986, had been averaging 66.08% Fe, 0.020% P, and 2.27% SiO_2 on a dry basis.[23] The SiO_2 content of the

low-silica acid pellet tended to be slightly lower and, in past years, ranged from 2.15% to 2.30% SiO_2 on a dry basis. As in 1988, most of the low-silica pellets went to the DRI plants of Sidbec-Dosco Inc. at Contrecouer, Quebec, and Georgetown Steel Corp. at Georgetown, SC. It is important to point out that less than 15% of the 1989 production run was devoted to low-silica pellets. The bulk of Port Cartier's output was standard acid pellets averaging 64.56% Fe, 0.009% P, and 4.74% SiO_2 on a wet basis.

Since August 1989, QCM has been owned by Dofasco Inc. (50% equity), Mitsui & Co. Ltd. of Japan (25%), and Companhia Auxiliar de Empresas de Mineracao (CAEMI) of Brazil (25%). Dofasco, the largest integrated steel producer in Canada, was to take 2 Mmt of fluxed pellets annually from the Port Cartier plant under a long-term contract that took effect in March 1990. The fluxed pellets were being shipped 1,500 km up the St. Lawrence Seaway to Dofasco's four blast furnaces at Hamilton, Ontario. The takeover of QCM allowed Dofasco to replace fluxed pellets from its Adams and Sherman Mines with less expensive ones from Port Cartier and still satisfy Hamilton's requirements. The two smaller mines, near Kirkland Lake in northern Ontario, were closed as scheduled following the changeover. Dofasco had been buying pellets from QCM on the open market for several years, making extensive blast furnace trials unnecessary.

The sale of QCM was a somewhat complicated affair. On March 31, 1989, Dofasco purchased 25% of the outstanding shares of QCM from USX Holdings Inc. The USX unit then signed a letter of intent to sell the remaining 75% of its equity in the mining operation to Elder Resources North America, a subsidiary of an Australian investment group. However, Dofasco decided to exercise its right of first refusal and purchased the other 75% of QCM from USX on June 30. The Canadian steelmaker acquired control of the Cartier Railway Co. and U.S. Steel Canada Inc. as part of the agreement. USX reportedly sold QCM as part of its asset redeployment program.

Mitsui and CAEMI were invited to become partners to help increase sales of QCM ore outside North America. The two accepted Dofasco's offer and bought 50% of QCM on July 31. Both companies were prominent in the international iron ore industry. Mitsui was a major Japanese trading company with direct or indirect ownership interests in iron mines in Australia and Brazil. Mitsui was the largest importer of iron ore into Japan in 1989 and was responsible for about 22% of the tonnage delivered to the Japanese steel industry. CAEMI was a Brazilian industrial group whose main interests were in mining and metallurgy. The Brazilian company was set up in 1950 to run the Serra do Navio manganese mine of Industria e Comercio de Minerios S.A. (ICOMI) in the Federal Territory of Amapa, but had since diversified into iron mining and the transportation of bulk materials. CAEMI owned 70% of Mineraçôes Brasileiras Reunidas S.A. (MBR), the second largest iron ore producer in Brazil, and had an international network of sales agents that marketed both iron and manganese ores.

Wabush Mines shipped 6.20 Mmt of pellets, approaching the record of 6.32 Mmt set in 1984. The company's beneficiating and agglomerating complex at Pointe Noire, Quebec, exceeded its rated capacity of 6.1 Mmt by 2%. Three types of pellets were made—comparable acid and fluxed pellets containing no more than 1% manganese (Mn) and an acid grade containing 2% Mn.

All of the pellet feed for Pointe Noire came from the Scully Mine in southwestern Labrador, which had been in operation since 1965. The mine and concentrator are near the town of Wabush at the southern end of the Labrador Trough. Over 50 years of reserves averaging 35.2% Fe remain, and less than 60% of the ore body had been stripped. The principal ore mineral is a friable, specular hematite that occurs in a highly folded, Lake Superior-type banded iron formation of Early Proterozoic age. The specularite is frequently associated with manganese in the form of pyrolusite or psilomelane.

Blending of the high- and low-manganese iron ores was required to ensure a constant ore grade for the concentrator. Humphrey spirals were used to make an initial concentrate, which was then fed to high-tension electromagnetic separators for further upgrading. Two types of concentrate were created by the blending process. One ran 66.45% Fe, 2.50% SiO_2, and 1.05% Mn; the other, 65.30% Fe, 2.54% SiO_2, and 2.04% Mn. At the beginning of 1989, Dofasco, Stelco, and the four other active partners in Wabush agreed to upgrade operations. A new stacker was commissioned at the Pointe Noire yards in mid-1989, and new equipment was ordered to reduce stack emissions from the pelletizing plant. A computerized truck dispatch system was installed at the Scully, and two new 170-short ton production trucks were purchased for the pit.

At yearend, the active partners were evaluating a proposal that would restructure ownership interests and resolve problems created by the bankruptcy filings of LTV and Wheeling-Pittsburgh. The bankruptcy claims against LTV for defaulting on the Wabush venture were excluded from the LTV settlement agreement approved in August 1989. LTV notified the partnership that it no longer wished to participate in the venture and put its 15.6% interest up for sale. The solvent partners had rights of first refusal under the existing project agreement. Wheeling-Pittsburgh's shares in the partnership were being held temporarily by CCI with approval of the bankruptcy court.

Algoma's integrated steelworks at Sault Ste. Marie, Ontario, consumed more than 4 Mmt of iron ore products in 1989. Receipts included about 2.4 Mmt of Tilden pellets brought across Lake Superior from Marquette, MI, and 1.23 Mmt of superfluxed sinter railed down the northeastern shore of the lake from Wawa.

The Algoma Ore Division at Wawa had been shipping sinter to Sault Ste. Marie since 1939. The bulk of the iron units for the sinter came from siderite mined at the George W. MacLeod Mine, an open stope and pillar operation in the Michipicoten Range, a complex assemblage of Precambrian volcanic and sedimentary rocks. Approximately 313,000 mt of purchased roll scale, 180,000 mt of Michigan limestone, 70,000 mt of iron oxide wastes from Sault Ste. Marie, and 50,000 mt of petroleum coke were mixed with the siderite to make the 1.23 Mmt of superfluxed sinter. The final product averaged 48.4% Fe and 7.7 SiO_2.

In August 1989, Algoma announced that it was halting all underground development work at the MacLeod.[24] The phaseout was to have been completed by April 1990. The halt affected 44 of the 350 employees in the Ore Division. Despite significant improvements in productivity, the siderite operation had been struggling to remain competitive. The mining and sintering of siderite, as

practiced at Wawa, was more costly than taconite mining and pelletizing, which was better suited to economies of scale. The mine was left with approximately 9 Mmt of usable reserves, which will permit Algoma to continue mining siderite until mid-1992.

During 1990 and 1991, Algoma will conduct cost studies to determine if it is feasible to substitute recyclable iron-rich waste materials from steelworks in the Great Lakes region for a significant part of the siderite. These waste materials could come from Sault Ste. Marie, Dofasco's steelworks at Hamilton, or a number of U.S. operations. The increased use of mill scale and other steelmaking wastes could have at least two advantages. First, the steelmaking wastes would raise the iron content of the sinter while diluting the silica. Second, the wastes would reduce environmental pollution control costs, both at Wawa and the originating steelworks. The sintering plant, which was commissioned in 1966, was already under orders from the Ontario Ministry of the Environment to reduce sulphur dioxide emissions. The wastes would lower the sulphur content of the sinter feed, reducing sulphur dioxide levels proportionately. If successful, the recycling project could extend the life of the MacLeod Mine beyond 2002.

As mentioned earlier, Dofasco closed the Adams Mine at Kirkland Lake and the Sherman Mine at Temagami on March 31, 1990. Factors that reportedly led to Dofasco's decision were as follows: difficult mining conditions, declining ore grades, high rail transportation costs to Dofasco's blast furnaces at Hamilton, and the small size of the two operations relative to other North American iron mines. Both mines were managed by Cliffs of Canada Ltd., a subsidiary of CCI, and had been in a highly unfavorable cost position since 1985. The Adams Mine began production in 1963 and was owned by Jones & Laughlin (now part of LTV Steel) until 1971. The Sherman Mine began production in 1968 and was 90% owned by Dofasco, with the remaining 10% controlled by Tetapaga Mining Co. Ltd., a second Canadian subsidiary of CCI. Each mining complex had an annual capacity of 1.1 Mmt per year and about 315 employees. Dofasco and CCI developed a compensation and benefit program to alleviate the effect of the shutdown on the two mining communities. The program consisted of a $4 million fund for regional development and a 3-year continuation of mine realty taxes totaling $3.8 million.

Both Ontario complexes operated continuously throughout 1989, although actual mining was suspended for a few weeks during the summer. The Adams produced 1.14 Mmt of fluxed pellets averaging 60.92% Fe and 5.30% SiO_2 on a wet basis.[25] The Sherman joint venture had a slightly lower output of 1.03 Mmt, but the chemical specifications of its pellets were almost identical to those from the Adams. The two pelletizing plants continued to produce at full capacity until closure.

Chile

Cia. Minera del Pacífico S.A. (CMP) produced 8.44 Mmt of pellets and ore in 1989, setting a new record for the restructured company.[26] Dramatic increases in production at both the El Romeral and El Laco Mines more than offset a 3% drop in output at the Huasco pelletizing plant. The Huasco plant operated close to full capacity, making 3.48 Mmt of self-fluxing pellets for blast furnaces and 0.25 Mmt of pellets for DRI plants. The 4.0-Mmt-per-year facility also generated 396,000 mt of special pellet feed and 121,000 mt of pellet chips. As in past years, the bulk of the preconcentrate feed for Huasco came from the beneficiation plant at the El Algarrobo Mines, about 85 km by rail to the southeast. The Algarrobo plant, which employs a dry magnetic separation process, made 4.60 Mmt of preconcentrates averaging about 60% Fe from 6.04 Mmt of crude ore. After the preconcentrate reached Huasco, it was ground finer and put through a wet magnetic separator to raise the iron content to 68% and drop the phosphorus content below 0.05%. The Huasco concentrator can process up to 5.5 Mmt per year of preconcentrate and had more than enough capacity to satisfy the single grate kiln unit. CMP was planning to increase the capacity of the pelletizing plant to 5.0 Mmt per year and reopen the Los Colorados Mine to meet the plant's increased requirements for preconcentrate.

Production of direct-shipping ore at El Romeral totaled 4.05 Mmt, 46% more than in 1988. The tonnage consisted of 2.08 Mmt of sinter fines averaging 65.2% Fe on a dry basis and 1.97 Mmt of lump ore. In December 1988, work began at El Romeral on the construction of a $15 million grinding and concentrating plant with a capacity of 1.2 Mmt of ore per year. The new plant would supplement the existing wet magnetic concentrator, which could process up to 4 Mmt of ore per year. The new concentrator was scheduled to start up in mid-1990 and was to make pellet feed from ores that would have been rejected in the past because of their high-phosphorus content.

El Laco, CMP's new magnetite operation in the High Andes, produced 80,000 mt of lump ore and 55,000 mt of sinter fines. The open pit mine is 4,800 m above sea level and is worked only 4 or 5 months of the year because of the severity of the weather at that altitude during the winter. Shipping began in November 1988. So far, all of the shipments have gone to Altos Hornos de Zapla in Argentina as part of a 5-year contract that called for the delivery of 360,000 mt of lump ore. The lump ore and fines were being trucked across the border to a railside storage area at Estación Olacapatos. About 65,000 tons of product was railed during 1989 from Olacapatos to the Zapla steelworks at Palpala.

CMP shipped 8.84 Mmt of ore and pellets in 1989, 16% more than in the previous year. Exports accounted for 7.74 Mmt or 88% of the total. Almost all of the remaining 12% was shipped in coastal vessels to the Huachipato steelworks at Talcahuano in Region VIII. The integrated steelworks was operated by Cia. Siderurgica Huachipato S.A., a sister company of CMP. Both the iron mines and the steelworks are owned by Cia. de Acero del Pacífico S.A. de Inversiones (CAP), the former parastatal iron and steel group that was privatized in 1987.

Thirteen countries purchased material from CMP. Of the 7.74 Mmt exported, 62% went to Japan, 14% to the Federal Republic of Germany, and 9% to France. The Japanese steel industry has taken El Romeral fines for more than 20 years. The purchases were covered by a series of long-term sale agreements worked out in the early 1970's when Mitsubishi Corp. and other Japanese trading companies agreed to help finance the modernization and expansion of the Chilean iron ore industry. Mitsubishi also participated in the financing of the Huasco plant and had taken most of the plant's output since its startup in 1978. During the 1983-86 downturn in Western markets, CMP became concerned about its heavy dependence on the Japanese market and has since signed long-term

contracts with steelmakers in France, the Federal Republic of Germany, the Republic of Korea, and Mexico.

CAP has almost 1 **billion** tons of demonstrated or inferred reserves distributed between seven mining properties as shown in the text table.

Property	Administrative region	Reserve base (million metric tons)
El Romeral	IV	237
El Laco	II	228
Cerro Negro Norte	III	138
Cristales	do.	138
El Algarrobo	do.	99
Los Colorados	do.	78
Alcaparra	do.	37
Total		955

Source: Cia. Minera del Pacifico S.A.

The company had additional resources at Cerro Imán northwest of Copiapó, at Mina Carmen northeast of Chañaral and at El Pleito south of Los Cristales. Cerro Imán and Mina Carmen are both in the Atacama Desert at the northern end of Chile's coastal magnetite belt.

France

In 1975, France was the sixth largest iron ore producer in the world, with an output of 49.65 Mmt. However, as the following table shows, iron ore production in both the Lorraine and Normandy basins gradually declined over the past 15 years because of competition from less expensive and better quality ores from Australia, Brazil, and Canada.

Between 1980 and 1989, pig iron production in France fell 19% because a number of obsolete furnaces were closed as part of the EC steelmaking rationalization program. At the same time, the country's exports of ore dropped from 8.7 Mmt to 3.5 Mmt. The Lorraine ores were at a disadvantage in recent years because of their high-phosphorus content, which was at odds with the increasingly stringent chemical requirements of advanced steelmaking. Total imports of ore declined from 18.6 Mmt to 12.6 Mmt between 1980 and 1983, but returned to pre-1983 levels and reached a record-high level of 20.1 Mmt in 1989. The largest gains during the decade were made by Australian and Canadian suppliers. French imports from Liberia and Mauritania were halved, but the biggest loser was Sweden, which dropped from second to seventh place.

Year	Production (thousand metric tons)				
	Lorraine region[1]	Western region[2]	Pyrenees[3]	Other	Total
1950–59	441,925	28,581	2,537	399	473,441
1960–69	558,375	33,456	1,131	161	593,122
1970–79	452,268	18,891	792	—	471,951
1980	27,663	1,219	99	—	28,981
1981	20,444	1,049	105	—	21,598
1982	18,242	1,060	109	—	19,411
1983	14,935	929	103	—	15,967
1984	13,986	939	105	—	15,029
1985	13,815	785	80	73	14,753
1986	11,604	740	92	124	12,560
1987	10,715	668	29	95	[4]11,507
1988	9,369	516	—	—	[4]9,983
1989	9,055	338	—	—	[4]9,368
Total 1980–89	149,830	8,244	721	291	159,158

[1]The Lorraine or Eastern region includes the basins of Longwy, Landres-Ottange, l'Orne, and Nancy. The data represent production of crude ore.
[2]The Western region includes the basins of Normandy, Anjou, and Brittany. The data represent production of marketable ore.
[3]The principal mines are in the Pyrenees-Orientales near Mount Canigou. The data represent production of crude ore that is considered totally marketable.
[4]Crude ore production. Marketable production in 1987, 1988 and 1989 totaled 11,225,063, 9,868,967, and 9,319,306 tons, respectively.
Sources: Les Mines de Fer Francaises en 1989 (U.I.M.M.), Annales des Mines, and Statistique de l'Industrie Minerale.

At the end of 1989, there were only three producers in France: Arbed SA and Usinor Sacilor in the Lorraine Basin and Société Métallurgique de Normandie (SMN) in the West. The last mine in the Pyrénées, the Batere, was closed in 1987. Arbed had two underground mines, Montrouge and Ferdinand, in the Bassin d' Amermont, northwest of Thionville. In 1989, 3.46 Mmt of ore from the two mines was railed across the border to Arbed's three blast furnaces at Esch-sur-Alzette in Luxembourg. Usinor Sacilor operated the Mairy, Moyeuvre, and Orne-Roncourt Mines near Briey. In the West, SMN was in the process of phasing out operations at its Soumont Mines south of Caen. Some of the Soumont personnel were to be transferred to mines in Lorraine. A limited amount of relatively low phosphorus ore was also coming from Rouge in the Department of Ille-et-Vilaine.

Liberia and Guinea

Liberia was able to export 12.75 Mmt of iron ore products in spite of its declining economic situation. The tonnage was only 7% less than the 13.65 Mmt shipped in 1988. The four largest buyers on a tonnage basis were the Federal Republic of Germany (46%), Italy (23%), France (8%), and Belgium (7%).

Production was restricted to two operations, the Bong Mining Co. complex northwest of Salala in Bong County and the Yekepa complex of the LAMCO Joint Venture in Nimba County. At the beginning of 1989, Bong was planning to expand mining to the Bong Peak area of its concession, while LAMCO was working with the Governments of Guinea and Liberia to develop the Pierre Richaud deposit across the border from Yekepa.

Société des Mines de Fer de Guinée pour l'Exploitation des Monts Nimba (MIFERGUI-NIMBA) was formed in 1973 to speed development of the Pierre Richaud deposit, but the joint Guinean-Liberian project was stymied by the subsequent decline of world iron ore prices

between 1982 and 1988. A 17-km-long railroad and turnaround was to be built from the Pierre Richaud mine site on Mount Nimba to the existing LAMCO railway terminal at Yekepa. The Guinean ores would then be railed the additional 265 km to LAMCO's port facilities at Buchanan, where they could be blended and wet screened before export. Use of LAMCO's existing infrastructure was needed to make the Guinean mine economically viable. The cost of constructing a separate rail line more than 350 km to Mount Nimba from the Guinean railway terminus at Kankan would be prohibitive. From Kankan, the ore would have to be railed an additional 660 km to the harbor at Conakry. The existing rail line from Conakry to Kankan was not designed for heavy-duty traffic and would have to be upgraded to handle ore cars. Iron ore loading facilities and docks would also have to be constructed at Conakry.

The joint Guinean-Liberian project is considered essential to the survival of the iron mines at Yekepa. High-grade reserves at the Nimba and Gbahm pits are almost exhausted. However, there is 400 Mmt of leaner reserves in the western area of the concession that could be developed with additional capital investment. The 400 Mmt figure includes 225 Mmt of lean ore left in the Tokadeh pit. LAMCO spent $12 million to reopen Tokadeh in 1985. This ore averages only 47.9% Fe and has a relatively high level of phosphorus, but could be marketed if it were blended with the richer Guinean ores that run 68.1% Fe. In addition, the undeveloped ore bodies at Mount Gangra and Mount Yuelliton have proven reserves of 97 Mmt and 77 Mmt, respectively. Their ores are somewhat richer than those at Tokadeh and run about 54% Fe. Adoption of the blending proposal would extend the life of the Yekepa complex beyond 2010.

This original plan to blend medium-grade Liberian ores with richer material from Guinea has been shelved for the time being. Because of growing demand in Europe for high-grade lump ore, the present plan is to direct ship the Guinean ores through Buchanan.

In April 1989, the two Governments, LAMCO, and the other partners in MIFERGUI-NIMBA approved a general document outlining how the joint project would be legally and financially managed. A new company, Nimba International Mining Co. (NIMCO), was to be set up in a neutral, offshore country and would take charge of all revenues and development funds. The Yekepa Mines would serve as a bridging operation and would continue to ship ore to Buchanan until the Guinean mine reached full production. This bridging operation would prevent key parts of the old LAMCO infrastructure from deteriorating. The Pierre Richaud has 315 Mmt of measured and indicated reserves and would be mined at the rate of 6.0 Mmt per year. Unfortunately, the future of the entire project is uncertain because of subsequent political events.

On July 29, citing exhaustion of its high-grade reserves, LAMCO halted all mining at Yekepa, but continued to process and ship stockpiled ore from Buchanan. The Government responded by terminating the concession and placing all of LAMCO's assets under the direct control of the Liberian Mining Corp. (LIMINCO)—the parastatal partner in the LAMCO Joint Venture. Shortly afterward, African Mining Consortium Ltd. (AMC) agreed to manage the Yekepa concession for LIMINCO and take over the bridging operation. AMC is a new company formed by British and North American investors that has ties to Hanna. AMC was to mine some 12 Mmt of blendable ore that remained on the Liberian side of the border at a rate of about 4 Mmt per year. Management of the mine was formally transfered to AMC on November 1. Gränges AB and the other private investors in LAMCO have since sold their assets in Liberia to LIMINCO for the symbolic sum of one dollar. Gränges was still negotiating the transfer of its interests in MIFERGUI.

AMC had just shipped its first 300,000 mt of ore when the political situation deteriorated. In December, insurrectionist forces invaded Nimba County from the Ivory Coast. At yearend, Liberia was embroiled in civil war. By May 1990, the insurgents had captured Yekepa, the rest of Nimba County, and most of Grand Bassa County. A subsequent Government counterattack failed to dislodge rebel units from Buchanan. Unconfirmed reports from rebel territory stated that the Yekepa complex and most of the rail line to Buchanan had escaped serious damage. Both sides seemed interested in preserving the infrastructure of the country. Bong's mining and pelletizing facilities were not damaged by the fighting because of their isolated location, but the company was eventually forced to suspend shipments and halt production after rebel forces reached the suburbs of Monrovia. The political instability in Liberia was of grave concern to potential investors in the MIFERGUI-NIMBA Project.

Mexico

Mexican iron ore producers continued to satisfy most of the needs of the country's iron and steel industry. The competitiveness of the Mexican mines was strengthened when international iron ore prices rose at the beginning of 1989. Total production of usable ore was 14.8 Mmt, a drop of 9.7% from the 1988 tonnage. Pena Colorada S.A. and Siderugica Lazaro Cardenas-Las Truchas S.A. (SICARTSA) were the principal producers of ore and agglomerates, accounting for 36.5% and 26.8% of the national total, respectively. Mexican ore reserves were estimated to be 587 Mmt.

Mexican blast furnace operators continued to use pellets for the bulk of their iron units. Total pellet production was estimated to be 7.53 Mmt, significantly less than total demand. As a result, 440,000 mt of pellets had to be imported from Brazil and Chile to meet the demand of the SICARTSA II complex in the State of Michoacan. Pena Colorada was the leading pellet producer in 1989 with 3.07 Mmt or 40.8% of the national total. The output was the highest ever in the history of the enterprise, with the Minatitlan pelletizing plant operating at full capacity for the first time since its startup in 1974. With the exception of Pena Colorada, all five of the other pellet producers cut back their output. SICARTSA I experienced the sharpest drop, with pellet production falling 23.4% from its 1988 level. The loss in output was primarily the result of an extended work stoppage. SICARTSA is part of the State-controlled SIDERMEX Group and has financial ties to Altos Hornos de Mexico S.A. de C.V.

The Cerro Nahuatl mining complex of HYLSA S.A. reached an optimal level of production during its first full year of operation. The new operation in the State of Colima was to be the principal source of iron ore during the 1990's for Las Encinas, S.A., HYLSA's mining subsidiary. Las Encinas had a pelletizing plant at nearby Alzada and a second mine at Pihuamo in the neighboring State of Jalisco. About 90% of the capital investments

approved by the Las Encinas management were earmarked for the Nahuatl project.

The SIDERMEX Group also invested heavily in its iron ore operations in 1989. About 36% of its total investments for the year went to upgrade operations at the Hercules mining complex near Sierra Mojada in Coahuila. The Hercules complex was operated by Minera del Norte, S.A., another of SIDERMEX's subsidiaries, and produced concentrate averaging 65.0% Fe.

South Africa, Republic of

The South African iron ore industry had its best year since 1981. Production reached 30 Mmt, with 14.6 Mmt going for export. Exports increased 32% between 1988 and 1989, putting the country ahead of Liberia and Venezuela in terms of gross tonnage. The jump in exports moved the Republic of South Africa from ninth to seventh place in the list of major exporting countries.

Iscor Ltd. shipped 20.94 Mmt of iron ore products during the year and was by far the largest of the country's seven producers. Approximately 17 Mmt came from the company's Sishen open pit operation north of Postmasburg in Cape Province. The bulk of the Sishen material was railed to the deepwater terminal at Saldanha Bay for export. The terminal exported 7.93 Mmt of lump ore and 3.98 Mmt of fines in 1989.[27] The 11.92 Mmt represented 81% of the country's total exports, with most of the tonnage going to Japan and the EC. The South Atlantic port is an 861 km haul from Sishen. However, the rail costs are partially offset by the efficiency and 10,000-mt-per-hour capacity of the port's loading facilities. The berth at Saldanha Bay is similar in size to the No. 2 pier at Tubarào and can accomodate vessels up to 280,000 dwt.

Iscor also railed 9.02 Mmt of direct-shipping ore and concentrates to its wholly owned steelworks at Vanderbijlpark, Newcastle, and Pretoria. Part of the 9 Mmt came from the Thabazimbi Mine in the northwest quadrant of the Transvaal.

The underground and open pit operations at Thabazimbi produced about 2.4 Mmt of direct-shipping ore in 1989. The mine had seven separate sources of ore, but only four were being worked.[28] About half of Thabazimbi's output came from the new West Donkerpoort pit, which opened in 1988 and was producing about 125,000 mt of run-of-mine ore per month. The original Donkerpoort pit was almost exhausted and had an output of only 26,000 mt per month. This older pit had less than 0.8 Mmt of high-grade ore remaining that was recoverable by surface mining, but had more than 3.5 Mmt of reserves at depth. Iscor's long-range mining plan called for the site to be converted to an underground mine at some future date. At least 28,000 mt per month was being taken from the Vanderbijl ore reserve. The East Mine, an underground operation, was producing about 78,000 mt per month. Mining of the East Kwaggashoek ore body was scheduled to begin in 1993, following a scaledown of operations at the East Mine. The Bobbejaanwater ore body was being held in reserve.

The Thabazimbi ore was similar to that at Sishen. Both were composed largely of hematite derived from a Lake Superior-type banded ironstone. Thabazimbi was Iscor's oldest mine, in production since 1933. During the 57 years of operation, the mine produced 96.3 Mmt of high-grade ore, with 58% coming from underground workings.

Iscor made several changes in the ironmaking part of its operations. The company produced 632,000 mt of DRI at its four-module complex in Vanderbijlpark in fiscal year 1987-88, but shut down its single DRI unit at Dunswart.[29] Steelmaking was halted at Dunswart in October 1987. Both DRI plants were coal-based. The 150,000-mt-per-year Dunswart plant was built in 1973 and employed the Codir process. The 600,000-mt-per-year Vanderbijlpark DRI complex started up in 1984 and employs the SL-RN process.

Blast furnace operations at Iscor's Pretoria works were being scaled back in conjunction with the phasing in of the new Corex operation.[30] The Pretoria Corex plant is the first facility in the world to produce molten iron on an industrial basis by charging coal directly into the smelting furnace. A key feature of the Corex process is that it uses untreated raw coal in place of coke. Coking coal was becoming increasingly scarce in the Republic of South Africa, but the country had large reserves of coals of lower rank. Iscor was able to bypass the conventional coke oven-blast furnace route and substitute these cheaper and readily available noncoking coals. The process produces hot metal with carbon and silicon levels approaching blast furnace standards. However, the sulfur content is much higher because of the substitution of raw coal for coke.

The Corex plant was completed in less than 3 years by Voest-Alpine Industrieanlagenbau and was commissioned on a trial basis in August 1988. Several modifications were made between February and November 1989, and the plant was turned over to Iscor on December 22. The new facility was designed to produce 300,000 mt of hot metal per year and was expected to be operating at about 80% of capacity by February 1990. Iscor located the plant at Pretoria, instead of Vanderbijlpark or Newcastle, for two reasons. First, Pretoria's two coke batteries were nearing the end of their operational life. Second, Pretoria's steelmaking operations needed the byproduct export gas generated by the Corex process.

In February 1988, the South African Government announced that it was abandoning industrial regulatory policies that had been in place for more than 60 years and would privatize many of the companies owned by the state. After a review that lasted more than a year, Government officials decided that Iscor would be the first of the parastatal companies to be sold. In May 1989, the South African Parliament passed legislation formally authorizing the sale of Iscor. Several restrictions on ownership were put into Iscor's articles of incorporation to prevent the company from turning into a monopoly or being dominated by foreign interests. In early October, the Government offered 83.8% of the shares in Iscor to the general public, with preferences and discounts being given to employees and pensioners of the company.[31] The remaining 16.2% was retained by the state, for a total issue of 1.85 billion shares.

Spain

Four companies produced a total of 4.57 Mmt of iron ore products in 1989—Compania Andaluza de Mines, S.A. (3.26 Mmt), Agrupacion Minera, S.A. (0.79 Mmt), Prereducidos Integrales del Suroeste de Espana, S.A. (0.21 Mmt), and Metalquimica del Nervion, S.A. (0.31 Mmt). The output of Metalquimica consisted entirely of roasted pyrites recovered as a coproduct of its copper, zinc, and precious metals operations near Bilbao. Production of individual companies over the past 10 years is broken out in the text table.

Company	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
	Production in million metric tons gross weight unless otherwise specified										
Cia. Andaluza de Minas, S.A.	3.500	3.277	3.134	3.379	3.164	3.724	3.740	3.604	3.355	2.873	3.255
Cia. Minera Sierra Menera, S.A.	2.124	2.344	2.078	1.889	1.961	1.598	1.053	.835	—	—	—
Agrupacion Minera, S.A.[1]	1.994	2.057	2.068	2.023	2.022	1.773	1.287	1.184	.607	.926	.792
PRESUR[2]	.498	.543	.330	—	—	—	—	—	.088	.067	.210
Metalquimica del Nervion, S.A.	.318	.370	.380	.370	.352	.352	.360	.340	.295	.269	.310
Minero Siderurgica de Ponferrada, S.A.	.370	.386	.324	.320	—	—	—	—	—	—	—
Other companies and unspecified	.023	.249	.169	.281	.441	.514	.277	.090	.154	.077	—
Total production	8.827	9.226	8.483	8.262	7.940	7.961	6.717	6.053	4.499	4.212	4.567
Average iron content (percent)	45.2	45.4	45.0	47.4	44.7	44.7	45.2	45.6	46.9	45.6	46.6
Total employment	1,944	1,751	1,625	1,570	1,326	1,236	1,298	1,230	906	867	800
Number of mines	17	17	15	14	12	11	9	9	9	9	7

[1]AGRUMINSA is a subsidiary of the steelmaker, Altos Hornos de Vizcaya S.A.
[2]Both Prereducidos Integrales del Suroeste de Espana, S.A. (PRESUR) and Altos Hornos have ties to the parastatal Instituto Nacional de Industria. PRESUR bought the Cala and San Guillermo mines from Minera del Andevalo in 1985.

Source: Cia. Andaluza de Minas, S.A.

Spain had the fifth largest steel industry in the EC but was a net importer of iron ore. A total of 6.94 Mmt entered the country during the year. Almost half of the material came from Brazil, which supplied 3.00 Mmt. Other suppliers included Australia (0.87 Mmt), Mauritania (0.87 Mmt), Liberia (0.84 Mmt), Canada (0.75 Mmt), and Venezuela (0.61 Mmt). A total of 2.39 Mmt was exported, with the bulk of the shipments going to other steel producing members of the EC. The five biggest customers were the Netherlands (0.77 Mmt), France (0.60 Mmt), the United Kingdom (0.32 Mmt), Romania (0.28 Mmt), and Belgium (0.23 Mmt).

Cia. Andaluza de Minas, S.A. (CAM) shipped 3.21 Mmt of Granada fines from its docks at the Mediterranean port of Almeria. The fines were recovered from heterogeneous, but predominantly hematitic, ores mined and processed at the company's Marquesado Mine in the Andalucia region of southeastern Spain. At least 32 different types of ore are recognized, ranging from compact carbonaceous hematite to micaceous, highly fractured goethite. The mine was connected to Almeria by a 100-km-long railway. CAM's sales improved significantly between 1988 and 1989. In 1988, the company shipped only 2.90 Mmt of products. The 1989 shipments would have been even higher if a severe storm had not seriously damaged the ship loader at Almeria on December 18. The loading boom was blown down into the sea, blocking the berth. CAM immediately declared force majeure and began work on a replacement. The new loader was commissioned on May 19, 1990, but over 900,000 mt of sales was lost during the 5-month shutdown. On the positive side, the new unit will allow the port to handle 500,000 mt per month.[32]

Vietnam and Laos

Vietnam, after 50 years of political conflict, war, and economic turmoil, had begun to seriously reevaluate its mineral resources. The reevaluation was part of the Government's reform program launched in 1986 to stimulate the stagnating economy by loosening bureaucratic restrictions. One of the goals of the program was to encourage growth by increasing mineral exports. A seemingly liberal law on foreign investment was adopted in January 1988 to attract capital and technical assistance from multinational companies.

Until 1987, little emphasis was placed on expanding the iron ore industry. The only integrated steelworks in the country was at Thai Nguyen, 60 km north of Hanoi. The steelworks had not been able to operate anywhere near its rated capacity of 200,000 mt per year of crude steel because of power shortages and transportation problems. In past years, a significant part of the iron ore for Thai Nguyen came from the nearby Trai Cau Mine in Bac Thai Province and some smaller mines near Lao Cai in Hoang Lien Son Province, northwest of Hanoi.

The most important iron mine in Vietnam is at Thach Ke in Nghe Tinh Province, 50 km southeast of the coastal city of Vinh.[33] The magnetite deposit was discovered during an aeromagnetic survey and was extensively drilled between 1975 and 1984. The deposit is part of a skarn created when Triassic granite intruded Paleozoic carbonates. Reserves were estimated to be about 540 Mmt. The ore typically assays 61% total Fe, 1.8% Al_2O_3, 1.2% MgO, and 0.05% P. The open pit mine was still in the early stages of development, and the Vietnamese Ministry of Machinery and Metallurgy had approached the Japanese steel industry for technical and financial help.[34] Mining must be carefully planned because the site is only 1.5 km from the Gulf of Tonkin, and precautions will have to be taken to prevent the infiltration of seawater into the pit. Most of the ore would be exported to Japan in exchange for finished steel. Port facilities and roads would have to built because there was very little infrastructure in the district.

The long-term outlook for iron mining was actually much more promising for Laos than for Vietnam. It has been known for 30 years that there were at least two world-class iron deposits in the Laotian Province of Xieng Khouang.[35] The upper reaches of the Mekong Basin have a number of other prospects of potential economic interest, both in Xieng Khouang and the adjoining Loei region of Thailand. The entire area is extremely mountainous, isolated, and poorly explored.

The largest of the two Laotian deposits was at Pha Lek Mountain,[36] about 60

km south-southwest of the provincial capital of Xieng Khouang. Massive lenses of magnetite have formed along contacts between numerous small granitic or dioritic intrusions and the Devonian sedimentary country rock. The contact metasomatic mineralization covers an area of 60 km^2, and more than eight ore bodies have been identified. The high-grade ore bodies lie close to the surface and would require minimal stripping.

The second deposit, Phou Nhouan,[37] forms a mountain ridge on the eastern border of the Plain of Jars, just north of Xieng Khouang. The 5-km-long ridge is made up of Triassic sandstones and shales with apparently conformable beds of ironstone. The ironstone, a mixture of magnetite and grey hematite, can be readily identified by its characteristic bands of dark-red hematite and iron-stained silica. Combined high-grade resources of the two deposits were estimated to exceed 1 billion mt. So far, exploitation of the two deposits has been blocked by the lack of infrastructure in Laos, the high capital cost of development, and the absence of an integrated steelworks in the Mekong Basin. On a positive note, Laos had 3 operational hydroelectric plants—Tha Lat, Se Labum, and Nam Dong—as well as 53 sites where additional hydroelectric stations could be built, providing more than enough power for both an electric-furnace smelting complex and an electric-furnace steelmaking complex. The country also had significant reserves of coal in Vientiane and three other provinces that are suitable for coke production and sintering of fines.

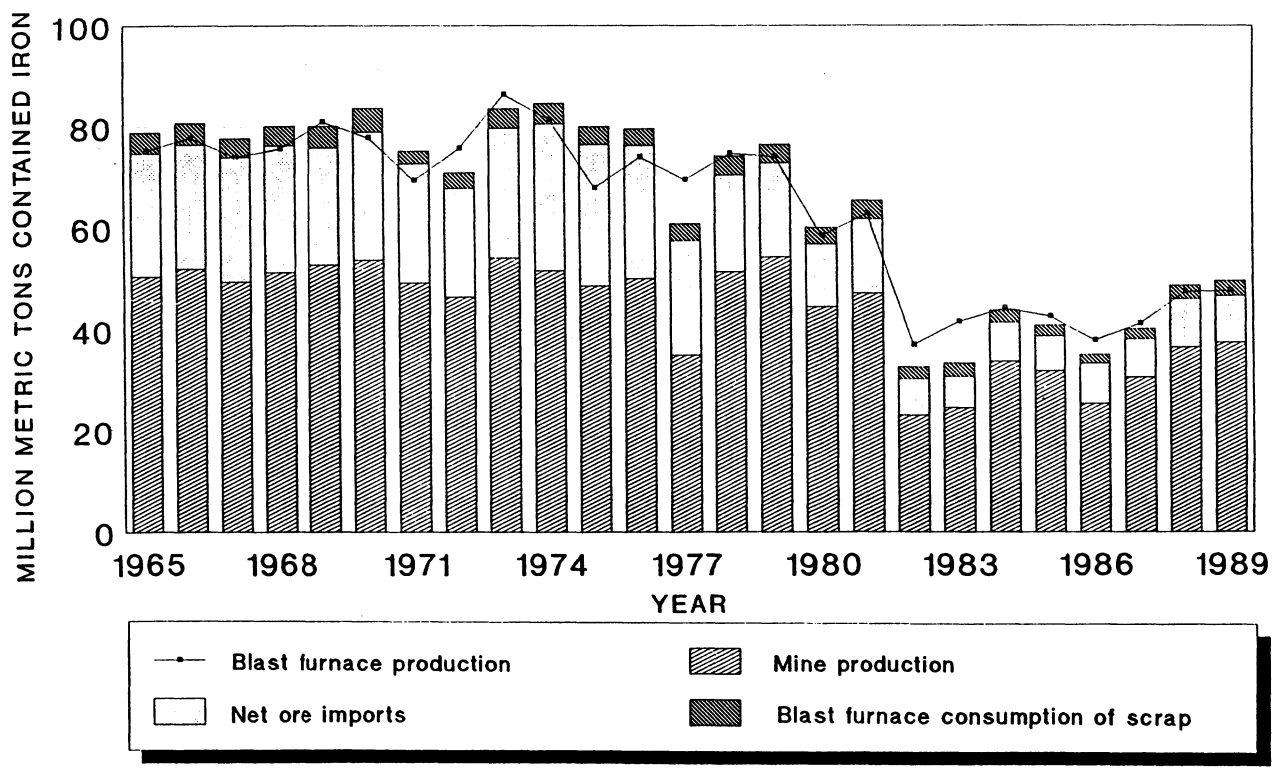
OUTLOOK

About 98% of the demand for iron ore came from the iron and steel industry. The remaining 2% was used in the manufacture of cement, heavy-medium materials, pigments, ballast, agricultural products, or specialty chemicals. As a result, demand for iron ore was tied directly to the production of raw steel and the availability of high-quality steel scrap. This relationship is shown for the United States in figure 3 which compares annual blast furnace production with the combined total of mine production, net ore imports, and blast furnace consumption of scrap. Because of this relationship, the reader is referred to the outlook sections in the "Iron and Steel" and "Iron and Steel Scrap" chapters. The dependence of the iron ore industry on steel demand is not expected to change in the near future.

In 1989, the world steel industry produced a record-high 783 Mmt of crude steel, drawing down large stockpiles of ore and agglomerates that had accumulated over the past decade. World demand for iron ore has improved considerably since 1987, but some serious marketing problems still have to be solved. During the 1980's, many iron mining companies were hurt by pig iron production cutbacks in the industrialized countries and were forced by economies of scale to either halt operations or build up stocks far above marketable levels. The cutbacks in pig iron production resulted from the following:

FIGURE 3

COMPARISON OF BLAST FURNACE PRODUCTION WITH THE SUM OF MINE PRODUCTION, NET ORE IMPORTS, AND BLAST FURNACE CONSUMPTION OF SCRAP



• Slackening demand for finished steel in the U.S. and several other industrialized countries who were struggling with recessionary forces,

• The proliferation of minimills that utilize electric arc furnaces and rely heavily on scrap,

• The increased use of scrap in basic oxygen furnaces (BOF's) at integrated steelworks, and

• The adoption of new ironmaking and steelmaking technologies.

In this last development, the installation of continuous casting equipment and the shutdown of obsolete open-hearth furnaces have improved the recovery of iron units while reducing the amount of in-house scrap available to the BOF. Because of these events, most iron ore suppliers were continually forced to lower their prices between 1981 and 1987 to maintain market share. This discouraging situation had eased somewhat since early 1988, but made mining companies reluctant to develop additional capacity and brought exploration to almost a complete standstill in North America.

Several world-class deposits remained undeveloped in 1990 because steelworks in the industrialized countries could not absorb additional mine production. The Carajás district in Brazil alone had 18 billion mt of high-grade ore resources, including 2.4 billion mt of measured reserves and 2.5 billion mt of indicated reserves. Other major undeveloped deposits that could be exploited exist in Alaska, Botswana, Eastern Siberia, Gabon, Guinea, Laos, and Senegal.

Improved demand for iron units led to a strengthening of spot prices for both standard and fluxed pellets between 1988 and 1990. Higher prices for quality scrap helped support the increase. However, prices for sinter fines remained weak because steelmakers in North America and Western Europe were forced to close several of their older sintering plants to comply with new environmental protection regulations. The price differential between pellets and fines was expected to exist for some time because several mines in developing countries had excess capacity to produce fines, but lacked the necessary risk capital needed to construct modern, state-of-the-art pelletizing facilities.

BACKGROUND

Definitions, Grades, and Specifications

Iron ore is composed of one or more minerals which, when heated in the presence of a reductant, will yield metallic iron. In commercial terms, the material must be minable at a profit to be called iron ore; otherwise, it is iron-bearing material, lean ore, or waste rock. Iron ore is normally composed of iron oxides, the mineral forms of which are magnetite, hematite, and goethite. Martite, a pseudomorph of hematite after magnetite, is commonly found in oxidized magnetite ores. Limonite is a general term for mixtures of cryptocrystalline minerals, predominantly goethite and hematite, which form bog iron deposits in the Eastern United States and oxidized cappings in the desert regions of the West. Iron carbonate (i.e., siderite) and iron sulfides such as pyrite are sometimes used to make pig iron, but they must be calcined to drive off carbon dioxide or sulfur before being charged to the blast furnace. Iron silicates such as chamosite may contain up to 42% iron but are not used as iron ore except in rare instances where they cannot be separated economically from iron oxides or carbonate. The chemical formula and iron content of each of these minerals are given in the text table.

Mineral	Crystal system	Chemical formula	Molecular weight	Iron fraction
Goethite	Orthorhombic	FeO(OH)	88.854	0.62853
Hematite[1]	Rhombohedral	Fe_2O_3	159.692	.69943
Ilmenite	do.	$FeTiO_3$	151.75	.36802
Magnetite	Isometric	Fe_3O_4	231.539	.72360
Marcasite	Orthorhombic	FeS_2	119.97	.46551
Pyrite	Isometric	do.	119.97	.46551
Pyrrhotite[2]	Hexagonal	FeS	87.91	.63527
Siderite	Rhombohedral	$FeCO_3$	115.856	.48204

[1]Martite is a variety of hematite that occurs in octahedrons or dodecahedrons and is pseudomorphous after magnetite.
[2]Pyrrhotite always contains less iron than is indicated by the stoichiometric formula. Stoichiometric FeS is known as troilite and occurs mainly in iron meteorites.

Iron ore as mined in its natural state is called crude ore. Crude ore may be merchantable without processing or with minimal processing such as crushing and screening, in which case it is called direct-shipping ore. The final ore product of a mining operation, whether direct-shipping ore or the product of extensive processing, is called usable ore or marketable ore. Usable ore includes lump ore, fines, concentrates, and agglomerates. Lump ore consists of particles 4.75 mm or larger. Fines are particles less than 4.75 mm in diameter; sinter feed consists mostly of fines larger than 100 mesh (147 micrometers), while fines smaller than 100 mesh may be classified as pellet feed. The products of beneficiation plants are called concentrates and are classified as coarse (+ 4.75 mm) or fine (− 4.75 mm) as indicated previously. Fine concentrates or natural ores are agglomerated to facilitate transportation and smelting; these products are called pellets, sinter, briquets, etc., depending on the agglomerating process used.

Taconite was originally applied to the hard, fine-grained, banded iron-bearing formation of the Mesabi Range. The term is now used to describe similar rocks in other parts of the world that contain low-grade ores with the same characteristics. If magnetite is the principal iron mineral, the rock is called magnetic taconite; if hematite is the principal iron mineral, the rock is called hematitic taconite or oxidized taconite. Jaspilite is used to describe relatively iron-rich banded hematitic iron formations of the type found in the Marquette and Vermilion Ranges of the Lake Superior District. Taconite pellets are iron oxide pellets produced from low-grade crude ores of the taconite type. In Minnesota, altered taconite from which silica has been partly leached by natural processes is sometimes referred to as semitaconite, or wash ore. Itabirite is a metamorphic rock with a schistose structure that is composed primarily of granular quartz, specular hematite, and some muscovite. The term was first used to describe a characteristic type of iron

formation in the Iron Quadrangle of Brazil that runs 30% to 50% Fe.

U.S. Lake Superior iron ores are graded and priced on the basis of chemical composition and physical structure. Bessemer ores contain 0.045% phosphorus or less; non-Bessemer ores contain more than 0.045% phosphorus; high-phosphorus ores contain 0.18% phosphorus or more. Manganiferous ore contains 2% or more manganese. Siliceous ore contains 18% or more of silica. Published prices for these ores are for a long or gross ton (2,240 pounds) of iron ore containing 51.5% iron, natural, delivered rail-of-vessel at lower lake ports. The natural iron content is based on gross weight, including moisture, and is always lower than the iron content calculated on a dry basis. Published prices for pellets are for a ltu of contained iron, natural, delivered rail-of-vessel at lower lake ports. Although prices are still published for Bessemer, phosphoric, manganiferous, and siliceous grades, very little ore of this type (locally known as natural ore) is now produced in the Lake Superior District. More than 97% of the district's output is pellets.

In iron ore transportation on the Great Lakes, lower lake ports refer to receiving ports such as Burns Harbor, Cleveland, Detroit, Indiana Harbor, Lorain, Toledo, etc. Upper lake ports refer to ore loading ports such as Escanaba, Marquette, Superior, and ports in Minnesota. Head of the Lakes refers to the Duluth-Superior area on the western shore of Lake Superior.

Industry Structure

The history of iron mining in early America has already been reviewed in several other publications of the Bureau of Mines and its predecessor.[38] 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.[39]

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.[40] 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-Altantic 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 two deep recessions from which the iron ore and steel industries have not yet fully recovered.

In 1989, iron ore was produced by 21 companies operating 21 mines, 16 concentration plants, and 9 pelletizing plants. The mines included 20 open pits and 1 underground operation. However, only 10 mines accounted for 99% 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, 11 U.S. companies and 3 Canadian companies engaged in production of iron and steel. Domestic steel companies directly controlled about 76% of production; Canadian steel companies, about 11% of production. Consumption of iron ore and agglomerates was distributed approximately as follows: blast furnaces, 97.6%; direct reduction plant, 0.5%; steel furnaces, 0.3%; and manufacture of cement, heavy-medium materials, and other products, 1.6%.

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.

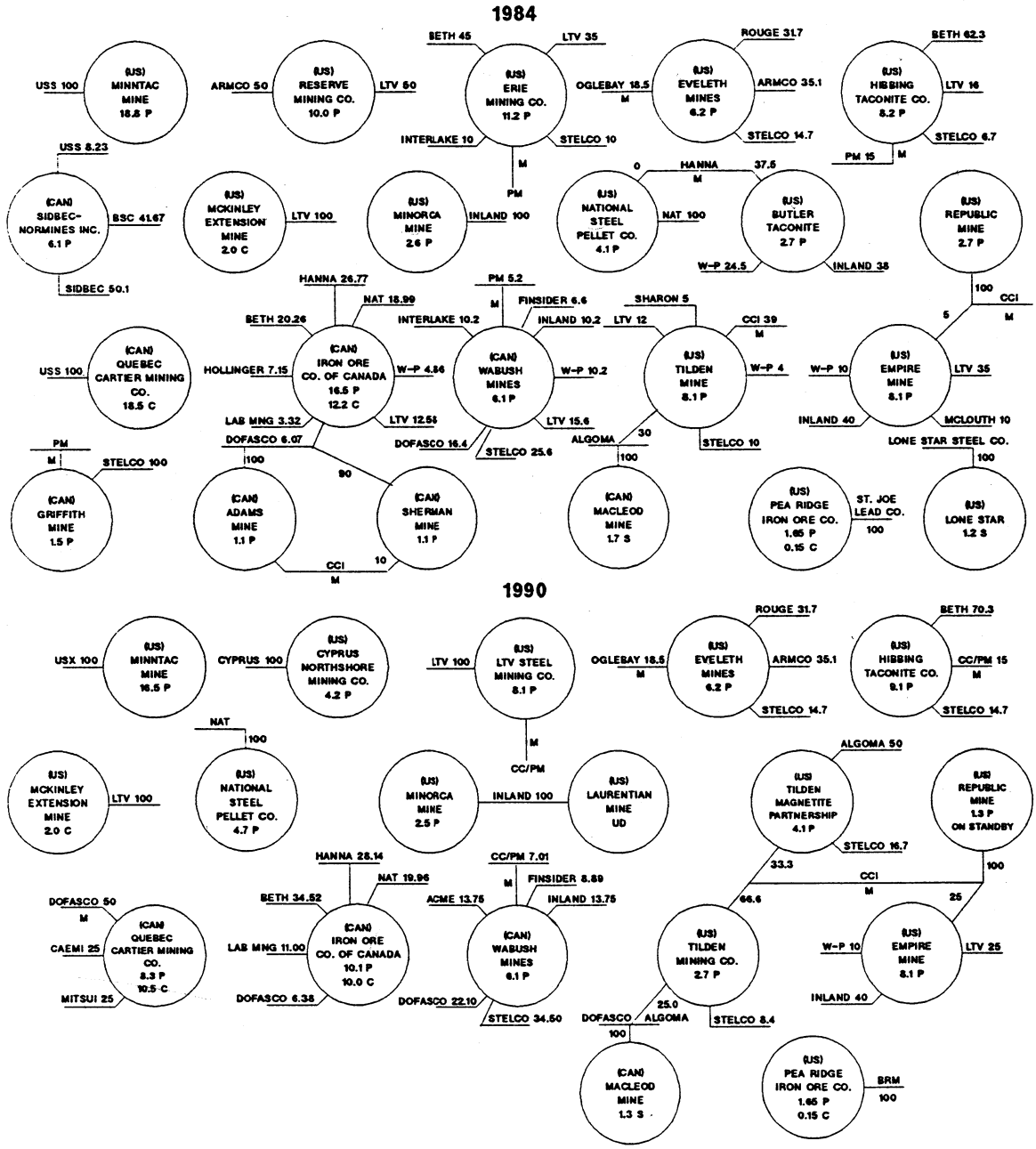
The iron ore industry of the United States and Canada has been undergoing a major restructuring since 1985 aimed at lowering pellet costs and improving financial health. The bulk of this restructuring occurred in the summer of 1986, when the industry was experiencing one of its worst years since the 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 1984 are shown in upper half of figure 4.[41] The updated diagram shown in the lower half illustrates how pervasive the restructuring has been since then.

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 and/or dolomite 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. Fluxed pellets comprised more than 25% of total U.S. production in 1989. 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 1988. Cyprus began shipping fluxed pellets in April 1990.

Combined United States and Canadian production represented only about 12% 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

FIGURE 4

PRODUCTION CAPACITY AND OWNERSHIP OF PRINCIPAL IRON MINES, UNITED STATES AND CANADA, FOR THE YEARS 1984 AND 1990



ACME:	ACME STEEL CO.	DOFASCO:	DOFASCO INC.	NAT:	NATIONAL STEEL CORP.
ALGOMA:	ALGOMA STEEL CORP. LTD.	FINSIDER:	FINANZIARIA SIDERURGICA S.P.A.	OGLEBAY:	OGLEBAY NORTON CO.
ARMCO:	ARMCO INC.	HANNA:	M. A. HANNA CO.	PM:	PICKANDS MATHER & CO.
BETH:	BETHLEHEM STEEL CORP.	HOLLINGER:	HOLLINGER-ARGUS LTD.	ROUGE:	ROUGE STEEL CO.
BRM:	BIG RIVER MINERALS CO.	INLAND:	INLAND STEEL CO.	SIDBEC:	SIDERURGIE DU QUEBEC
BSC:	BRITISH STEEL CORP.	INTERLAKE:	INTERLAKE INC.	SHARON:	SHARON STEEL CORP.
CAEMI:	CIA. AUXILIAR DE EMPRESAS DE MINERACAO	LAB MNG:	LABRADOR MINING & EXPLORATION CO. LTD.	STELCO:	STELCO INC.
CCI:	CLEVELAND-CLIFFS IRON CO.	LTV:	LTV STEEL CO.	USS:	UNITED STATES STEEL CORP.
CC/PM:	CLEVELAND-CLIFFS INC/PICKANDS MATHER	MCLOUTH:	MCLOUTH STEEL PRODUCTS CORP.	USX:	USX CORP.
CYPRUS:	CYPRUS MINERALS CO.	MITSUI:	MITSUI & CO. LTD.	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.

about 24% of world output in terms of metal content, followed by Brazil with 19% and Australia with 12%. Trends in world mine production since 1985 are shown on a country basis in table 19. Major mines are listed individually in table 20.

In 1988, the U.S.S.R. produced 249.7 Mmt of direct-shipping ore and concentrate. A large part of the concentrate was consumed to make 67.9 Mmt of pellets. The bulk of the iron ore produced in Australia, Brazil, India, and the Republic of South Africa consisted of high-grade direct-shipping ore or products derived from much higher grade crude ores than those mined in the United States.

Geology-Resources

Iron is the fourth most abundant rock-forming element, comprising about 5% of the Earth's crust. Astrophysical and seismic evidence suggest that the element has also combined with nickel to make up the bulk of the Earth's core. A small part of the crustal iron has been concentrated by sedimentary, igneous, or metamorphic processes into deposits containing up to 70% of the element.

The largest concentrations of iron are found in banded sedimentary iron formations of Precambrian age. (See figure 5.) 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 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 frequently underlie basin areas of hundreds or thousands of km^2. Most consist of fine-grained iron oxides and quartz, with accessory iron silicates and sometimes 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. Example 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, are oolitic ironstones 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 often 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, 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 are Iron Springs, UT; Eagle Mountain, CA; Hanover, NM; Cornwall and Morgantown, PA; El Romeral, Chile; and Marcona, Peru.

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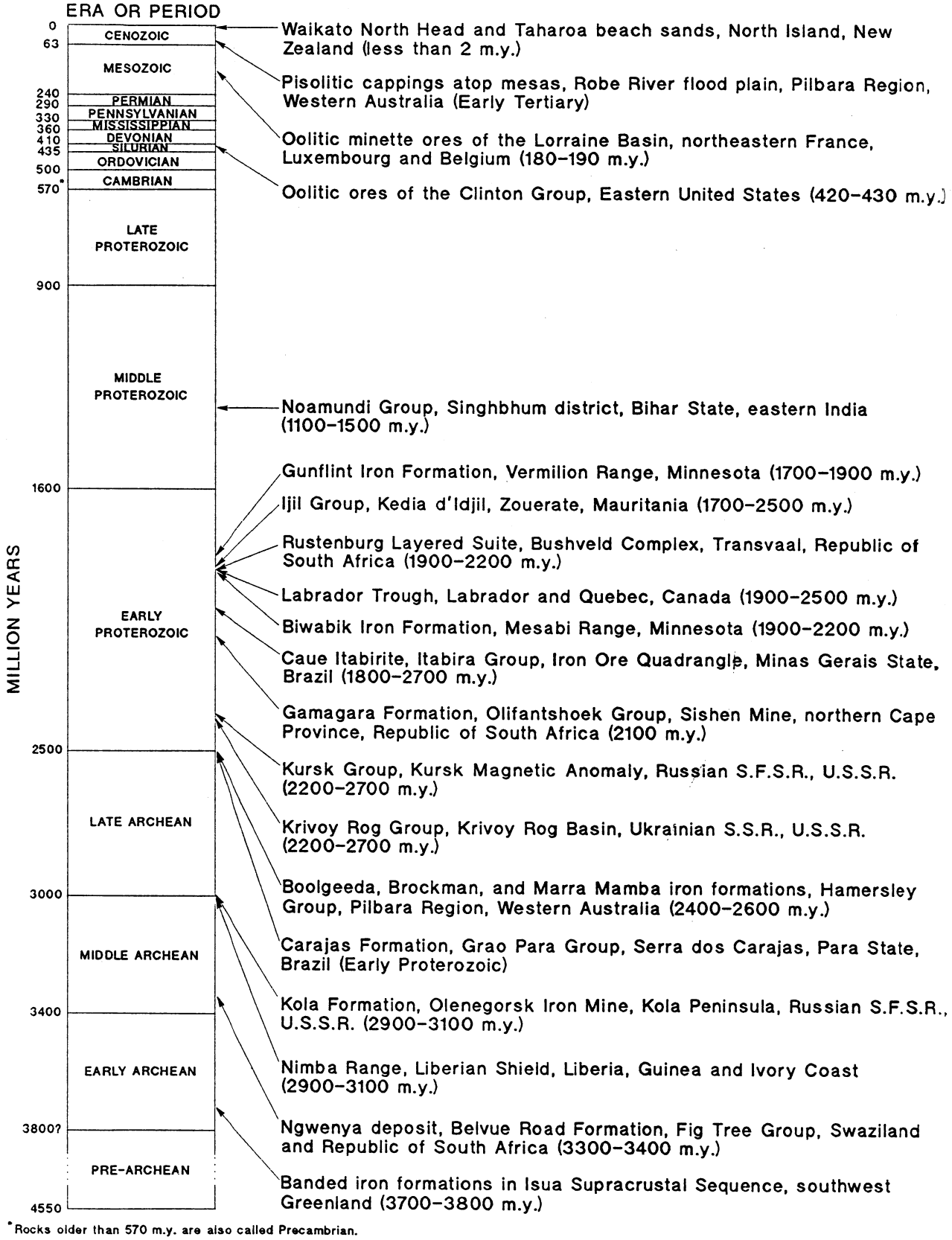
FIGURE 5

IRON DEPOSITION THROUGHOUT GEOLOGIC TIME



*Rocks older than 570 m.y. are also called Precambrian.

TABLE 1

SALIENT IRON ORE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Iron ore (usable,[1] less than 5% manganese):					
Production	49,533	39,486	47,648	57,515	59,032
Shipments	50,204	41,991	47,983	57,113	58,299
Value	$2,076,730	$1,472,511	$1,503,087	$1,716,661	$1,901,772
Average value at mines, dollars per ton	$41.37	$35.07	$31.33	$30.06	$32.62
Exports	5,114	4,553	5,093	5,285	5,365
Value	$240,557	$204,738	$198,254	$193,796	$192,796
Imports for consumption	16,024	17,011	16,849	20,183	19,596
Value	$452,267	$460,643	$408,783	$484,543	$522,262
Consumption (iron ore and agglomerates)	71,708	62,097	67,768	[2]83,694	[2]80,447
Stocks, Dec. 31:					
At mines[3]	6,046	3,307	2,402	2,957	3,800
At consuming plants	21,631	17,439	16,565	18,005	15,730
At U.S. docks	2,442	2,019	2,056	2,537	2,171
Manganiferous iron ore (5% to 35% manganese):					
Shipments	18	13	W	W	W
World: Production	[r]860,556	[r]865,977	889,498	[p]905,252	[e]921,867

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Direct-shipping ore, concentrates, agglomerates, and byproduct ore.
[2]Consumption data for 1988 and 1989 are not entirely comparable with those of previous years owing to changes in data collection.
[3]Excludes byproduct ore. These stocks are not comparable with those of 1982 and earlier years owing to the reclassification of some stocks from the usable to the byproduct category.

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 1989, 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	2,205	4,441	45,174	15,611	9,778	62.6	10.17	3.52	2.20
Minnesota	5,245	10,750	139,915	41,370	26,409	63.8	13.02	3.85	2.46
Total[1] or average	7,450	15,191	185,089	56,981	36,187	63.5	12.18	3.75	2.38
Other States[2]	278	528	2,717	2,052	1,226	59.8	5.15	3.89	2.32
Grand total[1] or average	7,728	15,719	187,806	59,032	37,413	63.4	11.95	3.76	2.38

[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 1989, BY DISTRICT, STATE, AND MINING METHOD

(Thousand metric tons unless otherwise specified and exclusive of ore containing 5% or more manganese)

District and State	Number of mines	Open pit	Underground	Total quantity
Lake Superior:				
Michigan	2	45,174	—	45,174
Minnesota	7	139,915	—	139,915
Total	9	185,089	—	185,089
Other States:				
Missouri	1	—	1,588	1,588
Other [2]	11	1,129	—	1,129
Total	12	1,129	1,588	2,717
Grand total	21	186,218	1,588	187,806

[1] Excludes byproduct ore.
[2] Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 4

USABLE IRON ORE PRODUCED IN THE UNITED STATES IN 1989, 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	(2)	—	15,611	15,611
Minnesota	—	612	40,757	41,370
Total	(2)	612	56,368	56,981
Other States:				
Missouri	—	97	917	1,014
Other[3]	1,038	W	—	1,038
Total	1,038	97	917	2,052
Grand total[4]	1,038	709	57,285	59,032

W Withheld to avoid disclosing company proprietary data; included with "Direct-shipping ore."
[1]Data may include pellet chips and screenings.
[2]Included with "Agglomerates" to avoid disclosing company proprietary data.
[3]Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.
[4]Data may not add to totals shown because of independent rounding.

TABLE 5

SHIPMENTS OF USABLE IRON ORE[1] FROM MINES IN THE UNITED STATES IN 1989

(Exclusive of ore containing 5% or more manganese)

District and State	Gross weight of ore shipped (thousand metric tons)				Average iron content, natural (percent)	Value (thousands)
	Direct-shipping ore	Concentrates	Agglomerates	Total		
Lake Superior:						
Michigan	([2])	—	15,045	15,045	62.6	W
Minnesota	—	612	40,432	41,044	63.6	$1,285,807
Total reportable or average	([2])	612	[3]55,476	56,089	63.3	1,285,807
Other States:						
Missouri	—	100	960	1,060	64.8	W
Other[4]	849	301	—	1,150	55.6	W
Total reportable or average	849	401	960	2,210	60.0	1,285,807
Total withheld	—	—	—	—	—	615,964
Grand total or average	849	1,013	[3]56,437	58,299	63.2	[3]1,901,772

W Withheld to avoid disclosing company proprietary data; included in "Total withheld."
[1]Includes byproduct ore.
[2]Included with "Agglomerates" to avoid disclosing company proprietary data.
[3]Data do not add to total shown because of independent rounding.
[4]Includes California, Montana, New Mexico, New York, 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]
1854–1982	538,494	334,629	325,474	105,189	3,415,864	71,465	8,280	9,869	4,809,267
1983	9,489	—	—	—	26,676	—	—	—	36,165
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
Total[1]	627,272	334,629	325,474	105,189	3,659,856	71,465	8,280	9,869	5,142,035

[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
		FLUXED PELLETS[4]					
1988	13,618	60.71	.017	4.52	.21	.24	2.10
1989	19,755	61.36	[5] .081	4.37	[5] .54	.16	2.12

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 $(CaO + MgO)/(SiO_2 + Al_2O_3)$ is 0.6 or greater.
[5]Being reviewed.

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

[1]Excludes dust, mill scale, and other revert iron-bearing materials added to sinter.
[2]Data may not add to totals shown because of independent rounding.

Source: American Iron Ore Association.

TABLE 9

CONSUMPTION OF IRON ORE AND AGGLOMERATES AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT

(Thousand metric tons)

Type of product	1985	1986	1987	1988	1989
Blast furnaces:					
Direct-shipping ore	2,904	1,893	2,696	5,155	3,211
Pellets	51,698	43,610	49,500	61,025	61,659
Sinter[1]	16,182	13,221	14,420	15,497	13,664
Total[2]	70,784	58,725	66,616	81,676	78,533
Steelmaking furnaces:					
Direct-shipping ore	90	65	123	194	142
Pellets	62	31	44	88	76
Sinter[1]	82	25	42	—	—
Total[2]	233	122	209	282	219
Grand total[2]	71,017	58,846	66,824	81,958	78,752

[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% ore 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

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]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 Bureau of Mines surveys.

TABLE 11

U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY OF DESTINATION

(Thousand metric tons and thousand dollars)

	1986		1987		1988		1989	
Country	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
India	(1)	17	—	—	(1)	25	1	59
Mexico	1	45	1	42	1	62	(1)	15
Netherlands	(1)	17	—	—	(1)	3	—	—
Venezuela	(1)	39	1	95	4	348	(1)	44
Other	(1)	20	(1)	9	3	109	4	345
Total[2]	4,553	204,738	5,093	198,254	5,285	193,796	5,365	192,796

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12

U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

(Thousand metric tons)

Year	Pellets	Concentrates	Coarse ores	Fine ores	Other[1]	Total[2]
1989	4,852	353	—	145	16	5,365

[1]Sum of briquettes (Schedule B 2601.12.0060), other agglomerates (2601.12.0090), and roasted pyrites (2601.20.0000).
[2]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1986		1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	10	86	194	5,141	1,076	16,780	394	5,211
Brazil	3,752	71,045	3,698	64,820	4,935	78,092	5,169	90,885
Canada	8,836	311,757	7,981	246,181	9,157	285,961	8,538	292,866
Chile	94	2,126	636	12,601	139	2,772	61	1,200
India	—	—	—	—	126	2,820	59	1,037
Liberia	1,511	21,855	994	13,707	128	1,460	200	2,950
Mauritania	66	1,158	412	6,403	522	7,864	594	10,130
Norway	—	—	—	—	—	—	40	693
Peru	92	2,429	84	1,691	181	2,939	186	4,280
Philippines[1]	56	1,504	59	1,575	239	5,432	66	1,622
Spain	—	—	1	27	—	—	—	—
Sweden	106	2,473	139	3,334	88	4,678	57	1,000
Venezuela	[2]2,346	[2]42,126	[3]2,622	[3]52,889	3,568	75,443	4,232	110,367
Other	140	4,083	29	413	[4]24	[4]301	([5])	21
Total[6]	17,011	460,643	16,849	408,783	20,183	484,543	19,596	522,262

[1]Sinter made from raw materials supplied by Australia, Brazil, and other countries.
[2]Excludes approximately 84,300 metric tons of sponge iron valued at $8,340,609, originally reported as iron ore.
[3]Excludes 18,370 metric tons of sponge iron valued at $1,849,584, originally reported as iron ore.
[4]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.
[5]Less than 1/2 unit.
[6]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 14

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

(Thousand metric tons and thousand dollars)

Type of product	1989		
	Quantity	Value	Unit value[1] (dollars per ton)
Concentrates	371	7,760	20.93
Coarse ores	662	15,566	23.52
Fine ores	11,629	297,913	25.62
Pellets	5,628	175,728	31.22
Other agglomerates	1,186	23,251	19.61
Roasted pyrites	121	2,045	16.97
Total[2]	19,596	522,262	26.65

[1]Unit values shown are calculated from unrounded data.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES IN 1989, BY COUNTRY AND TYPE OF PRODUCT

(Thousand metric tons)

Country of origin	Concentrates	Coarse ores	Fine ores	Pellets	Other agglomerates	Roasted pyrites	Total[1]
Australia	—	—	394	—	—	—	394
Brazil	130	64	3,714	400	740	120	5,169
Canada	143	(2)	5,248	3,146	1	—	8,538
Chile	—	10	51	—	—	—	61
India	—	—	—	59	—	—	59
Liberia	—	—	200	—	—	—	200
Mauritania	—	—	594	—	—	—	594
Norway	40	—	—	—	—	—	40
Peru	—	—	26	159	—	(2)	186
Philippines	—	—	—	—	[3]66	—	66
Sweden	57	—	—	—	—	—	57
Venezuela	—	587	1,403	1,863	379	—	4,232
Other	(2)	—	—	—	(2)	(2)	(2)
Total[1]	371	662	11,629	5,628	1,186	121	19,596

[1]Data may not add to totals because of independent rounding.
[2]Less than 1/2 unit.
[3]Sinter made from raw materials supplied by Australia, Brazil, and other countries.

Source: Bureau of the Census.

TABLE 16

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1986		1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore	5,656	144,725	5,975	125,887	7,759	183,932	6,062	158,193
Buffalo	(1)	25	(1)	30	(1)	14	—	—
Chicago	1,562	37,958	2,007	40,224	1,837	28,820	2,795	52,162
Cleveland	1,734	67,123	1,490	54,551	1,401	41,315	1,557	48,401
Detroit	388	17,798	637	27,196	520	19,607	528	24,773
Houston-Galveston	42	745	9	177	62	1,115	28	519
Mobile	2,473	64,317	1,063	22,645	1,595	40,708	2,284	68,830
New Orleans	1,594	31,052	1,530	27,230	1,496	22,673	1,845	30,830
Philadelphia	3,289	90,592	3,809	103,101	5,031	135,335	3,968	123,112
Other	271	6,308	328	7,743	482	11,024	529	15,442
Total[2]	17,011	460,643	16,849	408,783	20,183	484,543	19,596	522,262

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS OF PELLETS, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989	
	Quantity	Value
Brazil	400	11,287
Canada	3,146	104,984
India	59	1,037
Peru	159	3,930
Venezuela	1,863	54,490
Total	[1]5,628	175,728

[1]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 18

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants[1]	Units	
North America:				
Canada	5	6	13	26.44
Mexico	5	6	6	9.50
United States[2]	10	18	50	66.55
Total	20	30	69	102.49
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]	2	3	3	3.20
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	17	24	NA	100.35
Africa:				
Liberia[8]	1	1	1	3.00
Morocco[9]	1	1	1	.85
Nigeria[3]	1	1	1	1.45
South Africa, Republic of	1	1	1	.60
Total	4	4	4	5.90

See footnotes at end of table.

TABLE 18—Continued

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants[1]	Units	
Asia:				
Bahrain[3]	1	1	1	4.00
China[6]	4	4	NA	2.50
India[10]	1	1	1	2.00
Iran	1	1	1	2.50
Japan[3]	1	2	2	4.40
Total	8	9	NA	15.40
Oceania: Australia[11]	2	2	6	4.00
World total	58	82	NA	267.24

NA Not available.
[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 per year Republic plant, which has been on care and maintenance since 1981.
[3]Pellets produced from imported direct-shipping ores and/or concentrates.
[4]The older of the two plants operated by A/S Sydvaranger at Kirkenes has been idle since 1986. In addition, the 0.50 Mmt per year 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 per year. The 0.3 Mmt per year 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 per year) of the Bong Mining Co. The No. 1 plant has been idle since 1980.
[9]The Nador plant operated by Société 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 per year 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 per year at Dampier in Western Australia, but it has been closed since 1980.

Sources: Association of Iron Ore Exporting Countries (Geneva, Switzerland), Commodities Research Unit Ltd. (London, United Kingdom), International Iron and Steel Institute (Brussels, Belgium), Metal Bulletin Books Ltd. (Surrey, United Kingdom), Roskill Information Services Ltd. (London, United Kingdom), United Nations Commission on Trade and Development (UNCTAD), UNCTAD Trust Fund Project on Iron Ore Information, and Bureau of Mines.

TABLE 19

IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Gross weight[3]					Metal content[4]				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Albania[e 5]	1,130	1,150	1,200	1,200	1,200	376	380	[r]460	[r]460	460
Algeria	3,376	3,359	3,382	3,118	[6]2,748	1,705	1,679	1,691	1,559	[6]1,374
Argentina	639	810	567	674	[6]635	389	514	360	379	[6]340
Australia	97,447	94,015	101,748	96,084	[6]105,810	62,042	60,082	64,798	61,494	[6]67,313
Austria	3,270	3,120	3,061	2,301	[6]2,410	1,019	976	954	727	[6]740
Bolivia	—	11	7	34	[6]14	—	7	5	[e]21	9
Brazil	128,251	132,288	134,105	145,040	[6]153,700	[e]87,210	[e]89,960	91,200	98,600	103,000
Bulgaria	1,985	2,179	1,857	1,826	[6]1,613	607	661	559	[e]600	482
Canada[7]	39,502	36,167	37,702	38,742	[6]40,900	25,130	23,002	23,882	24,540	26,180
Chile	6,534	6,981	6,637	7,710	[6]8,474	3,967	4,197	4,380	5,089	[6]5,593
China[e 8]	80,000	90,000	100,000	[r]99,000	100,000	40,000	45,000	50,000	[r]49,500	50,000
Colombia	[r]440	[r]508	614	609	615	201	[re]234	[re]282	[re]280	283

See footnotes at end of table.

TABLE 19—Continued

IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Gross weight[3]					Metal content[4]				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Czechoslovakia	1,859	1,784	1,798	1,773	1,700	477	458	462	[e]440	400
Egypt	1,950	2,135	2,048	2,112	[6]2,562	975	[e]1,065	[e]1,100	[e]1,000	1,500
Finland[9]	1,122	973	648	556	—	[e]750	[e]390	588	360	—
France	14,447	[r]12,437	11,267	9,872	[6]9,319	4,536	[r]3,855	3,511	3,119	[6]2,945
German Democratic Republic[10]	30	—	—	—	—	15	—	—	—	—
Germany, Federal Republic of	1,034	717	247	70	[6]102	309	212	68	10	[6]14
Greece[5]	2,245	1,197	1,082	1,573	1,500	943	502	454	661	630
Hungary	311	—	—	—	—	75	—	—	—	—
India	42,545	47,800	51,018	49,961	[6]49,487	26,633	29,923	[e]31,937	31,276	[6]30,979
Indonesia	131	153	194	203	[6]143	76	89	113	118	[6]83
Iran[e 11]	[r]2,800	2,800	[r]2,500	[r]2,200	2,005	[r]1,600	1,600	[r]1,450	[r]1,250	1,150
Japan	338	291	266	96	[6]42	212	182	166	61	[6]25
Korea, North[e]	8,000	[r]8,500	[r]8,500	9,000	9,500	3,200	[r]4,000	[r]4,000	[r]4,200	4,400
Korea, Republic of	542	582	470	390	[6]334	304	326	263	218	[6]187
Liberia	15,318	15,295	13,742	12,767	11,700	9,420	9,480	[e]8,520	[e]7,910	7,450
Malaysia	182	208	161	132	[6]193	111	127	98	81	[6]118
Mauritania[12]	9,333	8,929	9,002	10,004	[6]11,138	6,066	5,804	5,851	6,503	7,240
Mexico[13]	7,820	7,298	7,523	8,431	[6]8,141	5,161	4,817	4,965	5,564	5,373
Morocco	191	196	210	114	[6]176	118	123	128	70	[6]107
New Zealand[14]	2,520	[e]2,580	2,290	2,240	2,000	1,425	[e]1,425	[e]1,300	1,266	1,150
Norway	3,468	3,659	3,141	2,644	[6]2,358	2,254	2,378	2,042	1,719	1,528
Peru	4,892	[r]5,036	5,019	4,171	4,300	[r]3,290	[r]3,356	3,305	2,839	[6]2,923
Poland	11	9	6	6	6	3	2	2	2	2
Portugal[15]	73	51	27	23	[6]13	[r]26	19	9	8	6
Romania	2,287	2,431	2,281	[e]2,300	[6]2,482	595	632	595	[e]596	647
Sierra Leone	[e]70	—	—	—	—	[e]40	—	—	—	—
South Africa, Republic of[16]	24,414	24,483	22,008	25,248	[6]29,958	15,076	15,424	13,865	[e]15,906	18,873
Spain[17]	6,463	6,089	4,492	4,212	[6]4,610	3,189	2,778	2,124	1,925	[6]2,150
Sweden	20,454	20,489	19,627	20,440	[6]21,578	13,500	[e]13,520	12,267	13,470	13,500
Thailand	94	37	97	99	[6]177	52	21	54	55	[6]98
Tunisia	309	311	295	325	[6]280	166	[e]167	159	[e]175	140
Turkey	3,994	5,249	5,366	5,693	[6]3,602	2,163	2,843	2,906	[e]3,100	1,950
U.S.S.R.	247,639	249,959	250,874	249,737	241,000	136,000	137,000	138,000	[re]137,000	132,000
United Kingdom	274	289	263	224	[6]34	60	61	58	49	[6]8
United States[17]	49,533	39,486	47,648	57,515	[6]59,032	31,798	25,295	30,526	36,468	[6]37,413
Venezuela	[r]14,710	[r]16,207	17,196	18,218	[6]18,053	[r]9,120	[r]10,050	10,660	11,289	11,190
Yugoslavia	5,478	6,618	5,983	5,545	[6]5,080	1,685	1,983	1,764	1,844	1,690
Zambia	1	1	1	([18])	[6]([18])	1	([18])	1	([18])	([18])
Zimbabwe	1,100	1,110	1,328	1,020	[6]1,143	[r]660	[r]670	824	632	686
Total	[r]860,556	[r]865,977	889,498	905,252	921,867	[r]504,730	[r]507,269	522,706	534,433	544,231

See footnotes on following page.

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Table includes data available through June 27, 1990.
[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 Bureau of Mines estimates: Albania, China, Hungary, and North Korea.
[5]Nickeliferous iron ore.
[6]Reported figure.
[7]Series represent gross weight and metal content of usable iron ore (including byproduct ore) actually produced, natural weight.
[8]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 marketable 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: 1985—131,500; 1986—142,480; 1987—157,000; 1988—154,380; and 1989—162,000.
[9]Includes magnetite concentrate, pelletized iron oxide (from roasted pyrite), and roasted pyrite (purple ore).
[10]Includes "roasted ore," presumably from pyrite, not separable from available sources.
[11]Data are for year beginning Mar. 21 of that stated.
[12]Gross weight is exported iron ore (Mauritania exports all of its iron ore).
[13]Gross weight calculated from reported iron content based on grade of 66% Fe.
[14]Concentrates from titaniferous magnetite beach sands.
[15]Includes manganiferous iron ore.
[16]Includes magnetite ore as follows, in thousand metric tons, gross weight: 1985—3,607; 1986—4,000 (estimated); 1987—4,979; 1988—5,492; and 1989—6,594.
[17]Includes byproduct ore.
[18]Less than 1/2 unit.

TABLE 20

PRINCIPAL IRON MINES OF THE WORLD IN 1989[1]

Country	Company	Mine	Principal ore minerals
Australia	Goldsworthy Mining Ltd.	Shay Gap and Sunrise Hill, Pilbara, WA	Soft hematite and goethite.[2]
	Hamersley Iron Pty. Ltd.	Mount Tom Price, Pilbara, WA	Do.
	do.	Paraburdoo, Pilbara, WA	Do.
	Mount Newman Mining Co. Pty. Ltd.	Mount Whaleback, Pilbara, WA	Do.
	do.	Ore Body 29 (Marra Mamba), Pilbara, WA	Do.
	Robe River Iron Associates	Eastern Deepdale, Pannawonica, Pilbara, WA	Pisolitic limonite.
Brazil	Cia. Vale do Rio Doce	Carajas, Para	Hematite and goethite.
	do.	Caue, Minas Gerais	Secondary hematite and goethite derived from itabirite.
	do.	Conceicao-Dois Corregos, Minas Gerais	Do.
	do.	Timbopeba, Ouro Preto, Minas Gerais	Do.
	Ferteco Mineracao SA	Fabrica, Belo Horizonte, Minas Gerais	Do.
	Minas da Serra Geral SA	Capanema, Ouro Preto, Minas Gerais	Do.
	Mineracoes Brasileiras Reunidas SA	Aguas Claras and Mutuca, Belo Horizonte, Minas Gerais	Do.
	Samarco Mineracao SA	Germano and Alegria Sul, Minas Gerais	Do.
	SA Mineracao da Trindade	Alegria, Minas Gerais	Do.
Canada	Iron Ore Co. of Canada	Humphrey, Carol Lake, Labrador	Specular hematite and magnetite.
	Quebec Cartier Mining Co.	Mount Wright, Fermont, Quebec	Specular hematite.
	Wabush Mines	Scully, Wabush, Labrador	Do.
Chile	Cia. Minera del Pacifico SA	El Algarrobo, Vallenar, Region III	Titaniferous magnetite.
	do.	El Romeral, La Serena, Region IV	Do.
China	Anshan Metallurgical Co.	Dagushan, Liaoning	Magnetite and hematite occurring in taconite.
	do.	Dongganshan, Liaoning	Do.
	do.	Gongchangling, Liaoning	Do.
	do.	Qidashan, Liaoning	Do.
	do.	Yangian, Liaoning	Do.
	Baotou Iron and Steel Co.	Baiyin, Nei Monggol	Magnetite and hematite-martite.

See footnotes at end of table.

TABLE 20—Continued

PRINCIPAL IRON MINES OF THE WORLD IN 1989[1]

Country	Company	Mine	Principal ore minerals
China—Continued	Benxi Iron and Steel Co.	Nanfen and Waitoushan, Liaoning	Magnetite and hematite occurring in taconite.
	Hainan Mining Co.	Shilu, Hainan	Hematite and magnetite.
	Maanshan Iron and Steel Co.	Gushan and Nanshan, Anhui	Titaniferous magnetite.
	do.	Taochong, Anhui	Do.
	Panzhihua Mining Co.	Lanjian and Zhujiabaobao, Sichuan	Titaniferous magnetite.
	Shoudu Iron and Steel Co.	Dashine, Beijing Municipality	Magnetite occurring in quartzite.
	do.	Shuichang, Beijing Municipality	Do.
	Wuhan Iron and Steel Co.	Chengchao, Hubei	NA
	do.	Daye Complex, Huangshi City, Hubei	Magnetite, hematite, chalcopyrite, and pyrite.
	do.	Jinshandian, Hubei	NA
	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.
	Indian Iron and Steel Co. Ltd.	Gua and Manoharpur, Singhbhum district, Bihar	Hematite.
	Kudremukh Iron Ore Co. Ltd.	Kudremukh, Chikmagalur district, Karnataka	Magnetite in taconite.
	Natl. Mineral Development Corp. Ltd.	Bailadila, Bastar district, Madhya Pradesh	Hematite.
	do.	Donimalai, Bellary district, Karnataka	Do.
	Steel Authority of India Ltd.	Kiriburu and Bolani, Singhbhum district, Bihar	Do.
	do.	Rajhara and Dalli, Durg district, Madhya Pradesh.	Do.
	do.	Kendujhar and Sundargarh districts, Orissa	Do.
	Tata Iron and Steel Co. Ltd	Noamundi, Singhbhum district, Bihar	Do.
	do.	Kendujhar district, Orissa	Do.
Korea, North	Government owned	Musan, Chongjin	Magnetite.
Liberia	Bong Mining Co.	Zaweah Pits and Bong Peak, Bong County	Hematite and magnetite associated with itabirite.
	LAMCO Joint Venture[4]	Nimba, Gbahm and Tokadeh Pits, Yekepa	Hematite and goethite.
Mauritania	Société Nationale Industrielle et Miniere	Tazadit (et alia), Kedia D'Idjil	Hematite.
	do.	El Rhein Guelb, Zouerate	Magnetite in taconite.
South Africa, Republic of	ISCOR Ltd.	Sishen, Griqualand West, Cape Province	Hematite.
	do.	Thabazimbi, Transvaal	Hematite and goethite.
Sweden	Luossavaara-Kiirunavaara AB	Kiruna, Lapland	Magnetite.
	do.	Malmberget, Lapland	Do.
U.S.S.R.	Government owned	Bakal, Ural Mountains, RSFSR	Sideroplesite and pistomesite (magnesian siderite).
	do.	Blagodat, Ural Mountains, RSFSR	Magnetite and martite
	do.	Gora Vysokaya, Ural Mountains, RSFSR	Do.
	do.	Kachar, Turgay Depression, Kazakh SSR	Magnetite.

See footnotes at end of table.

TABLE 20—Continued

PRINCIPAL IRON MINES OF THE WORLD IN 1989[1]

Country	Company	Mine	Principal ore minerals
U.S.S.R.—Continued	Government owned	Kaz, Gornaya Shoriya, RSFSR	Magnetite.
	do.	Kachkanar/Gusevogorsk, Ural Mountains, RSFSR	Titaniferous magnetite.
	do.	Korshunika, Angara-Ilim, Irkutsk Oblast, RSFSR	Magnesian magnetite.
	do.	Kostomuksha, Lake Kujto, Karelia ASSR	Magnetite.
	do.	Kovdor, Kola Peninsula, RSFSR	Do.
	do.	Kremenchug (four complexes), Ukrainian SSR	Magnetite, martite-hematite, and siderite.
	do.	Krivoy Rog (six complexes), Ukrainian SSR	Martite-hematite, limonite, and magnetite.
	do.	Lebedinsk, Kursk Magnetic Anomaly, RSFSR	Magnetite and hematite.
	do.	Lisakovsk, Turgay Depression, Kazakh SSR	Oolitic limonite and siderite.
	do.	Magnitnaya Gora, Ural Mountains, RSFSR	Magnetite and martite.
	do.	Mikhaylovsk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
	do.	Olenegorsk, Kola Peninsula, RSFSR	Magnetite and hematite.
	do.	Sheregesh and Tashtagol, Gornaya Shoriya, RSFSR	Magnetite.
	do.	Sokolov-Sarbaysk, Rudnyy, Kazakh SSR	Do.
	do.	Stoylensk, Kursk Magnetic Anomaly, RSFSR	Martite-hematite.
	do.	Yakovlevo, Kursk Magnetic Anomaly, RSFSR	Do.
United States	Empire Iron Mining Partnership	Empire, Marquette Range, Palmer, MI	Magnetite occurring in taconite.
	Eveleth Mines	Thunderbird, Mesabi Range, Eveleth, MN	Do.
	Hibbing Taconite Co.	Hibbing, Mesabi Range, Hibbing, MN	Do.
	LTV Steel Mining Co.	Erie, Mesabi Range, Hoyt Lakes, MN	Do.
	National Steel Pellet Co.	NSPC Project, Mesabi Range, Keewatin, MN	Do.
	Tilden Magnetite Partnership	Tilden, Marquette Range, Ishpeming, MI	Magnetite and hematite occurring in taconite.
	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.	San Isidro, 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 1988 or 1989.

[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]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.

IRON OXIDE PIGMENTS

By Donald P. Mickelsen

Mr. Mickelsen, a mineral industry specialist with 16 years Bureau of Mines experience, has been the commodity specialist for iron oxide pigments since 1985. Domestic survey data were prepared by the author, and international data tables were prepared by Audrey D. Wilkes, international data assistant.

U.S. mine production of crude iron oxide pigments increased significantly over that of 1988, while shipments increased moderately and value decreased. Total domestic shipments of finished natural and synthetic iron oxide pigments remained relatively unchanged from those of 1988. Synthetic iron oxides comprised 61% of all shipments. The sale of the Columbian Chemicals Inc.'s synthetic iron oxide business to Mobay Corp. was blocked by the Federal Trade Commission in March 1990.

Construction materials was the largest end use for iron oxide pigments, followed, in order of rank, by paints and coatings; colorants for ceramics, glass, paper, plastics, rubber, and textiles; ferrites; industrial chemicals; foundry sands; animal feed and fertilizer; and other end uses.

List prices for iron oxide pigments remained unchanged from those in 1988. Price increases proposed by one major producer had little effect on the market because of competitive pricing.

The United States imported more than twice as much iron oxide pigment in 1989 as it exported, but an exact comparison with 1988 data could not be made because of the conversion to the Harmonized Tariff Schedule by the U.S. International Trade Commission and the consequent incompatibility of the 1989 and 1988 classifications. Exports of pigment-grade iron oxides decreased substantially compared with those of 1988. U.S. imports for consumption of natural iron oxide pigments decreased substantially while synthetic iron oxide pigments increased slightly, resulting in an overall slight decrease in iron oxide pigment imports. Imports of natural iron oxide pigments are no longer delineated by color. Synthetic black pigment imports increased significantly, although synthetic red and yellow pigments imports increased only slightly. World mine production of natural iron oxide pigments for reporting countries also increased slightly in 1989.

LEGISLATION AND GOVERNMENT PROGRAMS

On January 1, 1989, U.S. Customs regulations and tariff schedules were modified in accordance with the Omnibus Trade and Competitiveness Act (Public Law 100-418) enacted by Congress on August 23, 1988. This law was passed in order to enhance the competitiveness of the Nation's industries and to improve the management of U.S. trade strategy. Subtitle B of the new law required that all tariff schedules conform to the nomenclature of the internationally established Harmonized System—a global system of classifying products for tariff purposes.

The new law restructured both the import and export classification systems. The new schedule B classification is now based on the organizational framework of the Harmonized Tariff Schedule of the United States. That is, equivalent import and export items are assigned the same 10-digit classification code. In the case of iron oxide pigment imports, 10 subheadings that applied to natural iron oxide pigments have been replaced by 4 less definitive codes, which also include the synthetic iron oxide pigments. The four synthetic import subheadings are now represented by statistical subdivisions. Iron oxide pigment exports are also represented by the same four subheadings as the imports.

Public Law 100-418 also requires

TABLE 1

SALIENT U.S. IRON OXIDE PIGMENTS STATISTICS

		1985	1986	1987	1988	1989
Mine production	metric tons	29,242	30,744	31,816	30,747	42,034
Crude pigments sold or used	do.	42,261	37,183	38,803	39,711	45,575
Value	thousands	$2,826	$2,908	$3,598	$3,815	$3,645
Finished pigments sold	metric tons	115,051	116,444	124,293	126,640	127,665
Value	thousands	$122,716	$126,388	$136,427	r$134,325	$134,567
Exports	metric tons	26,962	26,164	20,184	21,966	[1]9,966
Value	thousands	$27,574	$30,830	$31,689	$33,014	$15,700
Imports for consumption	metric tons	36,105	33,360	38,394	38,929	[1]36,669
Value	thousands	$22,565	$21,517	$20,680	$27,128	$30,540

r Revised.
[1] Data reflects conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989, Public Law 100-418, Subtitle B.

that U.S. Government agencies implement the use of metric units in their business activities by the end of fiscal year 1992. All of the iron oxide pigment trade statistics collected by the Bureau of the Census are now being compiled and published in metric units, as required by that law. Consequently, the Bureau of Mines will publish its iron oxide pigment statistics in metric units and has converted all numbers in the text and iron oxide pigment tables to metric tons, unless otherwise stated. To convert from metric tons to short tons, multiply by 1.10231.

PRODUCTION

Mine production of crude iron oxide pigments increased 37% over that of 1988, and shipments increased a moderate 15%. The bulk of these increases were attributed to stockpiling of crude material by one producer and an increase of sales for nonpigmentary purposes by another. Lower valued nonpigmentary iron oxide sales also accounted for an overall decrease in value of crude shipments of 4%. Four companies mined and shipped various grades of iron oxide pigments. One company in Georgia mined and shipped ocher; magnetite was mined and shipped by a company in Missouri; and, of two companies in Virginia, one mined and shipped sienna, umber, and ocher, and the other shipped umber. Cleveland Cliffs Iron Co., which permanently closed its Mather Mine in northern Michigan in 1979, continued to ship hematite from stockpiles. A new company, Swansea Minerals Inc., shipped minor amounts of a micaceous, specular hematite processed from mine tailings at the Swansea Mine, La Paz County, AZ.

Total domestic shipments of finished natural and synthetic iron oxide pigments, excluding regenerator oxide, steel plant waste, and magnetic iron oxide, remained relatively unchanged from those of 1988 in both quantity and value. Shipments of finished natural iron oxide pigments increased slightly in both quantity and value. These increases were influenced mainly by increases in the black magnetite and red iron oxide categories, which accounted for almost three quarters of the natural iron oxides shipped. Synthetic iron oxide pigments, which dominate the industry, comprised about two thirds of total shipments and experienced slight decreases in quantity in 1989, while total value remained essentially unchanged from 1988 levels. Slight decreases in shipments of synthetic iron oxide pigments occurred across the board, although value remained constant.

Iron oxides recovered from steel-plant wastes, including regenerator oxide and steel-plant dust, were reported by six domestic companies in 1989. Shipments totaled 30,745 tons and were valued at $4,163,000. Perox Inc., a regenerator oxide producer based in Pittsburgh, PA, was added to the Bureau of Mines survey in 1989. Of the remaining five companies who reported shipments, two showed increases, one remained the same, and two showed decreases when compared with those of 1988.

Pigment-grade iron oxides for use in magnetic applications were produced domestically in 1989, but are not included in table 2. Production and shipment data for magnetic iron oxides are not publishable because of their proprietary nature.

Domestic iron oxide pigment producers underwent a year of acquisition activities in 1989. In January, Cambrex Inc., a company that had an agreement in principle to purchase Pfizer Pigment Inc., one of three dominant domestic producers, terminated that agreement owing to a lack of business performance in the second half of 1988.[1] In August, Columbian Chemicals Co. announced it had signed a letter of intent to sell its iron oxide pigment plant in St. Louis, MO, to Mobay Corp., a

TABLE 2

FINISHED IRON OXIDE PIGMENTS SOLD BY PROCESSORS IN THE UNITED STATES, BY KIND

Kind	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Natural:				
Black: Magnetite	6,334	$1,228	10,253	$2,129
Brown:				
Iron oxide	W	W	W	W
Umbers:				
Burnt	W	W	W	W
Raw	W	W	W	W
Red:				
Iron oxide[1]	23,528	4,064	26,395	4,710
Sienna, burnt	W	W	W	W
Yellow:				
Ocher	W	W	W	W
Sienna, raw	W	W	W	W
Undistributed	15,810	8,141	12,725	7,218
Total[2]	45,671	13,433	49,373	14,057
Synthetic:				
Brown: Iron oxide[3]	24,254	r35,077	23,621	36,048
Red: Iron oxide	34,081	r52,334	32,748	50,833
Yellow: Iron oxide[4]	22,634	r33,482	21,923	33,629
Other: Speciality oxides	(5)	(5)	(5)	(5)
Mixtures of natural and synthetic iron oxides	(5)	(5)	(5)	(5)
Total[2]	80,969	r120,892	78,292	120,510
Grand total[2]	126,640	r134,325	127,665	134,567

r Revised. W Withheld to avoid disclosing company proprietary data; included with "Undistributed."
[1] Includes pyrite cinder.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes synthetic black iron oxide.
[4] Includes other specialty oxides and mixtures of natural and synthetic iron oxides.
[5] 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 1989

Producer	Mailing address	Plant location
Finished pigments:		
American Minerals Inc.	Box 677 Camden, NJ 08101	Camden, NJ.
Blue Ridge Talc Co. Inc.	Box 39 Henry, VA 24102	Henry, VA.
Columbian Chemicals Co.	303 Hofmeister St. Louis, MO 63125	St. Louis, MO, and Monmouth Junction, NJ.
Cyprus Specialty Metals Co.	301 Lindenwood Dr., Suite 301 Milwaukee, WI 53207	Frazer, PA.
Hilton-Davis Co.	2235 Langdon Farm Rd. Cincinnati, OH 45237	Cincinnati, OH.
Hoover Color Corp.	Box 218 Hiwassee, VA 24347	Hiwassee, VA.
Mobay Corp., Inorganic Chemicals Div.	Mobay Rd. Pittsburgh, PA 15205	New Martinsville, WV.
New Riverside Ochre Co.	Box 387 Cartersville, GA 30120	Cartersville, GA.
Pea Ridge Iron Ore Co.	Route 4 Sullivan, MO 63080	Sullivan, MO.
Pfizer Pigment Inc.	640 North 13th St. Easton, PA 18042	Emeryville, CA; East St. Louis, IL; Easton, PA.
Prince Manufacturing Co.	700 Lehigh St. Bowmanstown, PA 18030	Quincy, IL, and Bowmanstown, PA.
Solomon Grind-Chem Services Inc.	Box 8288 Springfield, IL 62791	Springfield, IL.
Crude pigments:		
Cleveland-Cliffs Iron Co., Mather Mine and Pioneer plant (closed July 31, 1979; shipping from stockpile.)	1100 Superior Ave. Cleveland, OH 44114	Negaunee, MI.
Hoover Color Corp.	Box 218 Hiwassee, VA 24347	Hiwassee, VA.
New Riverside Ochre Co.	Box 387 Cartersville, GA 30120	Cartersville, GA.
Pea Ridge Iron Ore Co.	Route 4 Sullivan, MO 63080	Sullivan, MO.
Swansea Minerals Inc.	6360 E. Rose Circle Dr. Scottsdale, AZ 85251	Tempe, AZ.
Virginia Earth Pigments Co.	Box 1866 Pulaski, VA 24301	Hillsville, VA.
Regenerator and steel plant waste iron oxides:		
Armco Inc.	P.O. Box 191 Ashland, KY 41101	Ashland, KY.
Gulf States Steel Inc.	174 South 26th St. Gadsden, AL 35904	Gadsden, AL.
Perox	95 32nd St. Pittsburgh, PA 15201	Birmingham, AL, and Sharon, PA.
Petco Inc.	225 S. 600 East Lehi, UT	Lehi, UT.
Shance Chemical Corp.	1 Depot Plaza Mamaroneck, NY 10543	Philadelphia, PA.
Weirton Steel Corp.	400 Three Springs Rd. Weirton, WV 26062	Weirton, WV.

subsidiary of the Federal Republic of Germany company Bayer AG. Columbian Chemicals and Mobay are the remaining two of the three dominant domestic synthetic iron oxide pigment producers, and the sale was subject to Federal Trade Commission (FTC) approval. This sale was subsequently blocked by the FTC, which cited restricted trade as justification for seeking an injunction on the sale.[2]

CONSUMPTION AND USES

Iron oxide pigments were consumed mainly as an ingredient in construction materials; in coatings; and as colorants for ceramics, glass, paper, plastics, rubber, and textiles. Consumption data shown in this chapter represent domestically produced and shipped iron oxide pigments as reported by producers. The United States also imports iron oxide pigments, which are distributed through various trading firms and color companies as well as by some of the domestic iron oxide pigment producers. The Bureau of Mines is unable to ascertain the end-use applications of these imported materials. End-use data shown in table 4 were based on data reported by producers to the Bureau of Mines and do not include imported iron oxide pigments, except for possible minor amounts mixed with domestic materials.

Consumption of iron oxide pigments in construction materials continued to be the largest end use. Use of domestically produced iron oxide pigments in construction material accounted for more than one-third of all shipments, the same as in 1988, and totaled 45,000 tons in 1989. In recent years construction use has been greater than the traditionally largest end use, paint and coatings, and was the end use with the most growth potential, because iron oxide pigment use in colored concrete blocks and roofing tiles was expanding. According to one study by F. W. Dodge, the Information Systems Div. of McGraw-Hill Co., newly started construction was valued at $261.2

billion in 1989, remaining practically the same as that of 1988. Construction starts varied by region: the north-central and western regions had gains of 5% and 1%, respectively. Nonresidential building was the strongest sector during the year, increasing 3% to a value of $93.1 billion; although the actual volume of work decreased 4%. Residential construction declined slightly to $120.4 billion; single-family homes remained stable, and apartment and condominium construction was down 8%. Nonbuilding construction, including public works and utilities, also declined slightly to $47.7 billion, principally owing to a large drop in highway and bridge construction.[3]

Coatings, the second largest use for iron oxide pigments, accounted for almost one-fourth of the iron oxide pigment consumption in 1989, decreasing slightly to 30,730 tons from 31,400 tons in 1988. Shipments for lacquer, paint, and varnish, as reported by the U.S. Department of Commerce, totaled about 1 billion gallons of coatings valued at $11.6 billion, down slightly in volume but up 7% in value over those of 1988. Architectural coatings comprised 51% of all shipments and totaled 533 million gallons; product coatings (original equipment manufacture) was 33% of shipments, or 337 million gallons; and special purpose coatings shipments were 16%, or 167 million gallons.[4]

Of all iron oxides, 17%, or 22,000 tons, were consumed as colorants for plastics, glass and ceramics, paper and textiles, and rubber, by order of rank. This was practically the same amount consumed in 1988. Iron oxide pigments were popular for these uses because of their low cost, coloring effectiveness in thermoplastics and thermosets, and acceptance by the Food and Drug Administration for food contact and medical applications.

The remaining 24% of reported iron oxide pigment consumption, in order of rank, was for use in foundry sands, industrial chemicals, ferrites, the manufacture of animal feed and fertilizers, and other end uses, including cosmetics, magnetic tape and magnetic ink, and polishing agents.

Regenerator oxides and steel-plant dust, not accounted for in table 4, were consumed mainly for use in the manufacture of ferrites, with lesser amounts used as colorants for cements and construction materials, industrial chemicals, foundry use, glass and ceramics, and fertilizers.

Magnetic iron oxides, also not included in table 4, were used mainly in the manufacture of ferromagnetic ceramics, magnetic media such as magnetic tapes and floppy disks, and in magnetic inks and toners.

PRICES

Domestic list prices for natural and synthetic grades of iron oxide pigments sold in 1989 by major producers remained practically unchanged from those of 1988. Although at least one major producer tried to increase prices beginning in the second quarter, competition from other producers discouraged this effort. The iron oxide pigment industry is an extremely competitive industry, and although some of the larger companies would like to increase prices to compensate for higher costs for labor, operations, and raw materials, competition from others makes this difficult. Synthetic iron oxides are the standard for the industry because they have the most consistent colors, highest tincture strength, and are easily dispersed. For these reasons, they command the highest prices and make up the greatest amount consumed. The competitive nature of the industry, however, has lowered the return for the companies involved and is one reason for the upheaval in ownership. Toward the end of the fourth quarter, prices were firming with little or no dis-

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	
	1988	1989	1988	1989	1988	1989
Coatings (industrial finishes, trade sales: lacquers, paints, varnishes)	25	24	16	17	30	29
Construction materials (cement, mortar, preformed concrete, roofing granules)	35	35	29	23	39	42
Colorants for ceramics, glass, paper, plastics, rubber, textiles	17	17	18	21	16	14
Foundry sands	6	5	17	12	—	([2])
Industrial chemicals (such as catalysts)	5	5	W	1	W	7
Ferrites	W	W	W	W	W	W
Animal feed and fertilizers	4	5	9	11	W	W
Other (including cosmetics, magnetic tape and magnetic ink, and polishing agents)	[3]8	[3]9	[4]11	[3]15	[5]15	[6]8
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 industrial chemical and ferrite iron oxide usage.
[5] Includes industrial chemical, ferrite, and animal feed and fertilizer iron oxide usage.
[6] Includes ferrite and animal feed and fertilizer iron oxide usage.

counting for bulk shipments. It was apparent that the new year would bring price increases of about 5 to 6 cents per pound for synthetic colors.[5]

Prices for imported iron oxide pigments also remained at 1988 levels. According to the American Paint and Coatings Journal, list prices for Italian burnt sienna were 50 to 78 cents per pound; for Turkish burnt umber, 47.5 to 56 cents per pound; and for Spanish red, 33.5 cents per pound.

FOREIGN TRADE

Trade statistics show that the United States imported 268% more iron oxide pigments than it exported in 1989. This apparently large trade imbalance was partly the result of the conversion of the U.S. foreign trade data system to the Harmonized Tariff Schedule on January 1, 1989, as required by Public Law 100-418. This law changed the classification codes for both iron oxide pigment imports and exports. Therefore, an exact comparison could not be made.

TABLE 5

PRICES QUOTED ON FINISHED IRON OXIDE PIGMENTS, PER POUND,[1] DECEMBER 31, 1989

Pigment	Low	High
Black:		
Natural	$0.1400	$0.2800
Synthetic	.7400	.9400
Brown:		
Natural	.1400	.2000
Metallic	.1900	.3950
Umber, burnt	.4700	.7000
Umber, Turkish, burnt[2]	.4750	.5600
Umber, raw	.4700	.6700
Vandyke brown	—	.5000
Synthetic	.7800	.8650
Red:		
Natural	.1950	.5000
Sienna, burnt	.5600	.7500
Sienna, Italian, burnt[2]	.5000	.7800
Synthetic	.5000	.9900
Spanish[2]	—	.3350
Yellow:		
Ocher	.1300	.5100
Sienna, raw	.5500	.6400
Synthetic	.7200	.9800
Micaceous:	.2700	.2700

[1] Prices shown represent list prices provided by domestic producers but are not to be considered definite or necessarily reflect contract prices for bulk shipments.
[2] American Paint and Coatings Journal.

U.S. exports of pigment-grade iron oxides and hydroxides decreased 55% in quantity and 52% in value when compared with those of 1988. However, because of the Harmonized Tariff Schedule classification changes, these data are not comparable. An analysis of the export data of the other grade iron oxide which increased 273% in quantity and 105% in value, indicated that pigment grade material was most likely included in this category. This analysis is based on the decrease in value of these other grades, which previously had a much greater average value, owing to the inclusion of magnetic materials in this category.

Exports of pigment-grade iron oxides went to 42 countries in 1989, principally in Asia, North America, and Europe. Chief destinations for iron oxide pigments were the Republic of Korea, Canada, and the Federal Republic of Germany. Exports of other grades of iron oxides and hydroxides were shipped mainly to the Federal Republic of Germany, Mexico, Japan, the Republic of Korea, and the United Kingdom, in order of rank.

U.S. imports for consumption of iron oxide pigments decreased 6% in quantity from those of 1988, but increased 13% in value. Imports were received from 19 countries in 1989, 1 more than in 1988. Imports of synthetic iron oxide pigments increased slightly in quantity and 17% in value. Synthetic iron oxides composed 86% of all imports received. Synthetic black, red, and yellow grades all increased in quantity, with the black grade showing a significant increase over that of 1988. The "other" category, including synthetic brown oxides, transparent oxides, and magnetic and precursor oxides, showed a sharp decrease. Synthetic iron oxides were received chiefly from Canada, the Federal Republic of Germany, Mexico, Japan, and the United Kingdom, in order of rank. Canada and the Federal Republic of Germany supplied 66% of the total synthetic iron oxides imported; Mexico, Japan, and the United Kingdom supplied 28%; and the remaining 6% were imported from other countries. Data on synthetic iron oxides imported from Canada were as reported by the Bureau of the Census. It is likely, however, that a large portion of this material reported as a synthetic iron oxide pigment was misclassified, and was actually a regenerator iron oxide. This was apparent, because one of the two Canadian companies exporting iron oxide material into the United States was a steel-plant operator, not a pigment producer.

U.S. imports of natural iron oxide pigments decreased 36% for both quantity and value from those of 1988. Unit value for natural iron oxide pigment imports remained unchanged. Since the conversion to the Harmonized Tariff Schedule, there no longer exist classification codes for the natural iron oxide pigment grades. In order to remedy this situation, the Bureau of Mines submitted a request to the U.S. International Trade Commission to reinstate classifications for natural iron oxide pigment colors. The large quantity of the natural micaceous iron oxides imports reported by the Bureau of the Census in 1989 was most likely misclassified material, particularly those shown from Canada. The chief supplier of micaceous iron oxides to the United States was Austria, from which 92 tons were received in 1989. Canada, Cyprus, the Federal Republic of Germany, and Spain, in order of rank, supplied 97% of all imports of natural iron oxides, and the remaining 3% came from other countries. Imports received from Cyprus were primarily of crude and finished sienna and umber grades; from the Federal Republic of Germany, primarily Vandyke brown; and from Spain, natural red hematite and ocher. Minor amounts of natural and synthetic iron oxide pigments were received and stored in bonded warehouses for future consumption.

WORLD REVIEW

World mine production of natural iron oxide pigments for reporting countries increased slightly in 1989, totaling 283,000 tons, up from 276,000 tons in 1988. Of the reporting countries, India reported the greatest production, more than one-half of the world total. Other large producers of natural iron oxide pigments were the United States, Spain, France, and Cyprus, ranked in the or-

TABLE 6

U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1988				1989[1]			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	12	$19	18	$64	10	$50	59	$208
Australia	287	463	557	893	292	357	732	1,404
Austria	—	—	—	—	14	18	—	—
Belgium-Luxembourg	60	244	388	685	43	43	433	877
Brazil	38	91	236	925	192	823	110	331
Bulgaria	—	—	41	139	—	—	—	—
Canada	3,436	5,549	361	522	1,316	2,195	1,087	3,538
Chile	10	46	—	—	1	2	—	—
China	16	100	—	—	16	73	31	113
Colombia	107	146	127	172	5	7	132	185
Costa Rica	4	8	—	—	—	—	—	—
Cyprus	5	8	—	—	—	—	—	—
Denmark	54	120	17	20	—	—	—	—
Dominican Republic	7	8	2	5	66	78	—	—
Ecuador	7	13	5	10	—	—	—	—
Egypt	—	—	39	57	—	—	—	—
El Salvador	—	—	—	—	20	36	—	—
Finland	9	16	—	—	18	33	18	33
France	432	1,639	130	284	235	1,397	156	852
Germany, Federal Republic of	10,258	8,642	498	1,715	1,292	2,010	12,236	12,644
Greece	—	—	19	29	—	—	42	29
Guatamala	21	20	—	—	71	63	—	—
Honduras	5	10	7	16	—	—	10	20
Hong Kong	658	1,771	262	1,117	538	1,567	504	1,566
India	40	111	442	2,318	56	169	185	771
Indonesia	29	116	11	30	38	42	200	137
Ireland	57	109	4	6	30	62	29	57
Israel	(2)	2	6	3	16	8	—	—
Italy	458	2,050	5	14	23	49	1,090	2,094
Jamaica	(2)	2	1	3	104	50	1	3
Japan	3,362	4,601	719	758	2,141	1,758	4,117	4,584
Korea, Republic of	553	856	2,887	12,605	427	995	3,538	13,777
Macao	—	—	—	—	—	—	73	104
Malaysia	29	35	13	17	43	43	54	95
Mexico	315	588	1,312	1,914	207	383	4,949	4,815
Netherlands	265	529	177	418	572	735	644	1,317
Netherlands Antilles	—	—	—	—	7	8	—	—
New Zealand	13	16	3	8	42	51	11	36
Pakistan	—	—	54	149	—	—	(2)	14
Peru	20	29	1	13	10	4	—	—
Philippines	106	127	116	199	121	195	106	121
Saudi Arabia	—	—	—	—	128	143	—	—
Singapore	16	66	120	377	164	537	202	408
South Africa, Republic of	37	244	—	—	44	65	854	693
Spain	22	50	75	86	116	190	10	11
Sweden	—	—	5	13	—	—	1	4
Switzerland	44	161	4	15	12	46	—	—
Taiwan	89	313	67	70	200	223	66	136

See footnotes at end of table.

TABLE 6—Continued

U.S. EXPORTS OF IRON OXIDES AND HYDROXIDES, BY COUNTRY

Country	1988				1989[1]			
	Pigment grade		Other grade		Pigment grade		Other grade	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Thailand	114	367	88	136	680	426	33	57
Trinidad	(2)	6	—	—	99	50	1,046	132
U.S.S.R.	—	—	100	60	200	139	3	20
United Kingdom	870	3,542	325	655	355	571	1,828	3,315
Venezuela	96	161	13	42	(2)	5	33	31
Yugoslavia	—	—	30	50	—	—	—	—
Other	5	19	2	7	—	—	9	33
Total[3]	21,966	33,014	9,286	26,618	9,966	15,700	34,631	54,567

[1] Data reflect conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989, Public Law 100-418, Subtitle B.
[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

U.S. IMPORTS FOR CONSUMPTION OF SELECTED IRON OXIDE PIGMENTS, BY TYPE

Type	1988		1989[1]		Major sources, 1989[2] (metric tons)
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thosands)	
Natural:					
Earth colors[3]	7,717[4]	2,132[4]	2,135	999	Cyprus 1,772; West Germany 317; Spain 20; Belgium 19; Nigeria 6.
Micaceous	(5)	(5)	2,826	355	Canada 2,418; Spain 274; Austria 92; France 40; Japan 1; United Kingdom 1.
Total[2]	7,717	2,132	4,961	1,354	
Synthetic:					
Black	5,109	1,430	7,550	11,441	Canada 4,518; Japan 2,224; West Germany 739; China 27; Mexico 19; Dominican Republic 19; United Kingdom 3; Sweden 1.
Red	10,124	4,657	11,599	4,675	Canada 6,121; West Germany 2,495; Mexico 1,207; Japan 958; Sweden 360; Brazil 121; Austria 102; Spain 101; Venezuela 80; Belgium 53; Dominican Republic 2.
Yellow	10,117	7,849	10,681	8,594	West Germany 4,256; Mexico 2,572; Canada 1,584; United Kingdom 1,244; Brazil 660; Spain 304; China 39; Venezuela 21.
Other[6]	5,861	11,061	1,878	4,476	West Germany 690; Japan 520; Canada 470; Netherlands 116; Mexico 57; Belgium 21; United Kingdom 4.
Total[2]	31,212	24,996	31,708	29,186	
Grand total[2]	38,929	27,128	36,669	30,540	

[1] Data reflect conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989, Public Law 100-418, Subtitle B.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes finished and crude natural ocher, sienna, umber, Vandyke brown, and other natural iron oxide pigments.
[4] Includes micaceous iron oxide pigments.
[5] Included with earth colors.
[6] Includes synthetic brown oxides, transparent oxides, and magnetic and precursor oxides.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF IRON OXIDE AND IRON HYDROXIDE PIGMENTS, BY COUNTRY

Country	Natural				Synthetic			
	1988		1989[1]		1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Austria	34	$10	92	$91	105	$119	102	$24
Belgium-Luxembourg	(2)	3	20	13	298	142	74	221
Brazil	—	—	—	—	668	470	781	603
Canada	478	170	2,418	156	13,712	3,036	12,693	3,564
China	—	—	—	—	—	—	66	32
Cyprus	4,507	833	1,772	382	—	—	—	—
Dominican Republic	—	—	—	—	—	—	21	29
France	(2)	2	40	25	182	477	—	—
Germany, Federal Republic of	1,455	417	317	550	8,954	8,522	8,180	6,720
Japan	383	272	1	7	2,574	8,493	3,702	13,152
Korea, Republic of	—	—	—	—	44	139	—	—
Mexico	(2)	3	—	—	3,365	2,363	3,855	3,020
Netherlands	16	6	—	—	413	247	116	101
Nigeria	—	—	6	22	—	—	—	—
Norway	—	—	—	—	2	3	—	—
Peru	1	151	(2)	31	—	—	—	—
Spain	751	195	294	71	387	387	405	311
Sweden	—	—	—	—	1	19	362	115
Switzerland	—	—	—	—	(2)	2	1	6
United Kingdom	92	70	1	7	568	570	1,251	1,199
Venezuela	—	—	—	—	—	—	101	90
Other	—	—	—	—	(2)	9	—	—
Total[3]	7,717	2,132	4,961	1,354	31,212	24,996	31,708	29,186

[1] Data reflect conversion to the Harmonized Tariff Schedule, effective Jan. 1, 1989, Public Law 100-418, Subtitle B.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

der named. Together with India, these countries produced 86% of the world total in 1989. In addition to the countries listed in table 9, other countries, including the centrally planned economy countries, produced natural iron oxide pigments in 1989. Production data for these countries, however, were not available. Natural red iron oxide was produced primarily by India and Spain; yellow ocher by Spain, the United States, Brazil, and the Republic of South Africa; and sienna by Cyprus and Italy. Cyprus was the major umber producer; Austria was the principal micaceous iron oxide producer; and the Federal Republic of Germany was the main Vandyke brown producer.

Synthetic iron oxides were one of the largest consumed colored inorganic pigments in the world. Their popularity was attributed to a favorable performance-price relationship. Iron oxides exhibit high tinctorial strength and hiding power, chemical resistance, lightfastness, and weatherfastness at low pigmentation costs. Synthetic iron oxides have made continuous gains in total market share over natural iron oxides because of product consistency, higher tinting strengths, and more saturated color shades compared with natural grades. Principal world producers of synthetic iron oxides, in order of rank, included the Federal Republic of Germany, the United States, the United Kingdom, and Japan.

According to the Japan Inorganic Chemical (Pharmaceutical) Industry Association, shipments of iron oxides in Japan were expected to increase 3% in 1989, growing to 215,300 tons. This was an increase similar to that experienced in 1988. In 1989, iron oxides used for magnetic materials, the dominant end use in Japan, were estimated to be 154,000 tons. Iron oxide pigment consumption in Japan in 1989 was estimated to be 30,000 tons, 42% of which was used in paints and the remainder in roads, construction materials, printing inks, synthetic resins, ceramics, papermaking, and other end uses, listed by order of rank. Another 31,000 tons of iron oxides was estimated to have been exported. Japan was producing more iron oxides from steel operations than it could consume in 1988, when it had iron oxide stocks of 25,000 tons. Iron oxide consumption in Japan is forecast to grow only slightly in the early 1990's. Japanese ferrite producers were operating at capacity, and increased ferrite production is expected in the United States.[6]

In the United Kingdom, the Cookson Group PLC and Magnesium International Corp. Ltd. formed a joint-venture company named Cookson Laminox Ltd. to manufacture synthetic

micaceous iron oxide (MIO). Based on a patented process developed by MPLC Laboratories Ltd., this technology will produce a synthetic iron oxide having the same lamellar characteristics as natural MIO, which impedes moisture penetration in paints and resists corrosion. The plant, having a capacity of 10,000 tons per year, was to be constructed at Peterlee near Durham. It was to ultimately create 40 jobs. Production was to begin in late 1989, and the pigment was to be marketed under the trade name Laminox.[7]

OUTLOOK

The outlook for the U.S. iron oxide pigment industry is expected to be one of continued growth despite a slight decrease in 1989. Domestic shipments of finished iron oxide pigments are forecast to range from 141,000 tons to 153,000 tons by 1995. It is probable that shipments will reach the middle range of this forecast. Principal factors are the continued popularity of earth-toned colors, continued growth in construction activities, and continued growth in paint and coatings production. The low forecast of 141,000 tons would result principally from an increased demand for other pigment materials used as substitutes for iron oxide pigments, from a decrease in construction activities, or from a decrease in paint and coatings demand.

Shipments of domestic iron oxide pigments for use in construction materials are expected to continue increasing moderately and to help push probable iron oxide pigment requirements to the middle range of the forecast. Consumption for use in paint and coatings is expected to experience slower growth. Projected growth rates indicate that the probable overall demand for domestic iron oxide pigments in the United States in 1995 will be 148,000 tons, representing an annual growth rate of 2.4%.

This forecast is based on the average annual growth rate of the gross national product (GNP) as prepared for the Bureau of Mines by DRI, a subsidiary of McGraw-Hill, which provides macroeconomic forecasting services. Iron oxide pigments used in construction materials in 1995 were forecast to range between 49,000 and 53,000 tons; end use for paint and coatings between 34,000 and 37,000 tons; and pigments used as colorants for ceramics, glass, paper, plastics, rubber, and textiles to range between 24,000 and 26,000 tons. Other end uses are expected to experience similar rates of growth, with the exception of ferrite use, which should reach the high end of the forecast of 3% per year or higher. A higher rate could also materialize if population growth increases at a higher rate than forecast or by changing trends in population movement.

TABLE 9

NATURAL IRON OXIDE PIGMENTS: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	4,020	1,027	1,022	815	900
Austria	11,583	11,730	10,807	9,938	9,000
Brazil	[r]6,320	[r]5,474	5,803	[r e]6,000	6,000
Canada[e]	2,000	2,000	2,000	2,000	2,000
Chile	8,224	4,404	8,145	8,542	8,300
Cyprus	12,200	10,000	12,500	10,060	10,000
France[e]	14,500	15,000	15,000	15,000	15,000
Germany, Federal Republic of[3]	15,764	11,365	10,003	[r e]8,000	5,000
India	108,549	98,668	145,245	[r e]145,000	145,000
Iran[e 4]	[5]4,300	4,300	4,300	4,300	4,300
Italy[e]	850	875	850	850	800
Pakistan (ocher)	553	608	1,792	1,040	1,000
Paraguay[e]	260	250	285	250	250
South Africa, Republic of	752	1,501	768	1,797	1,800
Spain:[e]					
Ocher	[5]10,293	10,500	10,500	10,500	10,500
Red iron oxide	21,000	20,000	[r]20,500	[r]20,500	20,500
United States	29,242	30,744	31,816	30,747	[5]42,034
Zimbabwe[e]	1,000	[5]207	200	[5]363	300

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 13, 1990.

[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.

[1] Chemical Marketing Reporter. Pfizer Iron Oxides Won't Go to Cambrex. V. 235, No. 3, Jan. 16, 1989, p. 4.

[2] ——. FTC Would Block Mobay Acquisition. V. 237, No. 12, Mar. 19, 1990, p. 4.

[3] American Paint and Coatings Journal. Building Starts Decline in 1989. V. 74, No. 38, pp. 15–16.

[4] Bureau of the Census (Dep. of Commerce). Paint, Varnish, and Lacquer. Rep. M28F(89)-12, 1989.

[5] American Paint and Coatings Journal. The Markets. Various Issues 1989.

[6] Roskill Information Services Ltd. (London). Roskill's Letter From Japan. Ferric Oxide: Japanese Demand Estimated to Grow by 3% to 215,300 Tons in 1989. RLJ No. 163, Nov. 1989, pp. 6–7.

[7] Pigment and Resin Technology (London). Cookson and Magnesium International in Joint Venture. Feb. 1989, pp. 22–23.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Iron Ore. Ch. in Minerals Yearbook, annual.

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American Paint and Coatings Journal
Modern Paint and Coatings

IRON AND STEEL

By Anthony T. Peters

Mr. Peters, a physical scientist with 33 years industry and Bureau of Mines experience, has been the commodity specialist for Iron and Steel since 1988. International data tables were prepared by Virginia Woodson and Harold Willis, international data assistants.

The year 1989 was a good but not outstanding one for the industry. Raw steel production was 97.9 million tons, with 84.5% utilization of capacity reported to be 115.9 million tons. This was about 2% less than that of the previous year, when almost 100 million tons were produced by steel mills operating at 89.2% utilization of a capacity of 112.3 million tons. Imports were approximately 19% of demand, kept moderate by the relatively weak dollar and the strong demand for steel worldwide.

The profits of the top nine domestic steelmakers declined by about 22% in comparison with that of the previous year, to $1.8 billion; by comparison, the profits in 1988 were actually eliminated by extraordinary expenses, and the $2.3 billion profit became a $559 million loss.

The year started very strongly, but by midyear steel demand, and thus production and prices, declined significantly. The first quarter capacity utilization of nearly 90% dropped to less than 80% near yearend. Table 1 summarizes the trends.

Worldwide, raw steel output reached another record high of 862.8 million tons. Increases of those of the previous year were registered by the European Community, which produced 154.1 million tons, an increase of more than 1%; Japan, 2% higher at 118.9 million tons; and the developing countries, most of which registered increases of 3% to 4%, to a total of 111.2 million tons.

Slight decreases occurred in the U.S.S.R. and Eastern Europe, but the People's Republic of China increased its production by approximately 3% over that of 1988.

TABLE 1

SALIENT IRON AND STEEL STATISTICS

(Thousand short tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Pig iron:[1]					
Production	49,963	44,287	48,308	55,745	55,873
Shipments:					
Steel production	49,547	43,312	47,413	54,833	55,299
Other uses	619	357	315	812	702
Exports[2]	32	41	50	e100	11
Imports[2]	338	295	355	r653	488
Steel:[1]					
Production of raw steel:[3]					
Carbon	76,699	71,413	77,976	86,823	86,231
Stainless	1,683	1,689	2,028	2,199	1,926
All other alloy	9,877	8,505	9,147	10,902	9,786
Total	88,259	[4]81,606	89,151	99,924	97,943
Capacity utilization, percent[5]	66.1	63.8	79.5	89.2	84.5
Net shipment of steel mill products	73,043	70,263	76,654	83,974	84,100
Annual average composite price for steel mill products[6]	27.6	24.8	25.4	25.4	25.2
Exports of major iron and steel products[2]	1,266	1,201	1,419	2,576	4,578
Imports of major iron and steel products[2]	25,707	22,145	21,534	22,310	17,333
Profits or (loss), million dollars	(34.0)	(4,149.9)	1,017.3	[7]2,300	1,478
World production:[8]					
Pig iron	r549,842	r546,606	561,230	p592,790	e599,740
Raw steel	r791,591	r784,118	r808,336	p857,941	e863,064

eEstimated. pPreliminary. rRevised.
[1]American Iron and Steel Institute (AISI).
[2]Bureau of the Census.
[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/pound
[7](558.9) after special charges and unusual expenses.
[8]Source: Bureau of Mines and the International Iron and Steel Institute.

LEGISLATION AND GOVERNMENT PROGRAMS

The most significant event for the steel industry was the extension of the Voluntary Restraint Agreement (VRA's) restricting steel imports into the United States for an additional 2½ years, until March 31, 1992. The law's short title was Steel Trade Liberalization Program

Implementation Act of 1989. The industry preferred that the law cover 5 years, but the 2½ year extension easily passed both the House of Representatives and the Senate with hardly any objection. This compromise version did not contain some provisions requested by the steel industry. Additional details are presented in the Foreign Trade section.

The Department of Energy (DOE), as authorized by the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988, signed with the American Iron and Steel Institute (AISI) an agreement to finance up to 70% of a $30 million cooperative program undertaken by eight member companies of AISI to develop a "direct steelmaking" process without coke ovens or blast furnaces. Details are discussed in the Technology section.

The DOE was also involved, under the terms of the Clean Coal Technology Act of 1987, in a development program for cleaning up coke plant emissions at the Sparrow's Point, MD, mill of Bethlehem Steel Corp. Also, the DOE financed part of a project to develop "superplastic" high-strength steels; two forges and a major minimill were involved.

The Environmental Protection Agency conditionally retained blast furnace slags, dusts, and sludges under the Bevill exemption for mineral processing wastes during 1989. These high-volume, low-hazard wastes from the extraction and beneficiation of ores and minerals were granted the exemption from subtitle C (hazardous) regulations under the Resource Conservation and Recovery Act, pending the evaluation of further hazard data. Slags, dusts, and sludges from the open-hearth and basic-oxygen furnaces were also conditionally retained during the same year. The Agency also extended the compliance time for the treatment of the electric arc furnace dust classified as hazardous until August 1990.

According to the Omnibus Trade and Competitiveness Act of 1988, the International Harmonized Customs Code System came into use on January 1, 1989. The act also mandated conversion of all governmental business to the metric system by 1992. Steel industry officials stated that the cost of the conversion, estimated at several billion dollars, would involve duplication and replacement of machinery, spare parts, tools, and rolling rolls. This rendered rapid adoption of the metric system impractical.

According to the requirements of the Comprehensive Anti-Apartheid Act of 1986, the President certified again that certain materials are "essential to the economy or defense of the United States" and must be excluded from sanctions against the Republic of South Africa. Exempted again from import controls were manganese, indispensable for all steels; chromium, the base of stainless steels; vanadium, essential for many tool steels; platinum group metals, irreplaceable in catalytic converters for automobile exhausts; and eight other materials.

The U.S. Department of Commerce determined that imports of new railroad rails from Canada were being subsidized and sold at 39% below fair trade value. Antidumping duties were assessed accordingly.

ISSUES

The raw materials of the steel industry are iron in the form of iron ore and scrap, coal in the form of coke, lime obtained from limestone, refractories, alloying materials, and coating metals. Adequacy of supply of some of these materials has been an issue in the steel industry.

The reserves of iron ore in North America are very large and are practically unlimited worldwide. (For details see the "Iron Ore" chapter.) Supplies of high-quality scrap, not contaminated with nonferrous metals, have been somewhat tight, but otherwise scrap supplies have been ample. The United States is a net exporter of scrap. These issues are discussed in the Iron and Steel Scrap chapter.

Coke represents a political problem. Although reserves of coking coals in the United States are very large, the coking industry is severely handicapped by harsh environmental rules. Fortunately, metallurgical coke, sometimes made from American coal, is obtainable from abroad, at a price. It does not appear that any new coke batteries will be built in the United States because of the uncertainty of environmental regulations. Possible changes in the Clean Air Act may cause the closure of several of the 40 existing coke plants. The reason is that there is either no technology available to meet the mandated limits or the large expenditures for compliance are not warranted by the age of the existing installations. Most U.S. coke batteries are more than 20 years old, with perhaps 10 to 15 years life remaining. If no new coke ovens are built, the value of coke imports may reach $3 billion per year if sufficient supplies from overseas are available. Availability of these supplies is uncertain.

Lime, the main refining flux, does not present any problems. Deposits of limestone are practically inexhaustible, and the lime burning kilns are under good ecological control. For details, consult the Lime chapter.

Ample sources of raw materials for furnace refractories are in existence, and the refractories industry, after some shakeouts in the 1980's, appears to be capable of supplying its primary customers, iron and steel plants, with all the goods needed.

Unfortunately, the country has ample supplies of only a few alloying elements, mainly silicon, and also the less important boron and molybdenum. The United States is totally dependent on imports for most others, including the irreplaceable and critical manganese and chromium mentioned earlier. The main reserve holder, producer, and supplier of these two metals is the Republic of South Africa. Shutting off the flows of manganese and chromium from the Republic of South Africa could grossly curtail steel production in the United States.

The two main coating metals, tin and zinc, were widely available, although their prices show strong variations. Some zinc was produced domestically, but most was imported. Apart from some recycled material, the United States is almost completely dependent on imports of tin. Fortunately, for many applications, chromized or aluminized steel could be used but, again, the country imports nearly all its chromium and some of its primary aluminum.

The other main issue confronting the steel industry was the question of the VRA's. The industry was skeptical that extension for only 2½ years was sufficient to complete the domestic modernization of plants and, especially, for negotiating free and fair trade in steel worldwide.

PRODUCTION

At yearend, there were 82 companies and independent subsidiaries producing

raw steel at 125 locations. Of these, 15 were integrated companies, organizations that produced raw iron by smelting iron ores and their concentrates and converting the iron to steel using the basic oxygen furnace refining process. This accounted for 60% of the production. The integrated mills also had several electric arc furnaces. The others were the minimills or nonintegrated operations that produce steel by remelting and refining iron and steel scrap, and some specialty steelmakers.

The State with the highest steel production again was Indiana, with 20.8 million tons; followed by Ohio, 16.4 million tons; and Pennsylvania, 11.9 million tons.

A summary of efficiency trends of the industry is presented in table 2.

There was an increase in the proportion of continuously cast steel for the year. This was probably due to some drop of production in the second half of the year—the less efficient ingot pouring operation would be suspended before any continuous casting operations were closed. The higher usage of work force reflects the tendency to hold on to skilled operators despite a drop in operations.

TABLE 2

EFFICIENCY TRENDS OF U.S. STEEL PRODUCTION

Year	Raw steel			Average steel[1] product yield (percent)	Manpower[2] input (hour per shipped ton)
	Capacity (thousand short tons)	Utilization (percent)	Continuous cast (percent)		
1989	115,900	84.5	64.8	86.4	[p]5.9
1988	112,200	89.2	61.3	84.0	5.7
1987	112,200	79.5	59.8	86.0	4.6
1986	127,000	63.8	55.2	86.1	5.1
1985	133,600	66.1	44.4	82.6	5.7
1984	135,300	68.4	39.6	79.7	6.4
1983	150,600	56.2	32.1	79.9	7.0
1982	154,020	48.4	29.0	82.6	8.5
1981	154,300	78.3	21.6	73.2	8.5
1980	153,700	72.8	20.3	75.0	9.0
1979	155,300	87.8	16.9	73.5	8.9

[p]Preliminary.
[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.

Integrated Mills

Armco Steel Corp. sold a 40% interest in its Eastern Division, producing flat products, to Kawasaki Steel Co. for $350 million; the Japanese partner proposed to invest another $350 million in rehabilitation of the Middletown, OH, and Ashland, KY, works in exchange for a further 10% ownership.

Inland Steel Co. culminated its long cooperation with the Japanese Nippon Steel Corp. by selling Nippon 13% of Inland's stock for $185 million and buying 1% of Nippon Steel, the world's largest steelmaker. Because Inland had a number of profitable steel service subsidiaries, this was largely regarded as an antitakeover maneuver.

The LTV Steel Corp. completed the sale of its Bar Products Div. to its employees through an Employee Stock Ownership Plan. The new company was called Republic Engineered Steels, Inc.

United States Steel Corp. (USS) sold, for an undisclosed sum, a 50% interest in its only bar products integrated mill, the Lorain Works, to the Japanese Kobe Steel Corp. Kobe specializes in the production of high quality bar steels, and the announced purpose of the sale was the production of special bars for the Japanese-owned automotive companies in the United States. Major upgrading of the mill was planned.

An old rod mill from the South Works of USS at Chicago, IL, was sold to the Colombian Aceria del Rio Paz. Dismantling of this mill left only a wide flange mill operating.

USS also announced the construction of a third continuous caster at its Gary, IN, works. This will make Gary a 100% cast operation.

Minimills

For the first time in history, a nonintegrated steelmaker shipped more steel than an integrated company. North Star Steel Corp. shipped 2.26 million tons from its four mills whereas Wheeling-Pittsburgh Steel Corp. shipped 2.23 million tons. Nucor Steel Corp. was not far behind with shipments of 2.10 million tons. Once the two new mills of Nucor are producing at capacity, Nucor should be shipping in excess of 2½ million tons from its six operations. One, Nucor-Yamato Steel Corp., is 50% owned by the Japanese partner.

Nucor achieved a spectacular first in mid-1989 by starting the production of flat products using a new "thin slab casting" technique, developed in Germany. It appeared that by yearend the Crawfordsville, IN plant reached about 30% of its capacity of 800,000 tons of hot-rolled coils. The entire greenfield mill cost $265 million or $331 per yearly product ton. This was considered low by integrated steel mill standards. Cold rolling was to be added within 1 or 2 years, but the width of only 52 inches (1,320 millimeters) makes the steel unsuitable for many applications, such as automotive use. Furthermore, electric furnace steel possesses some charateristics inherently undesirable for deep-formed flat products, mainly because of its relatively high contents of nitrogen and residual elements, such as chromium and copper.

Another first for Nucor was the mentioned Nucor-Yamato plant that makes large-size, wide-flange beams. This was a new product for minimills. This market had been occupied by the integrated majors.

Northwestern Steel Corp. was moving in the same direction, having bought the abandoned Houston, TX works of Armco Steel. This mill was to be converted to the production of large sections, including wide-flange beams. It was to be supplied by shaped cast blanks made on a continuous caster to be constructed at the main works in Sterling, IL. Like most minimills, Northwestern was also completing a ladle metallurgy station aimed at improved steel control. The heat size of this minimill was 380 tons, the largest electric furnace heat in the world, making this installation very unique.

Once this expansion is completed in 1990, Northwestern's capacity would be in excess of 2½ million tons per year.

Birmingham Steel Corp. announced that, in conjunction with Proler International Inc., a scrap processor, and Danieli S.P.A., an Italian mill machinery manufacturer, it would be building a flat products mill in Texas, to be named Buffalo Steel Corp. Proler owned 35% and Danieli 15% of the enterprise. The mill was to cast medium thickness slabs, 5 inches (127 millimeters) thick, and roll them on a hot strip mill reconditioned by Danieli. The abandoned Baytown Works of U.S. Steel Corp. was bought by Birmingham, and the environmental protection permits were transferred to the new owners. This made the startup of the new $260 million, 1.2-million-ton hot strip mill possible as early as 1991.

The small New Jersey Steel Corp., a producer of reinforcing bars, announced a plan to build a flat products mill of 500,000-ton capacity using the thin slab casting technique, apparently the same as that utilized by Nucor.

Oregon Steel Corp., Portland, OR, bought an unused plate mill from California Steel Corp. for $7.5 million. This mill, with a capacity in excess of 1 million tons of plate per year, was a part of the mills of the defunct Kaiser Steel Corp. in Fontana, CA, bought by California Steel in 1984. The mill was to stay in place and roll only about 150,000 tons per year of plate, which was needed for Oregon Steel's tube mill in Napa, CA. Enlargement of the melt shop in Portland would increase the tonnage at the Fontana mill.

A new minimill started production in 1989. This was the First Mississippi Corp. Inc., in Hollsopple, PA, with a capacity of 110,000 tons. Its two 40-ton furnaces were charged mostly with direct reduced iron and featured oxygen fuel burners and argon stirring from the bottom. This enabled the mill to make very low carbon low residuals clean steel. Once a ladle furnace and a horizontal caster are installed in 1990, this relatively small operation may be the most technologically advanced in the world. Until then, it makes ingots for sale.

Statistics regarding steel production and materials consumption are shown in tables 3 through 6.

Foreign Investments in the U.S. Steel Industry

The purchase of a small specialty steel producer by a Canadian steel corporation

TABLE 3

MATERIALS CONSUMED IN BLAST FURNACES AND PIG IRON PRODUCED

(Thousand short tons)

Material	1985	1986	1987	1988	1989
Iron oxides:[1]					
Ores	3,201	2,087	2,972	5,682	3,539
Pellets	56,987	48,072	54,564	67,268	67,967
Sinter[2]	17,838	14,574	15,895	17,082	15,062
Total	78,026	64,733	73,431	90,032	86,568
Scrap[3]	2,381	2,079	3,389	3,007	3,362
Miscellaneous[4]	2,023	1,502	1,703	e1,900	e2,100
Coke	26,564	22,573	24,031	29,442	29,175
Fluxes[5]	3,132	2,247	2,131	e2,100	e2,000
Pig iron produced[6]	49,963	44,287	48,308	55,745	55,873

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.
[6]For disposition of iron, see table 1.

TABLE 4

SPECIFIC CONSUMPTION OF MATERIALS IN BLAST FURNACES

(Pounds per short ton)

Material	1985	1986	1987	1988	1989
Ores	118	94	123	204	127
Pellets	2,281	2,171	2,259	2,413	2,433
Sinter[1]	714	658	658	613	539
Total	3,113	2,923	3,040	3,230	3,099
Scrap[2]	95	94	140	108	120
Miscellaneous[3]	81	68	71	e68	e75
Coke	1,063	1,019	995	1,056	1,044
Fluxes[4]	125	101	88	75	e72

eEstimated.
[1]Includes sintered ore and pellets, fines, dust, mill scale and other revert iron bearing materials; also some nodules.
[2]Mainly briquetted turnings and borings, shredded scrap, etc.; scrap produced at blast furnaces and remelted not included.
[3]Mainly revert materials not sintered.
[4]Includes fluxes used in sintering at the steel plant, but excludes fluxes consumed in agglomeration at the iron ore mine.

Source: American Iron and Steel Institute and the Bureau of Mines.

TABLE 5

U.S. STEEL PRODUCTION, BY TYPE OF FURNACE PROCESS

Year	Basic oxygen		Basic open hearth		Basic electric arc		Total
	(thousand short tons)	(percent)	(thousand short tons)	(percent)	(thousand short tons)	(percent)	(thousand short tons)
1989	58,348	59.6	4,442	4.5	35,154	35.9	[1]97,943
1988	57,960	58.0	5,118	5.1	36,846	36.9	99,924
1987	52,496	58.9	2,666	3.0	33,989	38.1	89,151
1986	47,885	58.7	3,330	4.1	30,390	37.2	[1]81,606
1985	51,885	58.8	6,428	7.3	29,946	33.9	88,259

[1]Data do not add to total shown because of independent rounding.

TABLE 6

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
1989	16,680	51,626	1,020	2,105	30,981	730	48,681	54,461
1988	17,484	52,446	r978	r3,858	34,345	248	r52,807	r56,552
1987	15,230	47,525	992	2,057	32,009	304	8,321	49,612
1986	14,753	41,582	1,556	2,325	31,166	313	47,475	44,220
1985	15,339	44,515	2,411	4,737	32,252	503	50,002	49,755

rRevised.
[1]Pig iron mainly as liquid in basic oxygen and open hearth furnaces.
[2]Consumption of scrap appears to be underreported.

TABLE 7

FOREIGN INVESTMENTS IN THE U.S. STEEL INDUSTRY IN 1989

U.S. partner or seller	Foreign partner company	Country	Kind of venture	Foreign ownership (percent)
Armco Steel	Kawasaki Steel	Japan	Integrated mill	50
National Steel	Nippon Kokan Steel	do.	do.	50
U.S. Steel	Kobe Steel	do.	do.	50
Wheeling-Pittsburgh Steel	Nisshin Steel	do.	do.	10
Copperweld Steel	Daido Steel	do.	Specialty bar mill	17
Ft. Wayne Steel	Slater Steel	Canada	do.	100
Inland Steel	Nippon Steel	Japan	Integrated mill	13
Do.	do.	do.	Cold rolling mill	40
Do.	do.	do.	Galvanizing lines (2)	50
LTV Steel	Sumitomo Steel	Korea	Electrogalvanizing lines (2)	50
U.S. Steel	Pohang Steel	do.	Cold rolling mill	50
Wheeling-Pittsburgh Steel	Nisshin Steel	Japan	Electroganvanizing line	50
Nucor Corp.	Yamato Steel	do.	Minimill	50
California Steel	Kawasaki Steel	do.	Flat rolling mill	50
Do.	CVRD	Brazil	do.	50
Al Tech Co.	Sammi Group	Korea	Stainless steel mill	100
Avesta Co.	Avesta Co.,	Sweden	Stainless plate mill	100

Source: The WEFA Group, company reports

in 1980 did not cause much concern. Formation of California Steel Corp. in 1984 by a joint venture involving American, Brazilian, and Japanese interests was welcomed. This was the purchase and start-up of the rolling end of the defunct Kaiser Steel Corp. in Fontana, CA. Since then a number of major joint ventures came into being, mostly in 1989. Table 7 illustrates this trend.

Also, at least three small minimills, Auburn Steel Co., Auburn, NY, Razorback Steel Corp., Newport, AR, and Tamco, Etiwanda, CA, are owned by Japanese interests. The bankrupt Phoenix Steel Corp. in Claymont, DE, was modernized by its new Chinese owners. It started again in 1989 to produce plates, working as Citisteel Corp.

The U.S. partners of foreign investors in domestic steel operations usually put up relatively small amounts of cash in joint ventures, totaling up to 1989 about $450 million. The location itself and the local and marketing expertise were most critical. The foreign partner invariably provided the majorities of the funds, totaling a little more than $3 billion, plus technical expertise.

CONSUMPTION

Apparent consumption is the sum of steel mill shipments plus imports minus exports, with an adjustment, always small, for inventory change over the period in question. Before about 1960, the

United States was a net steel exporter, but thereafter it imported increasingly high amounts of steel. Imports in some months accounted for 30% of demand; consequently, correlation of demand with domestic production is poor, especially since the latter was affected by unpredictable occurrences such as steel or automotive strikes, introduction of the VRA's, etc.

The kind of demand is well known and fairly constant, judging from the extensive reports of shipments by the AISI and customs data for imports. Unfortunately, the categories are not identical, especially since the introduction of the Harmonized Tariff System in 1989. Thus, direct addition of categories is not possible. Furthermore, opinions vary as to the ferrous content of secondary steel imports, i.e., those of goods consisting mainly of iron and steel.

Eliminating from the AISI data the 10% to 15% of shipments classified as "other" or "unclassified" leaves data presented in table 8 divided in three groups.

The first group, distribution of shipments by steel type, indicates a shift from alloy to carbon steel. This is probably a reflection of the wide adoption of high-strength low-alloy steels, which are usually reported as carbon grades.

The second group, distribution of shipments by products, shows few changes over the past 5 years except for a growth of electrogalvanized steel. It is expected that this growth will continue, especially because of automakers' preference for this kind of steel for many applications.

The last group, distribution by markets, introduces a new variable—shipments to steel service centers and distributors. The final use of this steel is not known, but information from the Steel Service Centers Institute, with more than 400 members handling about 24 million tons of domestic and imported steel, indicates that up to one-half of this steel is ultimately used in construction, with about one-quarter used for replacement automobile parts and by machinery makers. The balance is spread over many applications.

It is remarkable that the distribution of steel by the main markets hardly changed over the past 20 years. The only major change was a drop of steel use by the canmakers in favor of aluminum. This trend seems to have stopped, as indicated by the numbers in the table. The lowered shares of construction and of automotive and machinery markets in 1989 represent the weakness of these segments.

TABLE 8

DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENTAGE

	1985	1986	1987	1988	1989
Shipments by steel type:					
Carbon steel	88.1	88.9	89.0	92.7	93.4
Alloy steel	10.1	9.3	9.0	5.3	4.9
Stainless steel	1.8	1.8	2.0	2.0	1.7
Shipments by products:					
Wire rods	4.2	4.9	5.0	4.8	5.0
Structural shapes, 3 inches and over	5.2	6.0	6.3	5.8	6.0
Plates	5.9	5.1	5.3	8.7	8.6
Bars	7.8	8.2	7.9	7.7	10.8
Reinforcing bars	5.9	6.0	6.4	6.1	6.3
Pipe and tubing	5.6	4.2	4.7	5.3	4.8
Hot rolled sheet and strip	18.5	18.2	17.9	16.4	16.6
Cold	19.8	20.2	19.3	17.6	17.4
Tinplate	3.6	3.7	3.6	3.3	3.3
Galvanized sheet and strip:					
Hot dipped	9.4	10.3	10.0	9.2	10.1
Electrolytic	0.9	1.3	1.9	2.5	2.6
All others	13.2	11.9	11.7	12.6	8.5
Shipments by markets:					
Service centers and distributors	25.2	24.9	25.9	25.1	21.8
Construction	15.4	15.1	14.4	14.4	11.5
Automotive	17.7	16.9	14.8	15.0	13.3
Machinery	9.4	10.0	9.7	9.6	2.6
Containers	5.6	5.9	5.7	5.3	5.3
All others	26.7	27.2	29.5	30.6	45.5
Total shipments thousand short tons	75,657	72,737	80,646	88,391	84,100

Castings

The actual consumption of iron and steel castings is difficult to estimate for two reasons: (1) a large part of the demand is satisfied by imports of castings or of assemblies not reported as castings but in which castings are a major part of the weight, and (2) many large industrial users, such as the General Motors Corp. and most integrated steelmakers, have their own foundries. These make castings for their own use but also sometimes for sale, with the sold tonnages usually classified with "other products."

The American Cast Metals Association made the following estimates of total demand in 1989 in short tons: Gray iron.—7,210 million tons, with automobiles and trucks accounting for one-half of the total; Ductile iron.—3,300 million tons, pressure pipe and fittings consuming one-half of the total; Malleable iron.—320,000 tons; this is a decreasing commodity in favor of ductile iron; Plain carbon and low-alloy steel.—1,340 million tons; and high-alloy steel—130,000 tons, mainly stainless.

According to a survey by the U.S. Department of Commerce, ferrous foundries shipped the following amounts of castings: gray iron, 4,675 million tons; ductile iron, 2,815 million tons; malleable iron, 283,000 tons; and steel (carbon and alloy), 1,137 million tons. The differences between these numbers and the demand data shown previously probably represent imports.

The ferrous industry consists of about 1,200 foundries. Many use automated

production. A few also experiment with advanced melting methods; for example, General Motors was running an experimental electric plasma unit, with the goal of higher productivity, less melting loss, less pollution, and the ability to use low-grade feedstock such as turnings and borings.

STOCKS

There are no governmental stocks in existence. Steel mill inventories usually run to about 1 month's production, about 10 to 12 million tons, but one-half or more of this steel was earmarked for predictable future orders. Service centers typically carry about one-half of this amount, 6 to 7 million tons, representing 3 to 4 months of their shipments. Users' inventories are highly variable.

PRICES

Demand was strong and prices were firm at the begining of 1989. This was true, except for the depressed oil country tubular goods market, and little if any discounting. Near yearend, the demand was low, especially from the automakers, and discounting was severe, up to 20% from list price and even more in stainless steels.

In the market, it is the discounting practice that determines a steel price. The nominal list prices are of no significance in a buyers market. The numerous quality and grade extras are enforced only in the infrequent periods of steel being on allocation for spot orders. Each steel sale is a negotiated transaction, not of any open market type. The traditional steel salesman's expression "steel is not sold, it is bought" is a characterization of steel as being demand driven, except for new specialty grades. Hence, determination of actual steel selling prices is not really possible. This is also due to the fact that at least 20 common grades and more than 100 specialties are traded every day in hundreds of sizes, shapes, gages, surface finishes, coatings, and qualities.

The Iron Age Magazine Finished Steel Base Index moved slightly during the year from $495 per ton to $512, a change of only about 3½%, which reflected the published list prices. The index appears to be biased toward flat products made by the integrated steel producers and selling in the $350 to $700 range. The bars and structural shapes produced by the minimills and representing roughly 25% of all steel shipments cost much less and seem to be underreported in the index. In any case, the extent of discounting, even by minimills, made the published change of no practical significance.

The Iron Age Pig Iron Index was based on American-made foundry pig iron; because almost none was produced in the United States, the $213 per ton, unchanged for several years, was only of historical interest. The actual prices of Canadian and Brazilian pig iron were in the range of $170 to $190 per ton.

FOREIGN TRADE

Exports

The relatively weak dollar helped several U.S. mills to export significant amounts of steel, varying from semifinished to electrogalvanized, to markets that seemed to be closed only a few years earlier. Most integrated steel producers such as U.S. Steel, which reactivated its closed export division, Bethlehem; LTV; Inland; Armco; and Geneva, reported shipments to the Far East, Europe, and South America. A number of minimills; such as Chaparral Steel Co. and Thomas Steel Corp., also reported such shipments.

Chaparral Steel was the first American steelmaker to obtain the quality approval from the Japan Institute of Standards, the Japanese standards organization, which is needed to participate in almost all Japanese construction projects. Other producers indicated that they were in the process of obtaining this certification.

Total exports in 1989 exceeded 4½ million tons, the best year since 1980. Table 9 shows the major shippers and recipients of U.S. steel; tables 10 and 11 list the exports by product categories.

Imports

The majority of steel imports entered the country under the terms of the VRA's. The VRA's 1 were originally established in 1984 when import penetration at times reached 30% of U.S. consumption. The purpose of the restrictions was to enable the U.S. industry to modernize its facilities. These VRA's, now called VRA 1, expired in late 1989.

In July 1989, President Bush announced a Steel Trade Liberalization Program extending the VRA for 2½ years. Overall, the steel import limit was set at 18.4%, the level of imports during the last year of operation of VRA 1. As a result of protracted negotiations, VRA's were signed with the European Community and 16 other countries. Instead of specifying tons, the agreements specified levels of participation as a percentage of U.S. consumption in 1989. Furthermore, all signatories agreed to work toward the elimination of steel trade distorting practices, such as refunds of taxes, subsidies, etc. On this basis, most countries had their quotas increased in the second and third part of the pact's duration. Table 12 appended the VRA's. Table 13 shows the imports of pig iron, mainly for foundry use. Tables 14 and 15 show the steel imports by product categories. Table 16 shows details of imports of stainless steels.

Distribution between individual steel products did not change much from the previous VRA except that quotas for semifinished steel imports were increased for countries owning rerolling mills in the United States. The quotas for pipes and tubes were reduced from 38% to 24% of apparent consumption, reflecting the low demand level for the oil country tubular goods in the United States. Special steels were included in the overall VRA. The demand for semifinished steel, strong at the beginning of the year, tapered off to zero by midyear. Total imports were 17.3 million tons (disregarding castings) or approximately 19.5% of the total demand.

WORLD REVIEW

The production of pig iron, direct reduced iron, and raw steel (crude steel in Europe) in all countries is shown in tables 20 and 21. There are some minor discrepancies between the numbers published by the International Iron and Steel Institute and those obtained by the Bureau of Mines from individual inquiries; none appear to be significant.

Capacity

A precise estimate of steelmaking capacity is not possible. Not only is this number affected by normal operating conditions, such as variations of quality of raw materials and of product mix, but some countries count unused, obsolete

TABLE 9

U.S. MAIN STEEL PRODUCTS IMPORT AND EXPORT PARTNERS, BY COUNTRY

(Thousand short tons)

	1985		1986		1987		1988		1989	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Brazil	1,701	3	1,098	19	1,103	16	1,369	7	1,380	29
Canada	2,868	314	3,203	216	3,670	414	3,173	494	2,975	638
France	1,596	2	1,206	2	1,088	3	1,244	26	1,176	15
Germany, Federal Republic of	2,361	12	2,012	8	1,776	12	1,880	14	1,543	1,880
Japan	5,975	7	4,422	32	4,321	13	4,290	212	3,653	578
Korea, Republic of	1,899	6	1,525	16	1,296	24	1,307	45	993	725
All others	7,856	588	7,226	636	7,160	647	7,628	1,271	5,600	713
Total	24,256	932	20,692	929	20,414	1,129	20,891	2,069	17,320	4,578

TABLE 10

U.S. EXPORTS OF MAJOR IRON AND STEEL PRODUCTS

Product	1987		1988	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Steel mill products:				
Ingots, blooms, billets, slabs, sheet bars	73,543	$34,285	61,430	$34,637
Wire rods	8,850	15,200	10,768	17,405
Structural shapes, 3 inches and over	63,159	28,283	61,494	35,076
Structural shapes, under 3 inches	11,563	10,196	13,461	16,084
Sheet piling	2,552	1,637	428	369
Plates	96,538	67,655	119,393	104,591
Rails and track accessories	11,988	13,228	13,646	27,233
Wheels and axles	3,766	17,767	—	—
Concrete reinforcing bars	20,550	8,213	23,480	7,486
Bars, carbon, hot-rolled	40,675	18,272	45,305	21,645
Bars, alloy, hot-rolled	24,845	41,408	33,398	52,504
Bars, cold-finished	21,925	29,831	23,107	42,691
Hollow drill steel	1,677	2,850	2,102	3,402
Pipe and tubing	149,941	220,513	248,337	344,501
Wire	26,146	44,178	35,062	76,412
Nails, brads, spikes, staples	7,905	34,285	487	78,408
Blackplate	73,967	27,731	139,125	62,906
Tinplate and terneplate	172,842	71,794	301,392	147,875
Sheets, hot-rolled	80,001	67,933	419,037	197,935
Sheets, cold-rolled	46,685	45,866	102,965	119,155
Strip, hot-rolled	28,321	21,448	32,331	29,121
Strip, cold-rolled	15,838	45,802	55,676	76,458
Plates, sheets, strip, galvanized, coated or clad	110,705	81,222	323,529	206,391
Total[1]	1,093,982	949,597	2,065,955	1,702,286
Other steel products:				
Plates and sheets, fabricated	10,708	20,806	64,611	90,649

See footnote at end of table.

TABLE 10—Continued

U.S. EXPORTS OF MAJOR IRON AND STEEL PRODUCTS

Product	1987		1988	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Other steel products—Continued				
Structural shapes, fabricated	35,662	$70,791	44,832	$10,888
Architectural and ornamental work	1,472	5,532	33,101	63,481
Sashes and frames	5,462	20,639	2,485	4,993
Pipe and tube fittings	25,189	182,307	110,313	382,769
Conduit	5,631	6,376	—	—
Bolts and nuts	55,608	88,229	10,322	94,081
Forgings	78,202	83,824	107,522	60,407
Cast-steel rolls	1,880	2,700	2,907	10,820
Railway track material	5,774	1,259	4,648	5,023
Total[1]	225,587	482,464	380,741	723,111
Iron products:				
Cast-iron pipes, tubes, fittings	31,898	52,586	62,247	80,414
Iron castings	67,197	55,134	66,594	50,005
Total[1]	99,095	107,719	128,841	130,419
Grand total[1]	1,418,665	1,539,781	2,575,537	2,555,817

[1]Data may not add to totals shown because of independent rounding.
Source: Bureau of the Census; product grouping based on the Tariff Schedules of the USA.

Note: For 1989 data see table 11.

TABLE 11

U.S. EXPORTS OF MAJOR IRON AND STEEL PRODUCTS,[1] IN 1989

(Thousand short tons and thousand dollars)

Product	Quantity	Value[e]
Steel mill products:		
Semifinished sections	391	106,743
Wire rods	36	1,824
Structural shapes	181	69,504
Steel piling	5	2,050
Plates, cut lengths	137	53,430
Plates in coils	494	187,720
Rails and track accessories	17	5,304
Bars, hot-rolled	87	25,926
Bars, concrete reinforcing	88	22,968
Bar, cold-finished	41	34,358
Tool steel	18	20,970
Standard pipe	23	11,638
Oil country goods	320	192,960
Line pipe	28	16,940
Pipe, other	1	540
Pipe and tubing, stainless	8	7,600
Tubing not stainless	63	33,390
Wire	31	18,662
Black plate	—	—

See footnote at end of table.

installations as capacity as long as the facilities exist, while other countries do not. Developing countries and centrally planned economies usually regard the best output of several past years as capacity but overstate the possibilities of new installations, etc.

It appears that the world's steelmaking capacity under normal conditions is on the order of 940 million short tons per year.

CURRENT RESEARCH

Some problems of technology not caused by political factors were diminished by two general developments.

The past 5 years saw a strong growth of cooperative research managed by AISI and involving member steel producing companies, universities, and also major supply and customer companies if the subject involved a raw material or properties of steel; for instance, a Refractories Research Center was established at the University of Missouri at Rolla. Although the original planning expected about 10 member companies to share the cost, no less than 23 members and suppliers signed up.

TABLE 11—Continued

U.S. EXPORTS OF MAJOR IRON AND STEEL PRODUCTS,[1] IN 1989

(Thousand short tons and thousand dollars)

Product	Quantity	Value[e]
Steel mill products—Continued		
Tinplate	188	105,280
Tin-free coated steel	30	15,450
Sheets, hot-rolled	1,156	415,720
Sheets, cold-rolled	499	275,947
Sheets and strip, hot-galvanized	333	192,474
Sheets, electrogalvannized	111	65,823
Sheets, coated	103	62,212
Sheets, electrical	55	33,715
Strip, hot-rolled	44	18,392
Sheets, cold-rolled	89	41,563
Total steel mill products	4,578	2,063,103
Fabricated steel products:		
Structural shapes	125	97,375
Wire rope	3	4,020
Wire strand	7	8,435
Wire springs	37	44,585
Nails and staples	10	13,940
Industrial fasteners	136	19,565
Pipe and tube fittings	14	24,668
All other fabricated products	188	188,000
Total fabricated steel products	520	400,588
Total all steel products	5,098	2,463,691
Iron products:		
Tubes, pipes, and fittings	73	78,475
Castings	47	39,480
Total iron products	120	117,995

[e]Estimated.

[1]Product grouping based on Harmonized Tariff System of the United States.

TABLE 12

STEEL IMPORT VOLUNTARY RESTRAINT AGREEMENTS AS A PERCENT OF U.S. APPARENT CONSUMPTION, 1989

Country	VRA I	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	7.00
Finland	.24	.25	.25	.25
German Democratic Republic	.11	.10	.10	.10
Hungary	.03	.05	.05	.05
Japan	6.19	5.00	5.30	5.30

See footnote at end of table.

The flow of information became much more open than formerly. A good example was the wide variety of countries from which technical papers were presented at the annual Ironmaking and Steelmaking Conferences of the American Institute of Mining and Metallurgical Engineers. Papers originating abroad were uncommon before the 1980's, but in recent years about 20% of the presentations were from Japan, whereas another 20% or so came from other countries, including a few from the U.S.S.R.

An important development was initiation of the Direct Steelmaking Project, mostly funded by DOE and managed by AISI. This activity aimed at the development of a process to produce steel directly from iron ores or concentrates, bypassing the production of iron in blast furnaces and, thus, also the necessary coke ovens. Thus, pollution due to coke making and iron smelting is eliminated.

The process will be carried out in two connected vessels. The iron oxides, in whatever form, will be fed from the top along with coal, which will be the reducing agent. Oxygen for combustion will be blown in from the vessel's lower end. Partial refining of carbon-rich iron to crude steel is to take place there. Because this takes place in a closed system and the gases are returned to the first reduction vessel, pollution is eliminated or at least minimized.

The main differences between this process and the well-known methods of producing direct reduced iron are the use of coal instead of natural gas as a reductant and the production of crude liquid steel rather than solid, impure iron suitable as a scrap substitute.

An important development that occurred mainly in 1988 and 1989 was the wide adoption of flux pellets for the production of iron. Some details are discussed in the Iron Ore chapter.

Inland Steel Co. and the Research-Cottrell Corp. jointly developed a process for the reduction of sulfur levels in exhaust gases of coal-fired power stations and boilers. It involved controlled additions of limestone and lime powders into the flame. If widely adopted, it could reduce the acid rain problem.

The question of U.S. dependence on supplies of most alloying elements from foreign sources is discussed in the Issues section. The extent of possible substitutions was extensively studied, but not much progress can be expected in this area.

TABLE 12—Continued

STEEL IMPORT VOLUNTARY RESTRAINT AGREEMENTS AS A PERCENT OF U.S. APPARENT CONSUMPTION, 1989

Country	VRA I	First period[1]	Second period[1]	Third period[1]
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 13

U.S. IMPORTS OF PIG IRON, BY COUNTRY

(Short tons)

Country	1985	1986	1987	1988	1989
Brazil	130,762	143,154	118,736	496,916	341,933
Canada	166,291	112,607	209,898	145,366	132,935
South Africa, Republic of	30,504	32,944	—	—	—
Other	10,701	6,252	26,078	10,273	13,307
Total	338,258	294,957	354,712	652,555	488,175

The consumption of alloying elements in various steel types is shown in table 17. Because many grades of various richness exist in most materials under discussion (e.g., three grades of ferromanganese, and some alloying practices involve scrap, oxides, and other materials), the reported totals tend to understate the actual demand. The consumption of silicomanganese is definitely understated because several minimills did not reply to repeated inquiries by the Bureau of Mines, and they are the main consumers of this alloy.

The sources of the alloying elements and the extent of imports are shown in tables 18 and 19.

OUTLOOK

Steel production in the United States is too strongly affected by non-recurring events with unpredictable outcomes to be amenable to normal forecasting techniques. For instance, a major factor in the production level in 1991 will be a possible steel strike at U.S. Steel Corp. Strikes of up to 6-months duration occurred there in the past, and the corporation usually accounts for about 15% of U.S. steel production. In 1992, labor contracts expire at Bethlehem, National, and Inland Steel, and a prolonged strike or strikes could significantly affect the production level.

The costs of new clean air legislation should be known by 1991 or 1992, and these may have major impacts on steelmaking policy in this country. If the restrictions result in compliance expenditures that are higher than acceptable to the industry, the "hot ends" of some mills will be closed, and the steel will be obtained from abroad in semifinished form.

A major question is the VRA's that expire in 1992. If the VRA's are retained, not much change should occur in the slow growth steel production pattern, assuming that other factors, such as the value of the dollar, remain unchanged. However, if they are abandoned, the question becomes one of imports levels. If imports rise as high as those before the introduction of VRA in 1984, reaching up to 30% of consumption in individual months, U.S. steel production will contract sharply, and the shift to purchasing semifinished steel from abroad may be even more pronounced. If not, and the imports stay at 17% to 20% of consumption, production should not be severely affected.

As a very rough guess, it should be expected that in 1991–95, U.S. production in the case of combination of favorable factors could reach 115 million tons; if unfavorable factors predominated, raw steel production may be as low as 70 million tons.

One econometric model of steel production based on the actual production of 1982–89 assumes a steady growth with some shocks, such as a recession, assumed to occur in 1993–94. This model gives the following production numbers: 1991, 94.3 million tons; 1992, 93.6; 1993, 87.3; 1994, 78.5; followed by a recovery to 91.8 in 1995 and 100.7 in 1996.

BACKGROUND

Definition and Grades

Steel is probably the most versatile material known; its strength and hardness are proverbial. It can be cast into fairly intricate shapes, but its greatest advantage is the ability to deform without damage, at least within certain limits. Hence, large castings, called ingots, can be rolled into numerous sections used for structures, machines, and so forth, or into flat sheets and strips that can be formed into a multitude of products. They can also be drawn into wire, soft- or spring-quality.

Steel is by definition an alloy of iron with 0.02% to 1.7% carbon. Carbon is important because it is the chief controller of steel properties. Strength and hardness are directly proportional to the carbon content, as is heat treating, hardening by quenching from high temperature and subsequent tempering, toughening by reheating, or softening by annealing.

The soft steels containing less than 0.05% carbon are used for enameling sheets, for good atmospheric corrosion

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF MAJOR IRON AND STEEL PRODUCTS

Product	1987		1988	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Steel mill products:				
Ingots, blooms, billets, slabs, sheet bars	2,101,145	$468,889	2,576,935	$704,264
Wire rods	1,471,949	501,989	1,499,307	577,257
Structural shapes, 3 inches and over	1,778,314	537,598	1,847,288	700,028
Structural shapes, under 3 inches	140,469	56,708	132,538	60,656
Sheet piling	109,705	42,712	112,067	46,186
Plates	1,676,588	857,523	2,003,838	771,543
Rails and track accessories	227,869	66,454	268,699	84,166
Wheels and axles	18,120	13,433	50,734	34,894
Concrete reinforcing bars	351,632	87,143	357,253	93,494
Bars, carbon, hot-rolled	441,858	148,977	475,547	141,729
Bars, alloy, hot-rolled	176,968	100,350	207,844	122,480
Bars, cold-finished	222,639	182,735	251,894	211,392
Hollow drill steel	2,050	2,383	2,038	2,376
Welded pipe and tubing	1,758,349	729,688	1,787,400	904,281
Other pipe and tubing	969,191	559,035	1,414,584	375,695
Wire	607,185	393,244	542,098	435,655
Wire nails	440,746	257,209	6,061	8,221
Wire fencing, galvanized	21,358	17,688	24,454	19,391
Blackplate	159,779	72,050	145,166	73,850
Tinplate and terneplate	363,524	193,110	329,743	185,259
Sheets, hot-rolled	2,134,221	666,220	2,211,961	820,016
Sheets, cold-rolled	2,329,020	1,102,208	2,185,632	1,208,855
Sheets, coated (including galvanized)	2,577,799	1,297,140	2,147,148	1,178,429
Strip, carbon, hot-rolled	18,130	9,341	49,554	20,688
Strip, carbon, cold-rolled	102,028	82,980	5,572	9,309
Strip, alloy, hot- or cold-rolled (including stainless)	28,083	50,821	27,479	74,156
Plates, sheets, strip, electrolytically coated (other than with tin, lead, or zinc)	122,097	69,538	111,878	68,006
Total[1]	20,350,816	8,567,164	20,774,712	8,932,276
Other steel products:				
Plates, sheets, strip, fabricated	84,076	40,705	139,732	74,007
Structural shapes, fabricated	214,208	162,846	162,798	126,909
Pipe fitting	67,948	133,544	115,703	203,896
Rigid conduit	4,910	3,399	4,021	4,394
Bale ties made from strip	437	384	271	178
Nails, brads spikes, staples, tacks, not of wire	53,861	95,393	42,089	58,653
Bolts, nuts, rivets, washers, etc.	565,651	682,007	718,543	1,082,123
Forgings	28,983	25,720	36,817	35,744
Total[1]	1,020,073	1,143,999	1,219,974	1,585,904
Iron products:				
Cast-iron pipes, tubes, fittings	60,220	59,606	68,931	74,124
Iron castings	103,173	102,062	246,794	207,388
Total[1]	163,393	161,668	315,725	281,512
Grand total[1]	21,534,282	9,872,830	22,310,411	10,799,692

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

Source: Bureau of the Census; product grouping based on U.S. Tariff Schedules.

NOTE.—For 1989 data, see table 15.

TABLE 15

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS, 1989[1]

(Thousand short tons and thousand dollars)

	Quantity	Value[e]
Steel mill products:		
Semifinished sections	2,198	600,054
Wire rods	1,108	425,472
Structural shapes	1,509	579,456
Steel piling	86	30,000
Plates, cut lengths	938	365,820
Plates, in coils	500	190,000
Rails and track accessories	157	54,950
Bars, hot-rolled	776	231,248
Bars, concrete reinforcing	234	61,074
Bars, cold-finished	189	158,382
Tool steel	91	106,015
Standard pipe	806	407,836
Oil country goods	442	266,526
Line pipe	527	318,835
Pipe, other	10	5,540
Pipe and tubing-stainless	37	35,150
Tubing, other	563	329,355
Wire	494	297,388
Blackplate	145	74,820
Tinplate	337	188,720
Tin-free coated	115	59,225
Sheets, hot-rolled	1,898	723,138
Sheets, cold-rolled	1,877	878,644
Sheets and strip, hot galvanized	1,297	702,260
Sheets, electrogalvanized	328	194,504
Sheets, coated	236	142,544
Sheets, electrical	85	52,107
Strip, hot-rolled	111	46,398
Strip, cold-rolled	140	65,380
Total steel mill products	17,333	7,590,841
Fabricated steel products:		
Structural shapes	185	144,115
Wire rope	117	156,780
Wire strand	196	273,224
Wire springs	239	287,995
Nails and staples	391	545,054
Industrial fasteners	752	1,131,760
Pipe and tube	125	95,250
All other fabricated products	373	250,150
Total fabricated steel products	2,378	2,884,328
Total all steel products	19,711	10,475,169
Iron products:		
Tubes, pipes, and fittings	65	26,650
Castings	199	147,260
Total iron products	264	173,910

[e]Estimated.
[1]Product gouping based on U.S. Harmonized Tariff System.

resistance, and for electrical machines. Many are deep drawn, as into automotive bodies. Most stainless steels are low carbon.

The range of steels containing from 0.05% to about 0.15% carbon is mainly utilized for sheet and strip, where softness must ensure good formability; for example, a deep drawing steel used in flat products. Also, some alloy steels are made in this carbon range.

A carbon range from about 0.15% to 0.33% represents mainly structural steel for structures such as houses, bridges, and pipelines. Bars and plates are examples. Alloy grades exist.

From 0.34% to about 0.65% carbon, the steels are mainly rolled or forged into parts where high strength is the major requirement. Springs and plates are common in this range. Alloying elements are often used for critical requirements. Many products are heat treated.

Above 0.65% carbon, the steel becomes too hard, hence, too brittle for most uses. Some blades of agricultural implements, shafts, and tools not subject to shock loads are produced with up to about 1.0% carbon.

Steels containing more than 1.0% carbon are seldom if ever used. Equivalent strength level can be obtained by alloying and/or heat treatment without severe embrittlement. Special tool steels may have a higher carbon content.

Manganese is present in all steels. Although some manganese comes from the raw materials used—iron ore and scrap—more is usually added to liquid steel. It is required to combat the sharply embrittling effect of sulfur.

Sulfur is a common impurity, detrimental to steel properties except in resulfurized free-machining grades. Manganese acts as a strengthener and a weak hardener; but, because it does not impart brittleness to the steel, the steel retains its ductility. Therefore, manganese is often described as a promoter of toughness.

Most steels contain from 0.30% to 0.90% manganese. From 0.90% to 1.6% manganese is used to increase the strength and hardness of steels while retaining their toughness and, in steels with deliberate addition of sulfur (resulfurized grades), to minimize the resulting brittleness ("shortness") both when red hot and cold.

Many steels contain other alloying elements in addition to carbon. The purpose

TABLE 16

U.S. IMPORTS OF STAINLESS STEEL[1]

(Short tons)

Product	1986	1987	1988	1989
Semifinished	17,623	56,723	62,407	62,121
Plate	16,415	11,117	15,848	17,414
Sheet and strip	151,571	129,294	118,584	141,008
Bars and shapes	37,889	37,991	40,726	43,417
Wire and wire rods	36,038	37,394	39,861	43,016
Pipe and tube	33,274	26,446	36,752	37,257
Total	292,810	298,965	314,178	344,233

[1]All numbers are included in tables 14 and 15.

Source: International Trade Commission.

TABLE 17

APPROXIMATE CONSUMPTION OF METALS IN THE PRODUCTION OF STEEL AND IRON, 1988[1]

(Short tons)

Metal[1]	Steel					
	Carbon	Stainless	Alloy	Tool	Other	Cast iron
Cobalt	—	18	W	199	—	—
Ferroboron	503	26	313	W	—	—
Ferrochromium	8,913	400,432	51,326	4,338	—	7,957
Ferrocolumbium[2]	1,538	e700	1,426	W	22	—
Ferromanganese	354,264	18,874	80,260	402	977	12,142
Ferrophosphorus	8,483	10	1,335	—	—	2,141
Ferrosilicon	65,006	81,371	72,062	2,483	135	232,819
Ferrotitanium[3]	967	3,023	274	W	6	W
Ferrotungsten[3]	—	100	105	436	—	—
Lead (shot)	e1,400	—	e80	—	—	—
Molybdenum[3]	1,341	3,128	3,856	W	—	648
Nickel	—	50,219	7,522	W	—	1,225
Siliconmanganese[4]	85,585	5,306	24,026	W	429	1,642
Vanadium[2]	2,864	45	978	530	—	—

eEstimated. W Withheld to avoid disclosing company proprietary data.

[1]All grades of the respective alloy combined; molybdenum, vandium, nickel, cobalt, and lead shot shown as contained metal weights of all used forms combined.

[2]Consumption for High Strength, Low Alloy steels included in carbon steels.

[3]Including respective metal powders, oxides, and other forms converted to the ferroalloy.

[4]Underreported because of low response from minimills.

Note.—The steel production in 1988 was 99.99 metric tons, but presenting average alloy input per steel ton is technologically meaningless because of the large number of steel compositions.

Also, an estimated 30,000 tons of aluminum, mostly secondary, was used, most of it sacrificially for deoxidation, but some also for alloying; an estimated 15,000 tons of magnesium powder was used sacrificially for hot metal desulfurization and approximately 2,000 tons in the production of nodular cast iron.

Also, small amounts, under 500 tons, of bismuth, tellurium, and selenium were consumed in the production of free-cutting (free-machining) steels, approximately 5,000 tons of sulfur and less than 800 tons of calcium.

of alloying steels is to obtain specific properties or strengthen the steel to obtain weight savings for some particular design that otherwise would require a much heavier section of plain carbon steels.

High alloy steels, customarily regarded as those containing more than 5% of elements other than iron, include stainless steels based on chromium (12% to 30%) and high-speed tool steels, which retain their cutting edge at dull red heat, thereby allowing fast machining. In decreasing order of importance, these always have tungsten, molybdenum, chromium, and vanadium in their composition, and, in the highest grades, there is also cobalt.

More than 80% of steel production is plain (unalloyed) carbon steels. A major part of these are the lower carbon grades, up to 0.10% carbon, causing another complication; in lower carbon ranges (up to 0.20% carbon), ingot steels of nominally identical composition can be made in several types—as unkilled (rimmed or mechanically capped), semikilled, or killed (deoxidized) steels. The properties of these steels differ drastically as do the costs of their production.

The importance of differentiation between steel types is, however, decreasing because of the wide adoption of the continuous casting method of solidifying liquid steel. This method is applicable to one type only, namely killed steels. Nevertheless, because about 35% of the U.S. output was still made using the old method of pouring in 1989, it is desirable to describe the properties of the steel types.

Rimmed or capped steels are characterized by a smooth, good surface that persists throughout processing and results in a product that easily takes almost any surface finish. However, the mechanical properties are rather low and not very uniform. Hence, although this type formerly was extensively produced for galvanizing, tinplating, painting, etc., it could not be used for stressed parts or be subjected to strong deformation, such as deep drawing.

Killed steels have uniform and reliable mechanical properties; this fact results in such steels always being selected, for example, by a machine designer or builder of heavily stressed structures. The surface quality is not as good as that of the rimmed grades but generally acceptable; it can be improved by careful steel conditioning. The production cost as ingots is fairly high.

An intermediate type, semikilled steel, falls between the two main classes; it has good and fairly uniform, but not outstanding, mechanical properties and a surface good enough for unexposed applications. It was the main type used for bars and plates and structural sections, especially for structures that are not critically stressed. The production cost is low.

TABLE 18

COUNTRIES OF ORIGIN OF ALLOYING METALS

Metal	Principal producing countries
Boron	Japan,[1] United States
Chromium	Brazil, Finland, Greece, India, Republic of South Africa, Turkey, Zimbabwe
Cobalt	Canada, Zaire
Columbium	Brazil, Canada
Manganese	Australia, Brazil, Canada,[1] France,[1] Germany,[1] Mexico, Norway,[1] Republic of South Africa, United States[1]
Molybdenum	Chile, United States
Nickel	Canada, Colombia, Finland, Greece, New Caledonia
Phosphorus	United States
Silicon	Brazil, Canada, Iceland, Republic of South Africa, Venezuela
Titanium	Australia, Belgium,[1] United States,[1] U.S.S.R.
Tungsten	Australia, Bolivia, China, Peru, Portugal, Thailand
Vanadium	Republic of South Africa, United States[1]

[1]From imported ores or concentrates.

TABLE 19

IMPORTS OF FERROALLOYS, 1988

(Short tons)

Alloy[1]	Gross weight
Ferrochromium	475,909
Ferromanganese	763,642
Ferronickel	44,577
Ferrosilicon	230,897
Other alloys	10,299

[1]All grades of the respective alloy combined.

Technology

Before World War I, the stress was on "country building" goods: rails, structural sections, and plates. After the 1920's, the demand for "population comfort" items, essentially formable "flat products" (sheet and strip), became increasingly important.

World War II introduced the concepts of steel and raw materials conservation; for instance, the substitution of molybdenum, freely available in the United States, for the imported tungsten in tool steels.

These trends culminated in the development of a new family of High-Strength Low-Alloy steels, based mainly on manganese with either columbium (niobium in Europe) or vanadium or both, often with molybdenum and other elements.

The push toward the development of the new, higher strength products, hence lower weight for equivalent mechanical performance, was given by two industries: line pipe, which had to be light but strong for constructional purposes, and automobiles. The clean air acts required greater fuel economy. Thus, if the performance were not to suffer, automobiles had to become lighter. Hence, the need for strong yet lightweight steel.

The following sums up the growth and decay of steelmaking processes in North America.

Crucible.—The only process known before Bessemer; very slow, very small scale, erratic product quality.

Bessemer.—Origin unknown, this process developed because of the possible realization that steelmaking is an oxidation process contrary to the relatively well-known blast furnace production of iron. Growth was caused by rapidly expanding markets in "country building" structural steels, known as "heavy products," plus the availability of low-sulfur and phosphorus ores. The production rate reached 40 tons per hour. Decay was due to the inability to remelt mill return scrap

TABLE 20

PIG IRON[1] AND DIRECT REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	1,210	1,210	1,210	1,210	1,210
Argentina:					
Pig iron	r1,444	r1,791	1,931	1,759	2,320
Direct reduced iron	r1,090	r1,031	1,139	1,176	1,280
Australia	6,181	6,492	6,139	6,316	6,720
Austria	4,083	3,692	3,804	4,040	4,200
Belgium	9,617	8,876	9,087	10,083	9,900
Brazil:					
Pig iron	r20,597	r22,107	23,487	25,757	26,610
Direct reduced iron	314	325	223	215	260
Bulgaria	1,876	1,760	1,821	e1,800	1,800

See footnotes at end of table.

TABLE 20—Continued

PIG IRON[1] AND DIRECT REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1985	1986	1987	1988[p]	1989[e]
Burma:					
Pig iron	—	3	—	—	—
Direct reduced iron	33	33	22	22	22
Canada:					
Pig iron	10,654	10,195	10,713	10,470	11,560
Direct reduced iron	820	760	801	849	780
Chile	639	651	680	855	[5]748
China[e]	48,100	55,300	59,400	62,200	63,700
Colombia	258	349	359	341	330
Czechoslovakia	10,540	10,552	10,789	[e]10,800	10,800
Egypt:					
Pig iron	175	[e]220	[e]220	146	140
Direct reduced iron	—	33	520	771	760
Finland	2,084	2,190	2,274	2,396	2,500
France	17,004	15,412	16,305	16,314	[5]16,625
German Democratic Republic[6]	2,842	3,018	3,037	3,071	3,000
Germany, Federal Republic of:					
Pig iron	34,757	31,987	31,435	35,773	[5]36,130
Direct reduced iron	110	187	220	300	390
Greece[e]	154	180	180	180	180
Hungary	2,309	2,264	2,323	2,307	2,200
India:					
Pig iron	10,841	11,584	12,007	[e]11,000	12,100
Direct reduced iron	100	187	209	209	440
Indonesia: Direct reduced iron	1,101	1,460	1,013	1,080	[5]1,391
Iran:[e 7]					
Pig iron	276	276	276	276	276
Direct reduced iron	—	—	—	—	44
Iraq: Direct reduced iron	—	—	—	22	220
Italy	13,297	13,135	12,495	12,510	[5]12,941
Japan	88,812	82,289	80,929	87,408	[5]88,401
Korea, North[e]	6,400	6,400	6,400	7,200	7,200
Korea, Republic of	9,737	9,940	12,188	13,865	15,400
Libya: Direct reduced iron	—	—	—	—	100
Luxembourg[6]	3,036	2,921	2,541	2,779	[5]2,960
Malaysia: Direct reduced iron	570	640	651	500	[5]628
Mexico:					
Pig iron	[r]3,963	[r]4,119	4,092	4,054	3,580
Direct reduced iron	[r]1,653	[r]1,565	1,710	1,858	2,450
Morocco[e]	17	17	17	17	17
Netherlands	5,312	5,101	6,035	5,508	[5]5,708
New Zealand:[e]					
Pig iron	190	220	220	220	220
Direct reduced iron	190	90	—	—	—

See footnotes at end of table.

TABLE 20—Continued

PIG IRON[1] AND DIRECT REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand short tons)

Country[4]	1985	1986	1987	1988[p]	1989[e]
Nigeria: Direct reduced iron	243	121	154	160	160
Norway	657	617	408	405	300
Pakistan	885	983	998	1,028	1,100
Paraguay	—	—	37	89	100
Peru:					
Pig iron	[r]180	[r]238	204	183	250
Direct reduced iron	49	61	56	54	55
Poland	10,810	11,626	11,548	11,314	11,600
Portugal	466	473	480	491	[5]416
Qatar: Direct reduced iron	549	548	520	488	595
Romania	10,154	10,283	9,560	[e]9,400	9,100
Saudi Arabia: Direct reduced iron	1,100	1,290	1,450	1,080	1,330
South Africa, Republic of:					
Pig iron[e]	[5]7,247	7,500	7,400	7,200	7,100
Direct reduced iron	460	870	930	730	730
Spain	6,015	5,291	5,353	5,114	[5]6,307
Sweden	2,811	2,897	2,666	2,749	[5]2,910
Switzerland	73	87	[e]77	[e]77	77
Taiwan	3,780	[e]4,100	[r e]4,300	6,256	6,600
Trinidad and Tobago: Direct reduced iron	[r]226	[r]229	524	659	[5]675
Tunisia[e]	165	165	165	165	165
Turkey	3,520	4,041	4,892	5,419	[5]4,458
U.S.S.R.:					
Pig iron[e]	120,600	124,800	124,850	[r]125,700	125,700
Direct reduced iron	460	830	1,390	1,764	1,870
United Kingdom	11,443	10,676	13,246	14,392	13,900
United States:					
Pig iron	49,963	[r]43,951	48,337	55,745	[5]55,873
Direct reduced iron	154	176	231	320	320
Venezuela:					
Pig iron	[r]486	[r]541	521	534	[5]539
Direct reduced iron	2,910	3,240	3,473	2,983	3,060
Yugoslavia	3,439	3,376	3,160	3,214	[5]3,196
Zimbabwe[e]	743	710	[r]634	660	[5]573
Grand total	[r]561,974	[r]560,282	576,466	606,030	617,300
Of which:					
Pig iron	[r]549,842	[r]546,606	561,230	592,790	599,740
Direct reduced iron	[r]12,132	[r]13,676	15,236	15,240	17,560

[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 20, 1990.

[4]In addition to the countries listed, Vietnam and Zaire have facilities to produce pig iron and may have produced limited quantities during 1985–89, 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.

[7]Presumably from blast furnaces only. Although Iran has direct reduction iron plants attaining a reported 365,000 short tons per year capacity, no production data are available.

TABLE 21

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand short tons)

Country[3]	1985	1986	1987	1988[p]	1989[p]
Algeria[e]	[4]1,559	[r]1,540	[r]1,540	1,540	1,540
Angola[e]	11	11	11	11	11
Argentina	3,243	3,566	4,005	3,993	4,249
Australia	7,251	7,389	6,756	7,054	[e]7,300
Austria	5,137	4,731	4,741	5,027	[e]5,200
Bangladesh[5]	111	106	90	89	[e]88
Belgium	11,776	[r]10,770	10,788	12,370	12,068
Brazil	22,549	23,406	24,505	27,046	27,578
Bulgaria	3,245	3,268	3,357	[e]3,310	3,196
Canada	16,094	15,543	16,204	16,387	17,040
Chile	759	778	800	991	896
China[e]	51,500	57,400	61,700	[r]65,000	67,500
Colombia	584	697	759	831	778
Cuba	442	454	443	354	[e]390
Czechoslovakia	16,574	16,658	19,927	16,886	17,047
Denmark	582	697	668	717	689
Dominican Republic	66	110	97	83	61
Ecuador	20	19	28	26	26
Egypt	1,047	1,102	1,764	1,874	[e]1,870
El Salvador	13	10	14	12	17
Finland	2,776	2,850	2,942	3,084	[e]3,100
France	20,759	19,427	19,540	20,947	21,259
German Democratic Republic	8,656	8,782	9,086	8,963	[e]8,600
Germany, Federal Republic of	44,640	40,933	39,957	45,220	45,197
Greece	1,086	1,112	1,001	1,047	1,055
Guatemala	11	19	23	25	25
Honduras[e]	21	8	8	8	8
Hong Kong[e]	130	130	130	130	130
Hungary	4,019	4,095	3,991	3,950	[e]3,600
India[6]	12,185	12,596	14,201	15,773	15,905
Indonesia	1,323	1,653	1,653	[e]2,260	[e]2,200
Iran[e]	990	990	990	990	990
Ireland	224	229	243	299	357
Israel	110	121	128	[e]130	[e]130
Italy	[r]26,343	[r]25,224	25,197	26,191	27,746
Jamaica	13	12	21	28	[e]28
Japan	116,050	108,330	108,592	116,493	118,949
Jordan[e]	150	150	[r]260	[4]19	[4 7]15
Kenya[e]	([7])	([7])	([7])	([7])	—
Korea, North[e]	7,200	7,200	7,200	8,800	8,800
Korea, Republic of	14,924	16,043	18,499	21,073	[e]24,000
Luxembourg	4,349	4,084	3,639	4,033	4,102
Malaysia[e]	610	830	[4]827	600	600
Mexico	[r]8,156	[r]7,964	8,424	8,575	8,730

See footnotes at end of table.

TABLE 21—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand short tons)

Country[3]	1985	1986	1987	1988[p]	1989[p]
Morocco[e]	7	7	7	8	8
Netherlands	6,081	5,824	5,602	6,083	6,250
New Zealand	250	321	347	593	[e]550
Nigeria	280	220	203	212	[e]200
Norway	1,056	922	923	1,000	707
Pakistan[e]	770	880	1,000	[r]1,100	1,100
Paraguay	—	—	15	69	60
Peru	438	537	553	530	442
Philippines[e]	[4]276	276	280	[4]365	330
Poland	17,776	18,898	18,902	18,599	[e]18,740
Portugal	733	780	807	894	816
Qatar	588	559	542	581	[e]580
Romania	15,206	15,737	15,306	[e]15,400	15,890
Saudi Arabia[e]	[4]1,219	1,200	[4]1,505	1,545	1,600
Singapore[e]	390	390	390	[4]468	470
South Africa, Republic of	9,460	[e]9,700	9,259	9,700	[e]9,800
Spain	15,691	13,201	12,887	12,880	13,982
Sweden	5,305	5,192	5,065	5,268	[e]5,200
Switzerland	1,088	1,185	959	909	1,010
Syria[e]	76	76	77	77	77
Taiwan	5,871	6,260	6,558	8,997	[e]9,040
Thailand	493	510	589	608	759
Trinidad and Tobago	190	359	398	399	324
Tunisia[e]	[4]187	[4]200	200	200	200
Turkey	5,469	5,432	7,765	8,799	8,658
U.S.S.R.	170,492	176,976	178,450	179,717	[e]175,000
United Kingdom	17,331	16,326	19,208	20,958	20,738
United States	88,259	81,606	89,151	99,924	[4]97,943
Uruguay	43	44	33	32	43
Venezuela[6]	3,710	3,822	4,102	4,052	3,737
Vietnam[e]	120	120	120	125	130
Yugoslavia	4,938	4,981	4,814	4,946	4,960
Zimbabwe[e]	510	540	[4]570	[4]664	650
Total	[r]791,591	[r]784,118	808,336	857,941	863,064

[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 20, 1990.

[3]In addition to the countries listed, Burma, Ghana, Libya, and Mozambique are known to have steelmaking plants, but available information is inadequate to make reliable estimates of output levels.

[4]Reported figure.

[5]Data are for year ending June 30 of that stated.

[6]Includes steel castings.

[7]Revised to zero.

and customer scrap, to refine phosphorus and sulfur, and to produce alloy steels. The basic Bessemer process developed in Europe could not be utilized in the United States because it required high-phosphorus iron (more than 1.5% phosphorus), the phosphorus being the main internal fuel. Such ores do not occur in North America.

Open Hearth.—Developed from the need to remelt scrap as well as use iron from the blast furnaces and to produce low-alloy to medium-alloy steels (up to about 5% alloying elements). The process' moderate ability to refine sulfur and phosphorus out of raw materials later developed the basic lined version of the process. Because of the high capital and operating cost and low productivity in comparison with the basic oxygen process and the difficulty of intermittent operation, open hearth process began to decline. Decay was slowed down by extensive use of oxygen and natural gas, but accelerated by stringent air pollution controls. Only about 3% to 5% of U.S. production comes from old open hearths.

Electric Arc.—Originated because of the availability of cheap power and the need for making high-alloy steels. The process is economical in a large range of furnace sizes (5 to 300 tons, per heat). Its independence of iron supplies, ease of startup and shutdown (for weekends in foundries), good reproducibility (leading to ease of computerized control), and ease of synchronization with a continuous caster have promoted growth. About 35% to 40% of U.S. production comes from arc furnaces.

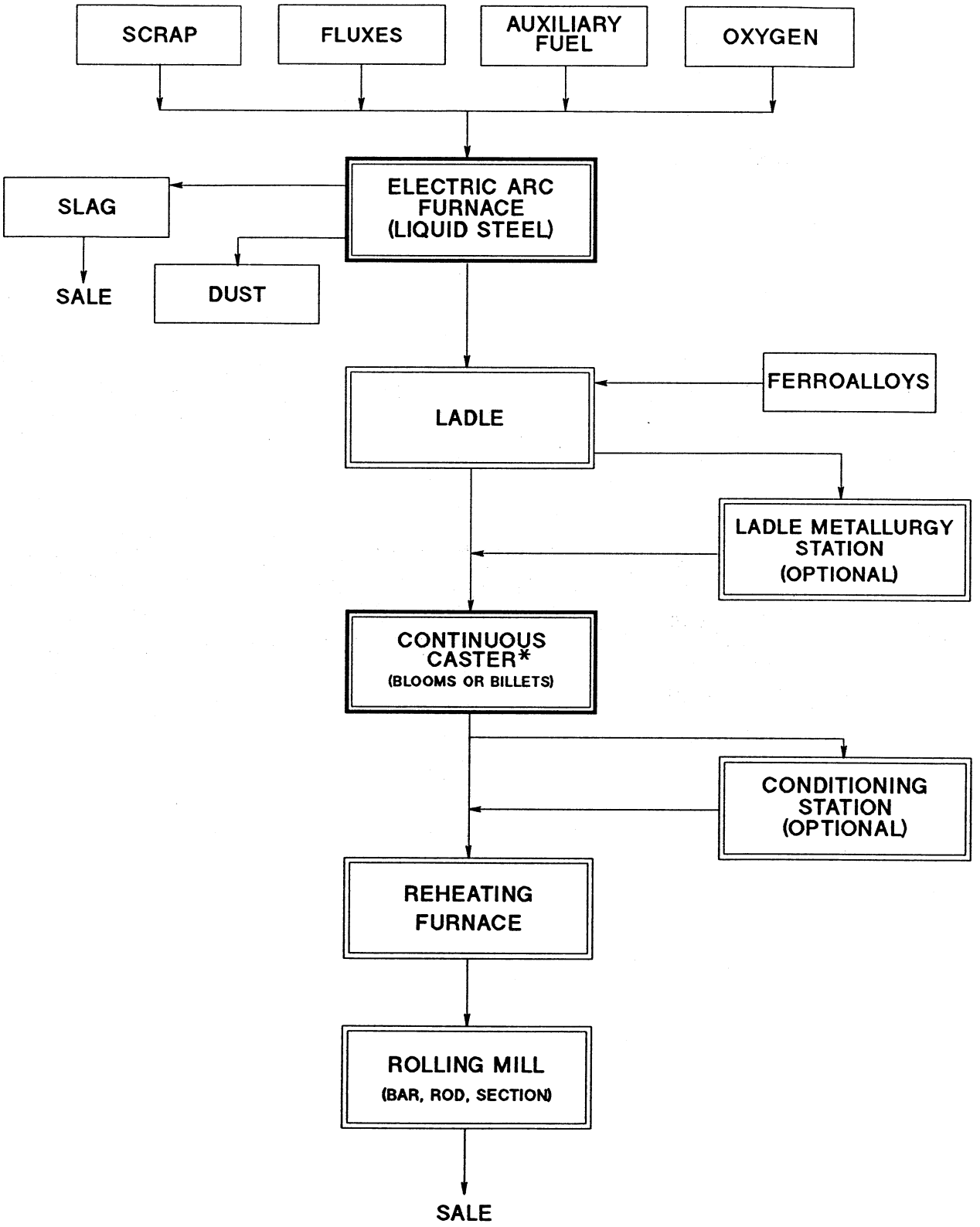
Basic Oxygen.—Originated from the unavailability of scrap in the country of its origin (Austria). It has high productivity and low capital cost of new installations, but requires hot metal from blast furnaces. The basic oxygen process will continue to be used. Flowsheets illustrating these different ironmaking and steelmaking practices are shown in figures 1 through 4.

OTHER SOURCES OF INFORMATION

American Iron and Steel Institute.
The Making, Shaping, and Treating of Steel.
Ferrous Production Metallurgy.
Steel—Upheaval in a Basic Industry.
The U.S. Steel Industry in Recurrent Crisis.
Economic History of the Iron and Steel Industry in the United States.
Steel in the United States: Restructuring to Compete.
World Steel in the 1980's: A Case of Survival.
Directory of Iron and Steel Plants.
Iron and Steel Works of the World.

FIGURE 1

TYPICAL MINIMILL PRACTICE (FOR SHAPE PRODUCTS)



*OR TO FOUNDING FLOOR IN A STEEL FOUNDRY

FIGURE 2

PRODUCTION OF IRON ("HOT METAL") IN AN INTEGRATED STEEL MILL

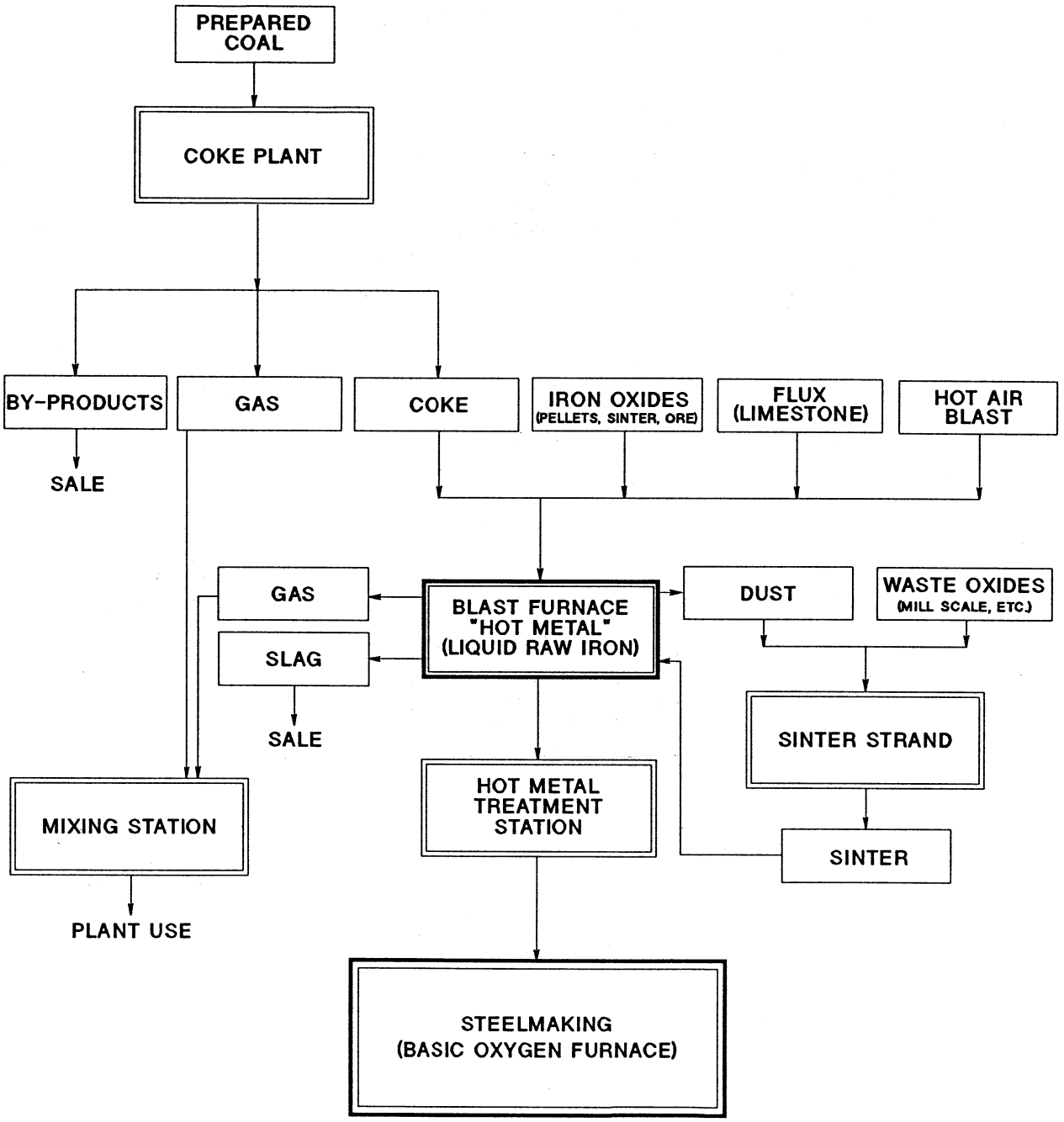
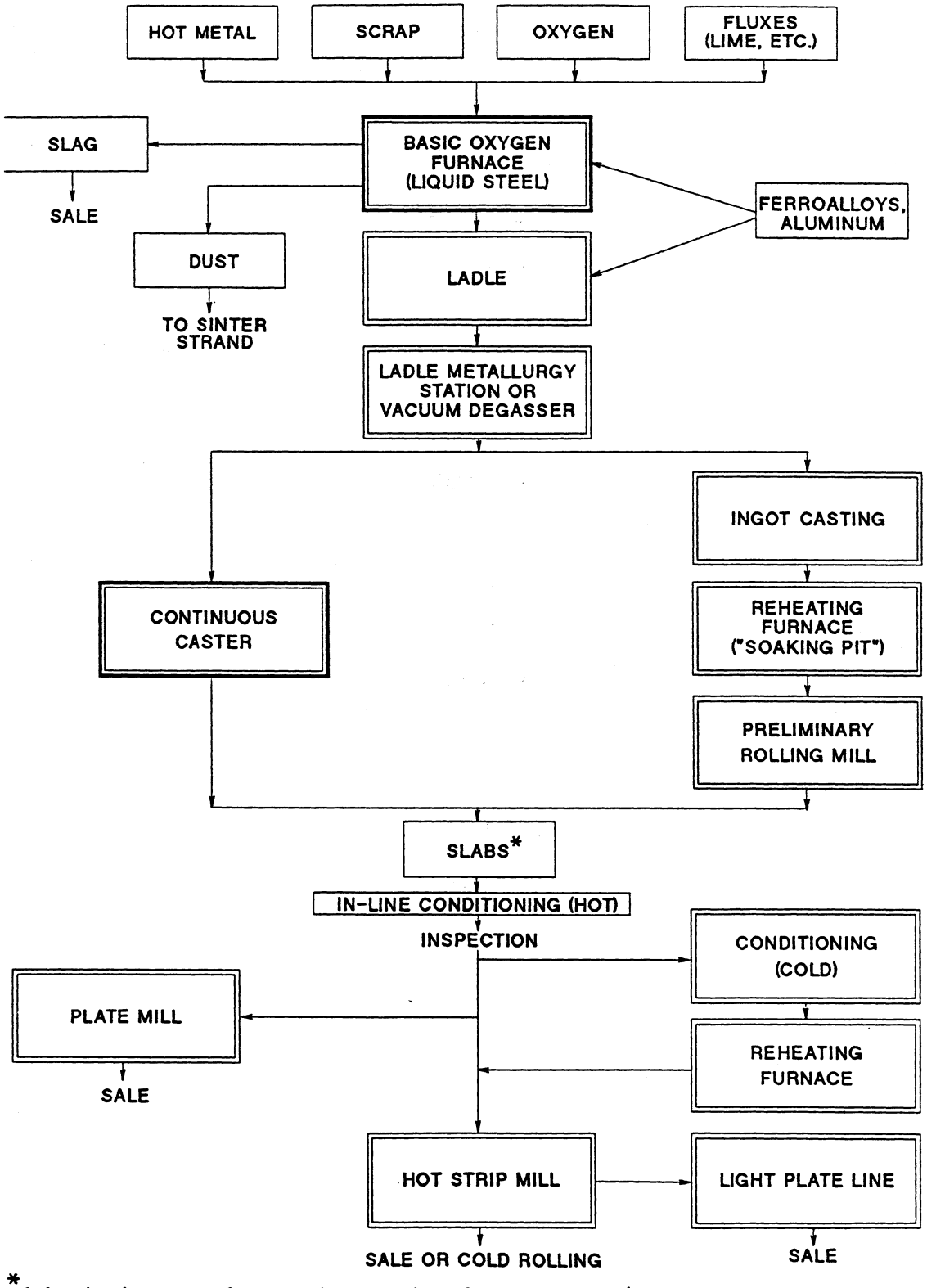


FIGURE 3

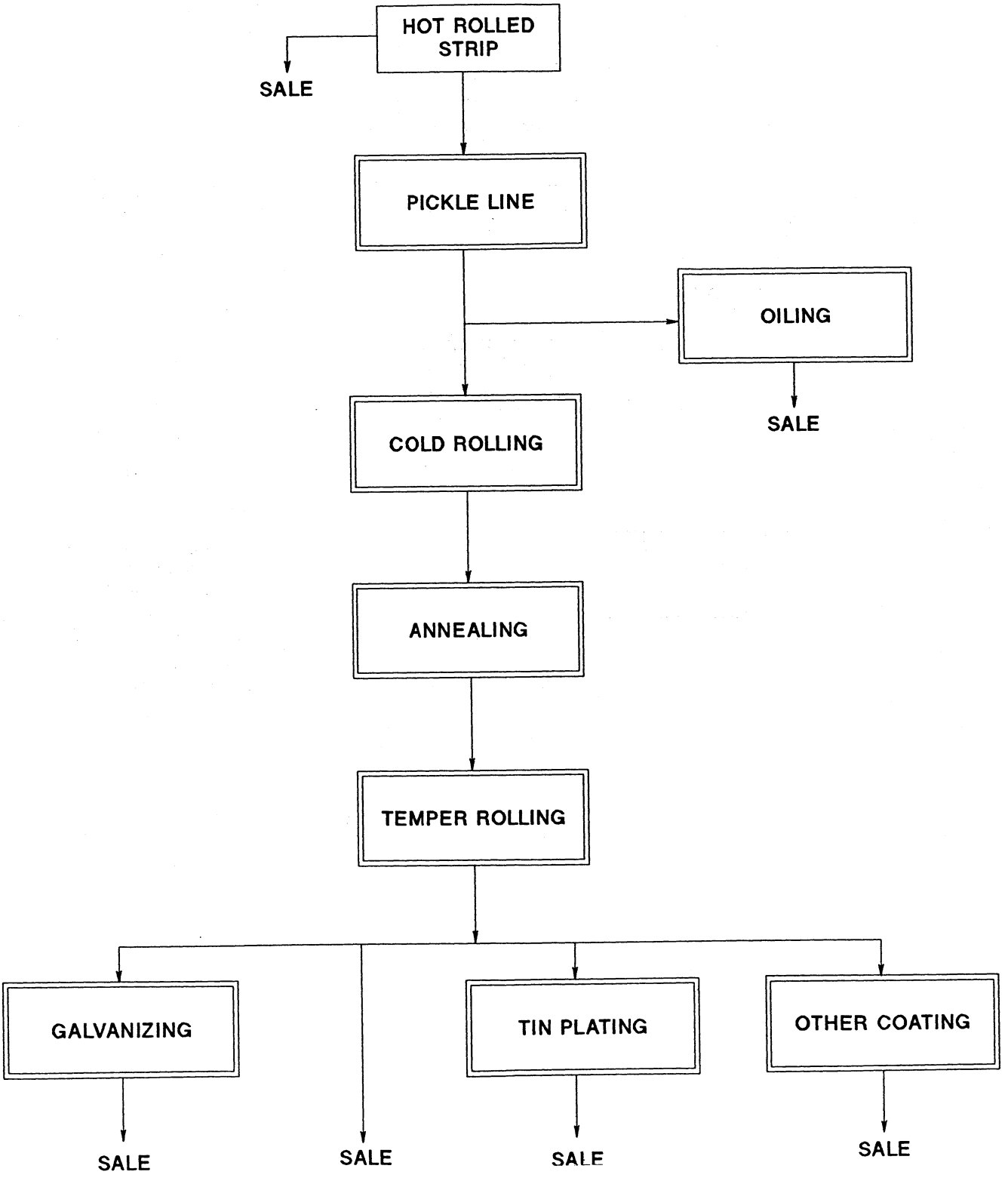
OXYGEN STEELMAKING AND HOT ROLLING IN AN INTEGRATED STEEL MILL



*A few basic oxygen furnace shops produce Shape Products (i.e., blooms or billets are cast).

FIGURE 4

COLD ROLLING AND COATING FLAT PRODUCTS



IRON AND STEEL SCRAP

By Raymond E. Brown

Mr. Brown, a physical scientist with 34 years of industry and 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, International Data Section. Tables 9 and 17 were prepared by the author.

DOMESTIC DATA COVERAGE

Brokers, dealers, and other outside sources supplied domestic consumers in 1989 with 43.6 million short tons[1] of all types of ferrous scrap at a delivered value of approximately $4.63 billion, while exporting 12.3 million tons (excluding rerolling material and ships, boats, and other vessels for scrapping) valued at $1.75 billion. In 1988, domestic consumers received 47.1 million tons at a delivered value of approximately $5.06 billion; exports totaled 10.1 million tons valued at $1.35 billion. This represented a 7% decrease for received quantities and a 22% increase for exported quantities.

Domestic production data for ferrous scrap were developed by the Bureau of Mines from voluntary monthly or annual surveys of U.S. operations. Of the operations to which a survey request was sent, 57% responded, representing an estimated 70% 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 0.3% for manufacturers of pig iron and raw steel and castings, 2% for manufacturers of steel castings, 5% for iron foundries and miscellaneous users, and 1% 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)

	1985	1986	1987	1988	1989
Stocks, Dec 31:					
Scrap at consumer plants	5,104	4,344	4,844	4,554	4,644
Pig iron at consumer and supplier plants	266	188	281	207	304
Total	5,370	4,532	5,125	4,761	4,948
Consumption:					
Scrap	70,493	65,856	68,303	76,822	72,209
Pig iron	51,411	45,604	50,030	59,047	58,387
Exports:					
Scrap (excludes rerolling material and ships, boats, and other vessels for scrapping)	9,950	11,704	10,367	10,098	12,290
Value	$918,186	$1,053,849	$967,018	$1,351,955	$1,748,643
Imports for consumption:					
Scrap (includes tinplate and terneplate)	611	724	843	1,038	1,120
Value	$46,480	$49,073	$82,016	$133,577	$149,109

LEGISLATION AND GOVERNMENT PROGRAMS

In 1989, the United States generated about 160 million tons of municipal solid waste (MSW). About 9% of this solid-waste stream was composed of metals. A large percentage of the metal fraction in the waste stream consisted of ferrous components. A proposal by the Environmental Protection Agency (EPA) to reduce air emission levels from incinerators by at least 90% and to improve the recycling marketplace included a provision that would mandate a 25% source separation before incineration. The EPA's overall agenda for action indicated that by 1992, the MSW stream diverted by source reduction and recycling would be increased from 10% to 25%, landfilling would be decreased from 80% to 55%, and the amount of MSW combusted in municipal waste combustors would be increased from 10% to 20%. This would be the first time that the Federal Government has required recycling.[2]

In accordance with section 3004 (g) (5) of the Resource Conservation and Recovery Act (RCRA), the EPA was proposing to prohibit the land disposal of certain hazardous wastes listed in the U.S. Code of Federal Regulations (40 CFR 268.12).[3] One comment by the American Foundrymen's Society Inc. on the proposal was that the proposed treatment standards for D006 (cadmium) and D008 (lead) were based on wastes that were dissimilar to those generated by foundries and should not be applied to foundry wastes.

As a result of an agreement between the Port Authority of New York and New Jersey and the New York State Legislative Commission on Solid Waste Management, the Port Authority conducted a study and published a report on export markets for post-consumer

secondary materials. The study was also designed to determine material composition and waste generation rates for these two States.[4]

On July 25, 1989, the President announced a steel trade liberalization program, under which the Voluntary Restraint Agreements (VRA's) would be extended for 2½ years, terminating on March 31, 1992. The President directed the U.S. Trade Representative to negotiate VRA's at an overall restraint level of 18.4%, which was the same as the 1988 VRA import penetration level.

The U.S. Office of Technology Assessment published a two-part report, including a summary, on MSW. The report examined the problems associated with MSW, which included increasing generation, declining landfill capacity, opposition to new management facilities, concerns about risks, and rising costs.[5]

The U.S. Department of Energy (DOE) signed final agreements in November for its part of a $40 million project to reduce sulfur dioxide emissions from coke oven gases at Bethlehem Steel Corp.'s, Sparrows Point, MD, plant. DOE would contribute $13.5 million to the project, announced in July, as part of a $92 million overhaul of the Baltimore, MD, facility.

AVAILABLE SUPPLY, CONSUMPTION, AND STOCKS

Overall domestic demand for ferrous scrap by the iron and steel and the ferrous castings industries, the major consumers of this raw material, decreased about 6% in 1989 compared with that of 1988. Domestic demand for ferrous scrap by producers of pig iron and raw steel was down by both a larger quantity and a larger percentage than that for producers of ferrous castings. Because of continued strong worldwide demand for ferrous scrap in 1989, prices for most grades remained high.

International Mill Service (IMS), Philadelphia, PA, started engineering work for on-site electric furnace dust processing facilities at Atlantic Steel Co., Atlanta, GA, and Lake Ontario Steel Co. (Lasco Steel), Whitby, Ontario, Canada. IMS already operated Tetronics plasma dust processing facilities at two other domestic minimills: Florida Steel Corp.'s mill in Jackson, TN, and the Nucor Corp. and Yamato Steel Co. joint venture in Blytheville, AR. IMS was one of only two domestic companies that operated facilities that used a thermal treatment process to remove zinc from electric arc furnace dust. Horsehead Resource Development Co., Palmerton, PA, was the other domestic company that performed thermal treatment of baghouse dust. Zinc recovered from baghouse dust by the IMS process was in metallic form, whereas that recovered by the Horsehead process was in oxide form. The EPA had given electric furnace (EF) operators a deadline of August 8, 1990, to treat EF dust to meet their standards. At that time, EF dust containing more than 15% zinc must be processed via thermal treatment.

The American Metal Market, New York, NY, and Recycling Times, Washington, DC, began quoting prices on clean used densified steel-bodied cans. Both of these publications provided prices per gross ton for various primary buying locations. A study by the Steel Can Recycling Institute, Pittsburgh, PA, revealed that steel food cans and steel beverage cans were recycled at a rate of 15% in 1988.

AMG Resources Corp., Pittsburgh, PA, planned to open a steel can recycling facility in St. Paul, MN. The plant would recycle 40,000 tons of steel cans annually from a five county area. Proler International, Houston, TX, had established a new satellite facility in Kansas City, KS. The facility would only serve as a collection point for post-consumer steel cans. The materials collected at the Kansas City location would be shipped by rail to Proler's plant in Houston, TX, for detinning.

Raytheon Service Co. (RSC), Burlington, MA, a wholly owned subsidiary of the Raytheon Co., Lexington, MA, has been the full service contractor for the Delaware Solid-Waste Authority resource recovery facility since March 1, 1984. Results from Bureau of Mines pilot-plant tests of MSW from approximately 1973 to 1981 were the basis for the design of two Raytheon commercial-scale reclamation plants. The Delaware Reclamation Plant (DRP) was one of these plants. An intensive cooperative effort was maintained between the Bureau of Mines and Raytheon during the MSW pilot-plant testing period. RSC designed, built, and operated the DRP located at Pigeon Point near Wilmington, DE. From MSW, RSC recovered and marketed ferrous and nonferrous metals and glass at the DRP. This plant also recovered a refuse derived fuel (RDF) that was fired at an adjacent energy-generating facility and produced humus products suitable for many horticultural applications. MSW delivered to the DRP was first shredded to a nominal 4-inch particle size. Shredded waste was then air classified to remove RDF. Following air classification, the remaining waste was then processed to remove ferrous scrap through a series of magnetic separators. The recycled ferrous scrap was then shipped loose directly to Lukens Steel Co., Coatesville, PA, through a broker, The David J. Joseph Company, Cincinnati, OH. The DRP recovered between 6,000 to 7,000 tons of ferrous scrap annually. More than half of the ferrous fraction was comprised of steel cans.

Bayou Steel Corp., La Place, LA, was accepting post-consumer ferrous scrap for its minimill steelmaking process. Bayou used virtually 100% scrap in its two 65-ton electric arc furnaces, which had a combined annual capacity of 700,000 tons of raw steel.

Kobe Steel Ltd., Tokyo, Japan, invested an estimated $300 to $400 million in USX Corp.'s Lorain Works in Lorain, OH. The plant consumed significant quantities of scrap. Birmingham Steel Corp., Birmingham, AL, agreed to be bought out by a corporation headed by one of its outside directors for $525 million. Harbert Corp., the purchaser, was a closely held Birmingham, AL, based company with interests in other areas. Birmingham Steel, a fast growing minimill chain, operated six plants in six states with a combined annual capacity of nearly 1.5 million tons.

North Star Steel Co., Minneapolis, MN, announced a tentative decision to discontinue operations at its Milton, PA, plant. North Star had negotiated for 6 months with union officials after buying the former Milton Manufacturing Co. minimill facility in February 1988. North Star's president was quoted as saying, "while the decision to close is not final, without acceptance of our final proposal to the union, we do not intend to continue operations at the Milton facility."

Razorback Steel Corp., Newport, AR, was sold for $20 million to a partnership formed by Sumitomo Corp. of America (SCA). Razorback was a small independent minimill operation that produced 200,000 tons per year of steel in two 30-ton electric arc furnaces. The purchasers included SCA and its parent company, Sumitomo Metal Industries Ltd. of Osaka, Japan; Yamato Kogyo Co. Ltd. of Himeji, Japan; and Auburn Steel Co. of Auburn, NY, owned by Kyoei Steel Ltd. of Osaka, Japan. The partnership was named Arkansas Steel Associates.

Ford Motor Co., Dearborn, MI, announced it would sell its Rouge Steel Co. subsidiary in Detroit, MI, to Marico Acquisition Co. Marico, composed of a group of investors, was an organization formed specifically for the purchase. Rouge Steel, the Nation's ninth largest steel producer, had two 225-ton electric arc furnaces with a combined annual raw steelmaking capacity of 900,000 tons.

Auto dismantlers continued to play a vital role in the recycling chain as suppliers of auto parts and scrap. The dismantling industry was a major source of scrap in the United States, handling seven to eight million vehicles each year. The Automotive Dismantlers and Recyclers Association (ADRA), Washington, DC, was supportive of legislation that promoted recycling to protect the environment and conserve natural resources.[6]

A symposium entitled "Steel Survival Strategies IV" was held in New York, NY, on June 27–28. Nearly 600 people attended the forum that was cosponsored by American Metal Market and Paine Webber Inc.'s World Steel Dynamics, both located in New York, NY.

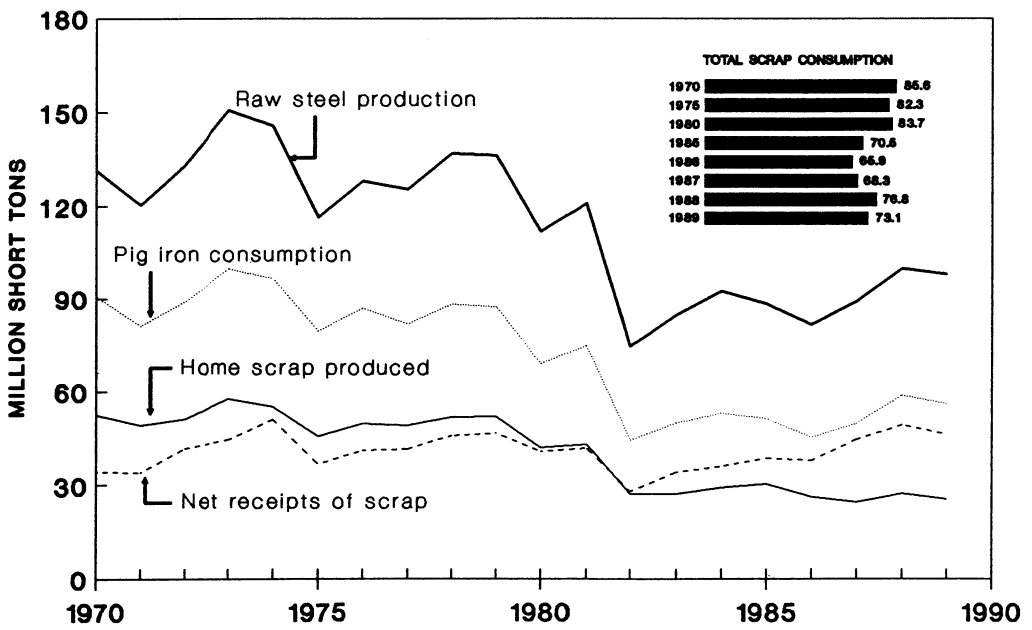
Imports of metallurgical-grade coke decreased about 14% in 1989 to 2.31 million tons compared with that of 1988. Metallurgical coke imports represented 7% of domestic apparent consumption in 1989 compared with 8% in 1988. The United States continued as a net importer of metallurgical coke. Domestic coal consumption in coke plants decreased slightly more than 1% in 1989 to 41.4 million tons. However, domestic metallurgical coal exports increased 5% in 1989 to 65.1 million tons compared with those of 1988.

Raw steel production was 97.9 million tons in 1989 compared with 99.9 million tons in 1988. The shares of raw steel produced by electric, basic oxygen, and open-hearth furnaces were, respectively, 36%, 60%, and 5% in 1989 and 37%, 58%, and 5% in 1988. Continuous cast steel production represented 65% of total raw steel production in 1989 compared with 61% in 1988. Raw steel capacity utilization was 85% in 1989 and 89% in 1988. However, raw steel production capability was 115.9 million tons in 1989 compared with 112.0 million tons in 1988.

Net shipments of all grades of steel mill products were 84.3 million tons in 1989 and 83.8 million tons in 1988. Imports of steel mill products decreased from 20.9 million tons in 1988 to 17.3 million tons in 1989. Exports of steel mill products increased sharply from 2.07 million tons in 1988 to 4.58 million tons in 1989. The apparent supply of steel mill products decreased from 102.7 million tons in 1988 to 97.0 million tons in 1989. Imports of steel mill products, as a share of the U.S. market, decreased from 20% in 1988 to 18% in 1989. Steel mill processing yields increased from 84% in 1988 to 86% in 1989. Pig iron production increased slightly from 55.7 million tons

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



in 1988 to 55.9 million tons in 1989.

Iron castings shipments totaled 7.77 million tons in 1989 compared with 9.59 million tons (revised) in 1988. Steel castings shipments totaled 1.14 million tons in 1989 compared with 1.21 million tons (revised) in 1988.

Steel mills accounted for 72% of all scrap received from brokers, dealers, and other outside sources; steel foundries received 5%; and iron castings producers and miscellaneous users received 23%. The apparent total domestic consumption of ferrous scrap in 1989, in million tons, was composed of 45.9 net receipts (total receipts minus shipments), 25.4 home scrap, and a buildup of 0.1 stocks. The 1989 total was 71.2 million tons; the apparent total domestic consumption was 77.3 million tons in 1988. The total market for U.S. scrap (net receipts plus exports minus imports) was 57.3 million tons in 1989 compared with 59.0 million tons in 1988. Stocks of ferrous scrap held by steel mills and ferrous foundries increased in 1989.

The percentage of scrap consumed in the United States to produce a ton of raw steel was about 60% in 1989. Of the steel scrap consumed by domestic steel mills, about three-fourths was purchased from sources outside the steel plant in 1989.

PRICES

Based on average composite delivered prices per long ton quoted weekly and monthly by the American Metal Market (AMM), No. 1 heavy melting steel scrap cost $107.30 in 1989, ranging from a low of $96.67 in November to a high of $116.07 in February. Based on Iron Age data, No. 1 heavy melting steel scrap cost $107.66 in 1989, ranging from $97.00 in December to $116.08 in February. The average composite price for No. 1 heavy melting steel scrap in 1989 was lower compared with that of 1988, by 2% based on AMM data and by 1% based on Iron Age data. Continued strong demand, primarily from European consumers, propelled the price of nickel-bearing stainless steel scrap to a record high in 1989. In the Pittsburgh, PA, area, prices paid by consumers for the bellwether 18-8 grade peaked at $1,675 to $1,700 per gross ton in March.

In 1989, the average price for total ferrous scrap exports increased 6% to $142.42 per short ton compared with that of 1988 while that of total imports increased 3% to $133.19 per short ton.

FOREIGN TRADE

For 1989, the foreign trade tables were based on the Harmonized Tariff Schedule (HTS) that became effective January 1, 1989. HTS increased the number of classes for both exports and imports (see the Bureau of Mines March 1989 Mineral Industry Surveys on Iron and Steel Scrap for more details). 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 1989 for all classes of ferrous scrap (including rerolling material and ships, boats, and other vessels for scrapping) reached a record high of $1.63 billion in value and 11.4 million tons in quantity. This was an increase of 28% in value and 20% in quantity compared with the 1988 surplus of $1.27 billion in value and 9.43 million tons in quantity. The balance of trade for all U.S. merchandise [exports (f.a.s.) less imports (customs value)] showed a deficit of $109 billion in 1989, down from a deficit of $119 billion in 1988.

The quantity and value of both exports and imports reached record highs in 1989. Both the quantity and value of exports in 1989 increased by a larger percentage than imports compared with that of 1988.

Total U.S. exports of ferrous scrap (excluding rerolling material; ships, boats, and other vessels for scrapping; stainless steel; and alloy steel) in 1989 went to 54 countries and totaled 11,435,701 tons valued at $1,319,041,944, which averaged $115.34 per ton. Six countries received 77% of the total quantity. The largest tonnages went to Turkey, 3,225,272 tons; the Republic of Korea, 2,779,185 tons; India, 943,828 tons; Canada, 936,626 tons; Mexico, 543,136 tons; and Japan, 357,539 tons. The value of scrap exports to these six countries was $1,012,605,738; 77% of the total value.

Total U.S. exports of stainless steel scrap in 1989 went to 30 countries and consisted of 291,609 tons valued at $320,682,621 averaging $1,099.70 per ton. Six countries received 83% of the total quantity. The largest tonnages went to Japan, 76,426 tons; the Republic of Korea, 58,537 tons; Spain, 51,492 tons; Canada, 23,929 tons; the Netherlands, 16,665 tons; and the Federal Republic of Germany, 15,293 tons. The value of stainless scrap exports to these six countries was $275,874,190, 86% of the total value.

U.S. exports of alloy steel scrap (excluding stainless steel) in 1989 were shipped to 42 countries. The total comprised 562,921 tons valued at $108,918,315, which averaged $193.49 per ton. Six countries received 68% of the total quantity; the largest tonnages went to the Republic of Korea, 149,017 tons; Canada, 72,487 tons; Taiwan, 49,555 tons; Japan, 43,713 tons; Sweden, 33,991 tons; and Saudi Arabia, 33,120 tons. The value of alloy steel scrap to these six countries was $64,812,644, 60% of the total value.

Total U.S. imports for consumption of iron and steel scrap were supplied by 31 countries in 1989. They contained 11,889 tons of tinplate waste or scrap valued at $1,902,585.

WORLD REVIEW

World demand for iron and steel scrap increased slightly in 1989, but for the second consecutive year it reached a new alltime high. Demand for ferrous scrap, on a percentage basis, was higher in developing countries than in industrialized or western world countries. The largest increase in demand on a percentage basis came from the Republic of Korea.

The United States continued to be the leading exporting country of iron and steel scrap. France, the Federal Republic of Germany, the U.S.S.R., and the United Kingdom were also major exporters of ferrous scrap.

The International Iron and Steel Institute (IISI) estimated that the world steel industry achieved a 40% recycling rate in 1989. The estimated 300 million tons of secondary raw materials consumed represented significant energy savings and reduction in steel mill emissions and in wastes sent to landfills.

The recycling rate for steel production was much higher than that for other basic engineering materials.

Metal Bulletin, United Kingdom, held its first international scrap and secondary metals conference in Padua, Italy, in September. Also, the planning and building of direct reduction plants continued in areas such as India and Venezuela.

IISI published its third survey on cokemaking capacity in the western world. The report included details on plant ownership, location, number of batteries and ovens, age profile and physical dimensions, and the various processes employed in the production of coke in 35 countries.[7]

The total number of shredders in operation worldwide in 1989 was estimated at 601 (see table 17). The United States was the world's leading country in the total number of shredders, power, and tonnage capacity. Japan followed the United States in the total number of shredders in operation. The total number of shredders in the European Community was about equal to that in the United States. The most significant development was in the United Kingdom where 57 existing shredders would be augmented by an additional 3. Although not indicated in table 17, new shredders were reported also in Taiwan and Singapore.

CURRENT RESEARCH

Nucor Corp., Darlington, SC, began operating the world's first thin-slab caster for sheet steel production in June at its new minimill plant in Crawfordsville, IN. Other companies had been planning to open new plants or modify existing mills to take advantage of this new technology. They included Co-Steel Inc., Toronto, Ontario, Canada; Falck SpA, Sesto San Giovanni, Italy; Avesta AB, Stockholm, Sweden; Yieh United Steel Corp., Kaohsiung, Taiwan; and New Jersey Steel Corp., Sayreville, NJ. Additionally, Birmingham Steel Corp., Birmingham, AL, had announced earlier in the year that with the help of international partners, it would build a ministrip mill. However, that decision was being reviewed at yearend.

Development of processes to extract iron from ore without the use of coke on a low economy-of-scale basis (500,000 tons per year), such as the Corex process and the iron carbide process, would likely result in a significant increase of "market-sized" flat-rolling steel mills throughout the world.[8] Industrial-scale production of the Corex process began at Iscor Ltd.'s Pretoria Works in the Republic of South Africa in 1989, and the world's first commercial-scale iron carbide plant would likely be in production in the United States by midyear 1991.

In September, General Motors Corp.'s Central Foundry Div., Defiance, OH, held a dedication ceremony for the first plasma melter in the foundry industry. To construct the plasma melter, General Motors, in conjunction with Westinghouse Electric Corp. and Modern Equipment Co., modified an existing cupola furnace and added six 1.5-megawatt direct current plasma torches to the tuyere sections to provide the needed heat source.[9]

Schott Incorporated, the coowner of a proprietary hot metal technology, was using a recuperative hot blast cupola for producing steelmaking quality molten iron. Charge materials to the cupola consisted of carbon-bearing, iron oxide agglomerates that were both self-reducing and self-fluxing and charge carbon that consisted of anthracite coal briquettes. This technology could be used by ironmaking facilities having annual capacities ranging from 100,000 tons per year to those with no upper limit on output. One concept under consideration was combining (duplexing) the molten iron with purchased ferrous scrap as a metallic charge to electric furnaces.[10]

The American Iron and Steel Institute organized a forum to identify research opportunities. Direct steelmaking, near net shape casting, and intelligent processing were selected as the most important areas to address.

Carnegie Mellon's Center for Materials Production (CMP), Pittsburgh, PA, was developing a cofunded project to determine the cost effectiveness of the CONSTEEL process for the continuous feeding, preheating, melting, and refining of steel scrap in the electric arc furnace. The project, with Florida Steel Corp., Tampa, FL, and seven sponsors, sought to develop an economic and energy analysis of the process.[11] Also, CMP held a symposium in Pittsburgh, PA, in November on commercially available processes and emerging technologies for treating electric arc furnace dust. The meeting included a thorough review of laws and regulations. Additionally, CMP sponsored a shredder residue planning meeting in Atlanta, GA, in October. The purpose of the meeting was to provide input to CMP and the Institute of Scrap Recycling Industries Inc., Washington, DC, so that an industry-wide meeting could be arranged to present and discuss solutions and useful research and development programs for the auto shredder residue (fluff) disposal problem.

In September, Tokyo Steel Manufacturing Co. Ltd., Tokyo, Japan, began operating what was believed to be the world's largest direct current (DC) arc furnace at its Kyushu Works. Initial monthly production of the 130-metric-ton DC arc furnace was 75,000 to 80,000 metric tons, tapping up to 23 heats per day.

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 despite a slight decrease in 1989 to about 57 million short tons. The total market for U.S. scrap is forecast to range from 59 mil-

lion 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.

[2] Federal Register. Environmental Protection Agency. Proposed Rules; Air Pollution. V. 54, No. 243, Dec. 20, 1989, pp. 52190-52304.

[3] ———. Environmental Protection Agency. Proposed Rules; Land Disposal Restrictions for Third Scheduled Wastes. V. 54, No. 224, Nov. 22, 1989, pp. 48372-48529.

[4] The Port Authority of New York and New Jersey. Export Markets for Post Consumer Secondary Materials. The Port Authority of NY and NJ, v. 1 and 2, 1989, 97 pp. and 328 pp.

[5] U.S. Congress, Office of Technology Assessment. Facing America's Trash: What Next for Municipal Sold Waste? GPO, Washington, DC. OTA-0-424 and 425, Oct. 1989, 377 pp. and 40 pp.

[6] Schram, K. Automotive Recyclers Supporting Environmental Protection in 90's. Recycling Today, v. 28, No. 1, Jan. 1990, p. 46.

[7] International Iron and Steel Institute (IISI). Western World Cokemaking Capacity. IISI, Brussels, Belgium, 1989, 67 pp.

[8] Marcus, P. F. Impact of Crawfordsville. 33 Metal Producing, v. 27, No. 8, Aug. 1989, p. 7.

[9] Balcerek, T. GM Melts its Metal in Plasma. American Metal Market, v. 97, No. 243, Dec. 15, 1989, pp. 4, 10.

[10] Schott Incorporated. Preliminary Engineering Study: Production of 240,000 TPY of Liquid Steel from an Electric Arc Furnace Shop Using Molten Iron and Scrap. Schott Inc., Pittsburgh, PA, June 12, 1989, 24 pp.

[11] Center for Materials Production. CONSTEEL Continuous Steel Scrap Preheating and Melting Process. CMP Newsletter, Pittsburgh, PA, v. 5, No. 4, Aug. 1989, p. 1.

TABLE 2

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP AND PIG IRON IN 1989, 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	369	19	27	54	443	19	60
Cut structural and plate	1,249	614	460	—	2,300	35	136
No. 1 heavy melting steel	8,594	−636	6,680	173	14,514	401	878
No. 2 heavy melting steel	3,257	145	910	2	4,392	13	305
No. 1 and electric-furnace bundles	5,899	78	982	4	6,111	760	550
No. 2 and all other bundles	811	65	131	—	986	44	47
Electric furnace, 1 foot and under (not bundles)	60	220	(1)	(1)	278	—	11
Railroad rails	221	15	26	2	265	—	9
Turnings and borings	900	92	158	—	1,132	25	51
Slag scrap (Fe content 70%)	1,164	451	1,844	1	3,202	212	158
Shredded or fragmentized	3,028	1,687	74	—	4,742	—	384
No. 1 busheling	1,563	216	145	(1)	1,915	49	100
All other carbon steel scrap	1,988	945	4,842	31	7,168	624	286
Stainless steel scrap	605	21	483	—	1,077	18	63
Alloy steel (except stainless)	99	135	602	10	812	26	112
Ingot mold and stool scrap	403	106	402	295	910	322	164
Machinery and cupola cast iron	2	−1	3	(1)	37	9	7
Cast-iron borings	147	(1)	1	(1)	123	12	3
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	248	−13	350	24	518	114	123
Other mixed scrap	557	131	86	(1)	765	33	69
Total[2]	31,162	4,292	18,206	594	[3]51,688	2,716	3,516
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	668	2	121	(1)	800	(1)	42
Cut structural and plate	464	13	67	(1)	537	—	52
No. 1 heavy melting steel	185	—	86	—	258	3	20
No. 2 heavy melting steel	137	2	—	—	158	—	10
No. 1 and electric-furnace bundles	16	—	(1)	—	17	—	2
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	66	—	11	—	76	—	6
Railroad rails	21	—	1	—	20	—	1
Turnings and borings	34	—	10	—	32	4	2
Slag scrap (Fe content 70%)	—	—	—	—	(1)	—	—
Shredded or fragmentized	54	—	—	—	56	—	(1)
No. 1 busheling	76	—	—	—	81	—	2
All other carbon steel scrap	367	—	188	—	547	—	28
Stainless steel scrap	34	2	37	—	79	1	10

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 1989, 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—Continued							
Alloy steel (except stainless)	86	—	157	—	243	2	74
Ingot mold and stool scrap	—	—	—	—	—	—	—
Machinery and cupola cast iron	8	41	(1)	—	49	—	8
Cast-iron borings	73	—	16	—	62	—	2
Motor blocks	(1)	—	1	—	1	—	—
Other iron scrap	31	—	75	—	95	9	10
Other mixed scrap	—	—	11	—	11	—	(1)
Total[2]	2,320	60	780	1	3,123	19	272
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	1,129	46	151	7	1,368	1	56
Cut structural and plate	1,203	23	73	(1)	1,308	(1)	78
No. 1 heavy melting steel	157	109	361	—	402	229	38
No. 2 heavy melting steel	167	—	70	—	209	29	4
No. 1 and electric-furnace bundles	209	205	60	—	475	—	6
No. 2 and all other bundles	172	—	1	—	178	—	23
Electric furnace, 1 foot and under (not bundles)	29	7	12	—	43	—	1
Railroad rails	270	2	2	—	275	2	32
Turnings and borings	431	1	23	—	446	4	48
Slag scrap (Fe content 70%)	23	—	—	—	23	—	1
Shredded or fragmentized	1,256	82	—	—	2,051	—	57
No. 1 busheling	530	100	17	—	642	—	16
All other carbon steel scrap	666	—	92	3	759	4	46
Stainless steel scrap	14	—	12	—	27	1	21
Alloy steel (except stainless)	29	—	12	—	42	(1)	14
Ingot mold and stool scrap	217	23	230	1	449	29	26
Machinery and cupola cast iron	1,165	243	450	29	1,894	5	140
Cast-iron borings	662	104	162	—	914	14	36
Motors blocks	482	61	724	—	1,231	15	47
Other iron scrap	735	63	2,850	(1)	3,631	45	97
Other mixed scrap	532	89	446	1	1,030	23	70
Total[2]	10,078	1,158	5,746	42	17,398	402	857
TOTAL—ALL TYPES OF MANUFACTURERS[2]							
Carbon steel:							
Low-phosphorus plate and punchings	2,166	67	298	61	2,611	20	158
Cut structural and plate	2,916	650	599	1	4,145	35	267
No. 1 heavy melting steel	8,936	-527	7,126	173	15,174	632	936
No. 2 heavy melting steel	3,561	147	980	2	4,758	41	320
No. 1 and electric-furnace bundles	6,123	283	1,042	4	6,603	760	558

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 1989, 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[2]—Continued							
Carbon steel—Continued							
No. 2 and all other bundles	983	65	132	—	1,164	44	70
Electric furnace, 1 foot and under (not bundles)	155	227	23	([1])	397	—	18
Railroad rails	512	17	29	2	559	2	42
Turnings and borings	1,364	93	192	—	1,611	33	102
Slag scrap (Fe content 70%)	1,187	451	1,844	1	3,225	212	159
Shredded or fragmentized	4,337	1,768	74	—	6,849	—	441
No. 1 busheling	2,169	316	162	([1])	2,638	49	118
All other carbon steel scrap	3,020	945	5,122	34	8,474	628	360
Stainless steel scrap	653	23	532	—	1,184	20	94
Alloy steel (except stainless)	214	135	771	10	1,097	28	199
Ingot mold and stool scrap	620	129	632	296	1,359	351	189
Machinery and cupola cast iron	1,175	283	454	29	1,980	14	155
Cast-iron borings	882	105	179	([1])	1,099	27	42
Motor blocks	483	61	725	—	1,232	15	47
Other iron scrap	1,014	50	3,275	24	4,244	168	230
Other mixed scrap	1,089	221	543	1	1,806	56	139
Grand total[2]	43,560	5,510	24,732	637	[3]72,209	3,136	4,644

[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 7.7 million short tons; that in open-hearth furnaces is understated by about 0.9 million short tons.

TABLE 3

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1989

(Thousand short tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS					
Pig iron	2,383	55,873	56,854	1,540	191
MANUFACTURERS OF STEEL CASTINGS					
Pig iron	27	—	26	2	6
IRON FOUNDRIES AND MISCELLANEOUS USERS					
Pig iron	1,606	—	1,507	54	108
TOTAL-ALL TYPES OF MANUFACTURERS					
Pig iron[1]	4,016	55,873	58,387	1,595	304
Direct-reduced or prereduced iron	1,830	—	1,793	5	47

[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 1989, 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]	3,314	—	—	—	—	—	3,314	—
Basic oxygen process[3]	16,712	54,431	—	—	—	—	16,712	54,431
Open-hearth furnace[4]	947	1,744	—	—	—	—	947	1,744
Electric furnace	[5]30,277	345	2,886	26	7,435	789	40,597	1,159
Cupola furnace	—	49	234	—	9,854	379	10,088	429
Other (including air furnace)[6]	436	10	3	—	112	23	551	33
Direct castings[7]	—	275	—	—	—	316	—	591
Total[1]	51,688	56,854	3,123	26	17,398	1,507	72,209	58,387

[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 was understated by about 0.9 million tons and pig iron was understated by about 1.6 million tons.
[5] Internal evaluation indicates that scrap consumption in electric furnaces operated by manufacturers of pig iron and raw steel and castings is understated by approximately 7.7 million short tons.
[6] Includes vacuum melting furnaces and miscellaneous uses.
[7] Includes ingot molds and stools.

TABLE 5

PROPORTION OF IRON AND STEEL SCRAP AND PIG IRON USED IN FURNACES IN THE UNITED STATES IN 1989

(Percentage)

Type of furnace	Scrap	Pig iron
Basic oxygen process	23.5	76.5
Open-hearth furnace	35.2	64.8
Electric furnace	99.9	.1
Cupola furnace	97.2	2.8
Other (including air furnace)	96.7	3.3

TABLE 6

IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1989, BY REGION AND STATE

(Thousand short tons)

Region and State	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	1,525	83	439	3	2,050	54	1,996
Pennsylvania	5,833	345	4,318	93	10,590	650	9,939
Total[2]	7,359	428	4,757	96	12,640	706	11,933
North Central:							
Illinois	4,408	1,243	2,378	16	8,045	98	7,947
Indiana	4,500	−41	5,127	4	9,590	848	8,742
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	3,484	233	1,353	([4])	5,069	1	5,068
Michigan	3,978	487	1,852	16	6,334	153	6,180
Ohio	6,648	737	3,815	396	11,596	876	10,720
Total[2]	23,019	2,700	14,525	431	40,633	1,976	38,657
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	4,364	1,085	1,898	27	7,373	117	7,258
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	5,978	1,298	2,703	55	10,034	319	9,716
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,840	40	850	28	3,758	20	3,738
Grand total[2]	43,560	5,510	24,732	637	74,439	3,136	71,303

[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 1989, 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	1,076	2	52	([3])	922	98	2,050	101
Pennsylvania	8,362	5,403	176	4	1,348	675	9,886	6,083
Total[2]	9,438	5,406	228	4	2,271	773	11,937	6,184
North Central:								
Illinois	5,898	2,552	209	—	1,853	83	7,960	2,635
Indiana	7,428	19,037	313	4	996	98	8,738	19,139
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	2,104	1	475	5	2,519	147	5,098	153
Michigan	3,754	5,726	7	—	2,414	130	6,174	5,856
Ohio	7,524	12,430	499	10	2,702	156	10,725	12,595
Total[2]	26,709	39,745	1,502	19	10,484	613	38,695	40,378
South Atlantic:								
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	6,044	6,248	15	—	1,310	48	7,369	6,297
South Central:								
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	6,969	4,095	614	1	2,208	56	9,790	4,152
Mountain and Pacific:								
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	2,528	1,360	765	1	1,126	16	4,419	1,377
Grand total[2]	51,688	56,854	3,123	26	17,399	1,507	72,209	58,387

[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.

TABLE 8

U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1989, 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	103	8	55	33	8	207	19
Pennsylvania	468	43	62	104	14	691	68
Total[1]	571	51	117	137	22	899	87
North Central:							
Illinois	400	—	13	41	7	460	17
Indiana	455	2	10	116	2	585	89
Iowa, Kansas, Minnesota, Missouri, Nebraska	188	(2)	2	19	31	240	15
Michigan	218	1	5	41	10	275	17
Ohio	475	26	30	66	10	606	24
Wisconsin	13	3	—	13	—	29	5
Total[1]	1,748	32	59	296	59	2,195	168
South Atlantic:							
Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	353	10	(2)	94	9	466	34
South Central:							
Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	690	(2)	9	93	13	805	12
Mountain and Pacific:							
Arizona, California, Colorado, Hawaii, Oregon, Utah, Washington	187	1	14	43	35	280	3
Grand total[1]	3,548	94	199	664	139	4,644	304

[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 1989

(Per long ton)

Month	Chicago	Pittsburgh	Philadelphia	Composite price[1]
January	$114.10	$117.86	$109.74	$113.90
February	118.32	119.89	110.00	116.07
March	113.00	115.91	108.65	112.52
April	113.00	114.10	109.50	112.20
May	113.00	114.55	111.73	113.09
June	113.00	109.27	112.73	111.67
July	108.00	103.00	111.00	107.33
August	108.00	102.83	103.74	104.86
September	108.00	98.85	101.00	102.62
October	101.09	96.64	101.00	99.58
November	96.00	93.00	101.00	96.67
December	94.50	95.65	101.00	97.05
Average 1989	108.33	106.80	106.76	107.30
Average 1988	113.47	113.78	99.69	108.98

[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	1985		1986		1987		1988		1989[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	446	38,445	365	31,436	331	30,516	628	62,367	1,033	106,296
China	387	32,793	340	28,506	249	23,423	31	5,010	49	11,129
Italy	307	30,250	286	26,177	175	15,675	89	12,926	162	27,446
Japan	2,110	199,135	1,725	170,015	986	123,051	649	148,362	478	139,245
Korea, Republic of	1,978	160,674	2,989	247,055	2,630	213,550	2,358	271,155	2,987	404,815
Mexico	597	57,535	318	29,981	501	48,278	916	101,785	574	63,585
Spain	910	72,312	673	51,771	417	42,503	404	108,067	658	119,784
Taiwan	414	45,163	667	74,387	426	46,629	669	89,021	407	64,386
Turkey	955	80,133	1,417	115,334	2,254	195,971	1,985	230,853	3,225	393,503
Venezuela	471	36,384	483	36,673	150	10,273	258	26,109	82	8,166
Other	1,373	165,360	2,441	242,514	2,247	217,149	2,112	296,298	2,636	410,288
Total[3]	9,950	918,186	11,704	1,053,849	10,367	967,018	10,098	1,351,955	12,290	1,748,643

[1] Excludes rerolling material and ships, boats, and other vessels for scrapping.
[2] U.S. exports were shipped to 63 countries.
[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)

Class	1985		1986		1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Export:										
No. 1 heavy melting scrap	2,766	218,593	2,922	230,519	2,446	200,980	2,400	255,370	2,789	308,485
No. 2 heavy melting scrap	767	58,537	797	58,879	579	45,994	691	68,102	1,050	109,101
No. 1 bundles	185	17,172	155	13,876	167	14,890	74	8,852	103	12,990
No. 2 bundles	306	21,160	301	21,095	366	23,623	371	31,567	462	41,505
Stainless steel scrap	180	104,898	165	90,066	172	94,025	243	239,807	292	320,683
Shredded steel scrap	2,559	220,320	3,495	293,040	3,314	298,259	2,910	343,188	3,854	486,999
Borings, shovelings, turnings	875	56,314	731	43,955	528	28,835	515	36,230	743	55,765
Other steel scrap[1]	1,646	162,484	2,048	209,094	2,033	195,197	2,042	277,281	1,774	276,420
Iron scrap	666	58,707	1,091	93,325	762	65,217	852	91,557	1,224	136,694
Total[2]	9,950	918,186	11,704	1,053,849	10,367	967,018	10,098	1,351,955	12,290	1,748,643
Ships, boats, and other vessels (for scrapping)	131	6,627	212	16,475	246	20,264	330	43,548	126	16,698
Rerolling material	110	15,604	78	11,302	57	8,863	42	7,330	59	11,397
Total exports[2]	10,191	940,416	11,994	1,081,626	10,670	996,145	10,470	1,402,833	12,476	1,776,738
Imports for consumption:										
Iron and steel scrap	611	46,480	724	49,073	843	82,016	1,038	133,577	1,120	149,109

[1] Includes terneplate and tinplate.

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

TABLE 12

U.S. EXPORTS OF REROLLING MATERIAL (SCRAP), BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1985		1986		1987		1988		1989	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	(1)	41	(1)	44	1	170	1	134	4	729
China	19	2,497	—	—	—	—	—	—	—	—
Korea, Republic of	—	—	—	—	(1)	8	—	—	—	—
Mexico	90	12,511	77	11,186	45	7,346	40	6,794	52	9,962
Turkey	—	—	—	—	10	1,111	—	—	—	—
Other	1	555	(1)	72	1	228	1	401	4	705
Total[2]	110	15,604	78	11,302	57	8,863	42	7,330	59	11,397

[1] Less than 1/2 unit.

[2] 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	1988		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Austria	18	$39	18	$27
Belgium-Luxembourg	36,398	430	—	—
Canada	841,888	113,048	951,063	121,454
France	4	5	29,508	207
Germany, Federal Republic of	43,428	225	3,747	1,215
Japan	15,924	1,577	65,794	5,885
Mexico	48,068	11,176	56,863	13,217
Netherlands	28,368	3,474	3,573	1,512
Sweden	24	3	90	211
United Kingdom	11,429	1,297	357	905
Other	12,272	2,303	8,508	4,477
Total[2]	1,037,821	133,577	1,119,521	149,109

[1] Includes tinplate and terneplate.
[2] Data may not add to totals shown because of independent rounding.

TABLE 14

IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
North America:					
Canada[2]	9,298	8,967	8,627	9,039	e9,400
United States[3 4 5]	65,702	70,493	65,856	68,303	76,822
Latin America:[6]					
Argentina	1,281	1,264	1,253	1,444	1,462
Brazil	6,971	7,714	7,934	8,068	8,461
Chile	237	241	152	241	320
Colombia	378	433	491	593	619
Ecuador	21	21	20	30	28
Mexico	3,181	3,413	3,253	2,844	3,772
Peru	343	257	292	343	304
Trinidad and Tobago	—	80	152	169	280
Uruguay	53	51	41	40	41
Venezuela	1,292	1,195	996	1,284	1,423
Central America, not further detailed	126	r111	r152	r151	137
Europe:					
European Community:[7]					
Belgium[8]	3,880	3,430	2,956	3,009	e3,500
Denmark[9]	718	656	776	714	719
France[5 10]	37,135	37,109	37,128	7,398	7,544
Germany, Federal Republic of[4]	20,510	20,517	18,795	17,813	20,445
Greece	e300	e300	e1,220	1,116	1,087
Ireland[11]	208	254	256	271	334
Italy	17,380	17,133	16,144	16,407	17,413
Luxembourg	1,857	1,761	1,644	1,461	1,624
Netherlands	1,797	1,658	41,436	1,442	1,502
Portugal	e600	e600	e420	435	516
Spain	10,911	11,152	9,548	9,405	9,904
United Kingdom	10,578	7,712	7,341	r7,783	8,553
European Free Trade Association:					
Austria[8]	1,851	1,681	1,615	1,624	1,714
Finland[8]	831	838	837	1,606	1,434
Norway[8 10]	638	597	e600	697	762
Sweden[3 8 10]	r e3,300	3,380	3,240	3,255	3,297
Switzerland[e]	915	915	1,100	1,100	1,200
Council for Mutual Economic Assistance:					
Bulgaria[e]	850	850	850	950	1,000
Czechoslovakia[3 4 10]	8,354	8,471	8,422	8,214	8,958
German Democratic Republic[3 4 8 10]	5,779	5,593	5,516	5,642	e5,700
Hungary	2,705	2,754	2,912	2,723	2,465
Poland[8]	9,630	9,490	10,070	r10,214	10,062
Romania[e]	4,300	4,280	4,300	4,500	4,700
U.S.S.R.	e64,500	66,139	77,200	78,200	79,400
Other: Yugoslavia[4 8 10]	e2,500	2,447	r2,523	r1,596	1,701
Africa: South Africa, Republic of[e 3]	3,000	3,300	3,500	3,500	3,750

See footnotes at end of table.

TABLE 14—Continued

IRON AND STEEL SCRAP CONSUMPTION IN SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
Asia:					
China[e]	10,900	11,700	12,500	13,500	14,000
India[e]	4,060	4,300	4,400	4,400	4,500
Japan[4]	47,934	48,685	44,378	[r]44,793	47,373
Korea, Republic of[e]	3,600	3,700	3,800	4,000	4,500
Taiwan[e 12]	1,700	1,700	1,800	2,000	2,250
Turkey[11]	1,863	2,127	[e]2,200	[e]2,500	[e]2,750
Oceania:					
Australia[e]	2,050	2,100	2,000	2,000	2,200
New Zealand[e]	180	150	150	150	160
Total	[r]346,197	[r]351,719	[r]350,946	[r]356,967	380,086

[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, 1988, v. 16, New York, 1989, 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] Excludes scrap consumed outside the steel industry.

[5] Source: U.S. Bureau of Mines.

[6] 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.

[7] Portugal and Spain became members of the European Community on Jan. 1, 1986.

[8] Excludes scrap consumed in iron foundries.

[9] 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.

[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] 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.

[12] Excludes a substantial tonnage derived from shipbreaking, possibly in the order of several million tons annually, for electric-furnace-equipped steel mills.

TABLE 15

IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
North America:					
Canada	876	968	[2]1,016	[2]1,198	[2]1,854
United States[2 3]	9,556	10,060	11,782	10,424	10,140
Latin America:					
Cuba[4]	159	129	122	165	[e]150
Mexico[2]	17	[r]24	24	25	52
Europe:					
European Community:[5]					
Belgium-Luxembourg	853	811	725	829	1,008
Denmark	258	298	202	246	328
France	4,525	4,366	3,484	3,558	4,070
Germany, Federal Republic of	3,602	3,756	3,768	4,650	5,067
Greece	1	1	1	[2]2	[2]3
Ireland	47	55	45	29	[2]35
Italy	21	11	8	[r]18	31
Netherlands	1,851	2,023	2,192	2,474	[2]3,150
Portugal	10	18	12	8	[2]14
Spain	4	1	1	18	66
United Kingdom	4,758	4,982	4,230	3,950	3,978
European Free Trade Association:					
Austria	23	35	24	101	52
Finland	11	11	—	—	—
Iceland	12	7	3	11	[2]5
Norway	23	10	9	[r]13	[2]24
Sweden	24	24	32	49	106
Switzerland	118	110	[2]67	[2]96	[2]86
Council for Mutual Economic Assistance:					
Bulgaria	53	42	4	39	40
Czechoslovakia[4]	205	155	112	110	180
German Democratic Republic[4]	40	29	8	[e]10	—
Hungary	87	30	7	118	166
Poland[2]	194	88	81	[e]90	[e]75
U.S.S.R.[2]	3,756	3,655	4,506	4,299	3,571
Other: Yugoslavia	157	191	174	405	399
Africa:					
Algeria[2]	91	93	164	166	[e]175
Morocco[2]	101	89	57	69	101
South Africa, Republic of[4]	53	74	161	78	[e]100

See footnote at end of table.

TABLE 15—Continued

IRON AND STEEL SCRAP EXPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
Asia:					
Bahrain[e]	10	10	10	10	10
Brunei	12	9	[e]10	[e]10	[e]10
China[4]	15	24	3	121	[e]150
Cyprus	15	16	15	5	18
Hong Kong[2]	331	332	304	353	409
India[e]	20	20	20	20	25
Indonesia[2]	1	1	7	3	[e]5
Japan	161	183	508	416	459
North Korea[4]	[e]10	2	28	20	[e]25
Korea, Republic of[2]	149	82	79	46	45
Kuwait	136	[e]100	[e]100	[e]100	[e]100
Malaysia[2]	22	24	51	49	[e]50
Philippines[2]	2	1	1	1	2
Saudi Arabia[e]	35	35	35	50	50
Singapore[2]	120	184	100	172	293
Taiwan[2]	223	428	310	108	83
Thailand[2]	4	4	6	5	5
Turkey	3	[2]4	5	6	8
United Arab Emirates[e]	10	10	10	10	10
Vietnam[4]	2	61	101	93	[e]95
Oceania:					
Australia[2]	409	555	623	965	[e]1,000
New Zealand[2]	4	[e]2	4	3	2
Total	33,180	34,233	35,351	[r]35,814	37,880

[e] Estimated. [r] Revised.

[1] Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1988, v. 16, New York, 1989, 28 pp.

[2] Source: Official trade returns of subject country.

[3] Includes rerolling material.

[4] Partial figure; compiled from import statistics of trading partner countries.

[5] Portugal and Spain became members of the European Community on Jan. 1, 1986.

TABLE 16

IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
North America:					
Canada	1,253	974	[2]827	[2]858	1,269
United States[2]	577	611	724	843	1,038
Latin America:					
Argentina[2]	2	1	1	1	1
Brazil[2]	34	35	541	161	[e]165
Chile	[e]10	[e]10	[2]19	[e]25	[e]20
Colombia[2]	48	[e]50	[e]50	[e]50	[e]50
Cuba[3]	106	109	98	[e]100	[e]100
Mexico[2]	696	[r]926	475	[e]500	[e]1,000
Peru[e]	20	20	20	20	20
Venezuela[2]	400	547	[e]550	[e]550	[e]700
Europe:					
European Community:[4]					
Belgium-Luxembourg	1,843	1,642	1,347	1,746	2,097
Denmark	146	53	133	98	129
France	449	508	389	572	883
Germany, Federal Republic of	1,935	1,776	1,517	1,311	1,551
Greece	362	345	502	[2]720	[2]470
Ireland	97	150	134	164	[2]197
Italy	6,047	6,368	5,232	5,413	5,578
Netherlands	527	646	936	1,148	[2]1,078
Portugal	132	116	114	101	[2]198
Spain	5,531	6,776	4,784	4,702	4,966
United Kingdom	37	55	52	[2]80	101
European Free Trade Association:					
Austria	400	263	127	76	112
Finland	36	125	71	60	18
Norway	14	12	7	35	180
Sweden	925	976	769	870	876
Switzerland	301	265	[2]357	[2]150	[2]94
Council for Mutual Economic Assistance:					
Czechoslovakia[3]	172	[r]49	[r]47	[e]50	[e]50
German Democratic Republic[3]	1,141	977	1,087	995	[e]1,000
Hungary	22	15	9	15	6
Poland[2]	8	6	6	7	3
U.S.S.R.[5]	49	28	49	[e]50	48
Other: Yugoslavia	861	804	718	759	822
Africa:					
Egypt[2]	1	2	2	2	[e]2
Morocco[2]	1	2	4	2	2
South Africa, Republic of[3]	61	8	[e]50	[e]25	[e]30

See footnotes at end of table.

TABLE 16—Continued

IRON AND STEEL SCRAP IMPORTS, BY SELECTED COUNTRIES[1]

(Thousand short tons)

Continent, country group, and country	1984	1985	1986	1987	1988
Asia:					
Bahrain[e]	3	3	3	3	3
China[3]	74	547	716	451	[e]500
Hong Kong[2]	31	22	37	48	95
India[e]	500	800	800	1,000	1,000
Indonesia[2]	268	210	524	508	[e]550
Japan	4,429	3,587	3,554	2,599	1,974
Korea, Republic of[2]	2,294	2,640	3,434	3,879	4,290
Malaysia[2]	53	37	5	244	[e]250
Pakistan[2]	134	169	162	647	[e]700
Philippines[2]	1	1	94	120	103
Singapore[2]	87	72	230	140	201
Syria[2]	2	[e]15	[e]15	[e]15	[e]15
Taiwan[2]	637	766	1,351	1,040	1,384
Thailand[2]	545	725	612	996	1,277
Turkey	1,144	[2]1,323	[2]1,983	3,121	3,348
Oceania:					
Australia	13	1	1	[e]1	[e]1
New Zealand[2]	3	3	6	[e]6	[e]4
Total	34,462	36,171	35,275	[r]37,077	40,549

[e] Estimated. [r] Revised.

[1] Unless otherwise noted, source is United Nations Economic Commission for Europe. Annual Bulletin of Steel Statistics for Europe, 1988, v. 16, New York, 1989, 38 pp.

[2] Source: Official trade returns of subject country.

[3] Partial figure; compiled from export statistics of trading partner countries.

[4] Portugal and Spain became members of the European Community on Jan. 1, 1986.

[5] Partial figure; compiled from incomplete returns of subject country and export statistics of trading partner countries.

TABLE 17

SHREDDER PROCESSING CAPACITY IN SELECTED COUNTRIES IN 1989[1]

Country	Shredder data						
	Total number of shredders in operation, including mills	Total power requirements, horsepower	Total annual capacity/ output, thousand metric tons[2]	Average power requirements per shredder, horsepower	Average annual capacity/ output per shredder, thousand metric tons	Average power requirements, horsepower per metric ton of annual capacity/output	Number of new plants under construction
North America:cNA							
Canada	22	60,000	1,500	2,700	68	.040	—
Mexico	4	6,600	e145	1,700	e36	e.046	—
United States	e190	e500,000	e13,000	e2,600	e68	e0.038	NA
Total	e216	e566,600	e14,645	e2,600	e68	e.039	—
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	—
Total	8	16,000	e364	2,000	e45	e.044	—
Western Europe:							
Austria	6	e7,500	120	e1,250	20	e.063	—
Belgium-Luxembourg	9	15,700	324	1,700	36	.048	—
Denmark	5	6,400	100	1,300	20	.064	—
Finland	2	e4,500	35	e2,300	17	e.130	1
France	34	45,790	933	1,300	27	.049	—
Germany, Federal Republic of	42	54,184	1,500	1,300	36	.036	1
Ireland	1	1,250	30	1,250	30	.042	—
Italy	14	20,000	700	1,400	50	.029	2
Netherlands	12	12,500	450	1,000	37	.028	—
Norway	3	2,900	112	970	37	.026	—
Portugal	2	e2,250	e47	e1,100	e24	e.048	—
Spain	12	14,500	e310	1,200	e26	e.047	—
Sweden	3	e8,500	e180	e2,800	e60	e.047	2
Switzerland	4	e5,000	e110	e1,250	e27	e.045	—
Turkey	1	2,000	e43	2,000	e43	e.047	—
United Kingdom	57	91,000	1,700	1,600	30	.054	3
Total	207	e293,974	e6,694	e1,400	e32	e.044	9
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	—
Total	11	e21,300	448	e1,900	e41	e.048	—
Africa:							
South Africa, Republic of	2	6,000	e130	3,000	e64	e.046	—
Total	2	6,000	e130	3,000	e64	e.046	—
Asia:							
Japan	140	114,900	3,446	820	25	.033	—
Total	140	114,900	3,446	820	25	.033	—

See footnotes at end of table.

TABLE 17—Continued

SHREDDER PROCESSING CAPACITY IN SELECTED COUNTRIES IN 1989[1]

Country	Shredder data						
	Total number of shredders in operation, including mills	Total power requirements, horsepower	Total annual capacity/ output, thousand metric tons[2]	Average power requirements per shredder, horsepower	Average annual capacity/ output per shredder, thousand metric tons	Average power requirements, horsepower per metric ton of annual capacity/output	Number of new plants under construction
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	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	—
Total	7	e11,750	e254	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	—
Total	10	e22,700	e483	e2,300	e48	e.047	—
World total	e601	e1,053,224	e26,464	e1,750	e44	e.040	9

e Estimated. NA Not available.

[1] Unless otherwise specified, source for figures developed by the Bureau of Mines is from the Institute of Scrap Recycling Industries Inc., the Bureau International de la Recuperation (BIR), or manufacturers of shredders.

[2] Thousand metric tons per year per 8-hour shift per 5-day week.

KYANITE AND RELATED MATERIALS

By Michael J. Potter

Mr. Potter, a physical scientist with 23 years industry and 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 Peter Roetzel, international data assistant.

U.S. kyanite production in 1989 was estimated to have decreased slightly compared with that of 1988 due to a drop in activity in the iron and steel industry, a major consumer of refractories.

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 1315° 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 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, at least part of the aluminum silicate they contain is converted to mullite.

There are three types of synthetic mullite. Low-temperature sintered synthetic mullite is made by sintering siliceous bauxite or mixtures of bauxite and kaolin above 1549° 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 size to boulders, was formerly imported into the United States. Indian reserves are limited, however, and material is no longer being exported.

DOMESTIC DATA COVERAGE

Domestic production data for kyanite and synthetic mullite were developed by the Bureau of Mines by means of two separate, voluntary, domestic surveys. The Bureau estimated kyanite production by using the last reported production levels adjusted by the trend of the iron and steel industry. In the synthetic mullite survey, all three canvassed operations responded, providing 100% of the total production tonnage data represented in table 1.

LEGISLATION

The allowable depletion rates for kyanite, established by the Tax Reform Act of 1969 and unchanged through 1989, were 22% for domestic production and 14% for foreign operations.

TABLE 1

U.S. PRODUCTION OF SYNTHETIC MULLITE

Year	Quantity (metric tons)	Value (thousands)
1985[e]	25,000	$5,450
1986[e]	W	W
1987	W	W
1988	W	W
1989	W	W

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

ISSUES

Andalusite continued to be imported into the United States in 1989 as one of several minerals and metals, which 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 are 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.

CONSUMPTION AND USES

Domestic consumption of kyanite and synthetic mullite was mostly in the Eastern States. Utilization of the materials was limited west of the Mississippi by the expense of shipping from the existing production facilities in the East.

The 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 comprise 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.

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.

PRICES

Prices at yearend 1989, in British pounds, from Industrial Minerals (London), were unchanged from the previous year. Price increases for 1989 in table 2 represent a stronger British pound against the U.S. dollar than in 1988.

FOREIGN TRADE

Shipments of U.S. kyanite, mullite, and synthetic mullite were believed to have been made to destinations in Europe and Asia. Imports of andalusite were approximately 10,300 metric tons from the Republic of South Africa, with a customs value of $1,550,000.

WORLD REVIEW

Capacity

Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

The data in table 4 are rated capacity for mines and refineries as of December 31, 1989. 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.

TABLE 2

PRICES OF KYANITE AND RELATED MATERIALS

(Dollars per metric ton)

	1988	1989
Andalusite. Transvaal, 57% Al_2O_3, bulk, c.i.f. main European port	139–154	144–160
Andalusite, Transvaal, 60% Al_2O_3, c.i.f. main European port	200	208
Sillimanite, South African 70% Al_2O_3, bags, c.i.f. main European port	293	304
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	139–239	144–248
U.S. kyanite, f.o.b. plant, carlots:		
Raw	70–137	70–137
Calcined	123–172	123–172

Source: Industrial Minerals (London). Dec. 1988, No. 255, p. 83, and Dec. 1989, No. 267, p. 75.

TABLE 3

U.S. IMPORT DUTIES

Tariff item	No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Kyanite, sillimanite, andalusite, and dumortierite	2508.5	Free	Free.
Mullite	2508.6	4.9% ad valorem	30% ad valorem.

TABLE 4

WORLD KYANITE AND RELATED MINERALS CAPACITY, DECEMBER 31, 1989

(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:	
Market economy countries[e]	20
Centrally planned economy countries[e]	180
Total	315
Africa:	
South Africa, Republic of:	
Andalusite	310
Sillimanite[e]	3
Zimbabwe: Kyanite	2
Total	315
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 (rounded)[1 2]	730

[e] Estimated. W Withheld to avoid disclosing proprietary data.
[1] Excludes U.S. kyanite and synthetic mullite.
[2] Data may not add to totals shown because of independent rounding.

South Africa, Republic of

The country's andalusite industry was described in a journal article, including occurrence, properties, producers, uses, reserves, production, mining, beneficiation, and outlook.[1]

CURRENT RESEARCH

The conversion of sillimanite to mullite was described in a paper entitled "Exploitation and Utilization of Sillimanite Minerals."[2] It was suggested that the temperature of initial decomposition and complete decomposition of sillimanite varies according to composition, impurity content, and grain size of the concentrate. When the grain size was less than 0.088 millimeter (mm), the sillimanite concentrate began to transform into mullite at 1,400° C and transformed into mullite completely at 1,700° C. When the grain size was larger than 0.088 mm, the initial conversion temperature of sillimanite concentrate became higher (approximately 1,500° C), and the complete conversion temperature was higher than 1,700° C.

OUTLOOK

Changes have taken place in ironmaking and steelmaking and other high-temperature industries such as more intensive agitation, higher temperatures, and larger temperature fluctuations. More durable refractories have been required to meet these challenges. At the same time, consumption of refractories per ton of steel and other materials produced has gone down. Some lower duty refractories are being replaced by higher duty ones

TABLE 5

KYANITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and commodity	1985	1986	1987	1988[p]	1989[e]
Australia:					
Kyanite	222	768	1,079	[e]500	500
Sillimanite[3]	428	133	77	64	70
Brazil: Kyanite	2,350	950	510	[r e]1,000	1,000
China: Unspecified[e]	2,500	2,500	2,500	2,500	2,500
France: Andalusite	56,600	50,900	50,000	[e]50,000	50,000
India:					
Andalusite	504	732	122	([4])	—
Kyanite	30,472	32,394	39,959	36,951	38,000
Sillimanite	17,095	[r]14,905	12,756	13,925	15,000
Kenya: Kyanite[e]	[5]1	1	1	1	1
Korea, Republic of: Andalusite	42	—	—	—	—
South Africa, Republic of:					
Andalusite	194,693	[r]181,466	194,373	259,556	270,000
Sillimanite	1,337	1,330	1,243	781	700
Spain: Andalusite	2,800	2,446	[e]2,500	[e]2,500	2,500
Sweden: Kyanite[e]	[5]2,200	5,000	5,000	5,000	5,000
United States:					
Kyanite	W	W	W	W	W
Mullite, synthetic[e]	24,500	W	W	W	W
Zimbabwe: Kyanite	[r]1,676	1,851	1,834	1,795	1,900

[e] Estimated. [p] Preliminary. [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 Mar. 30, 1990.
[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.
[4] Revised to zero.
[5] Reported figure.

based on kyanite-mullite. Raw or calcined kyanite provides needlelike blades in a refractory or ceramic body, which are interworked throughout and form a very mechanically strong product.[3] Because of these unique properties, kyanite has maintained a stable consumption pattern and should continue to do so in the near future.

BACKGROUND

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.

Industry Structure

Only a small number of countries world wide are currently producers of kyanite-group minerals. In France, the sole producer of andalusite is Denain-Anzin Mineraux Refractaire Ceramique (Damrec), a subsidiary of Mineraux Industrielle de Refractaire et Ceramique. Material is shipped to markets in Europe. India's reserves of lump kyanite are limited and material is not being exported. In the Republic of South Africa, the world's largest supplier of andalusite, producing companies include Annesley Andalusite (Pty) Ltd., Cullinan Minerals Ltd., Hoogenoeg Andalusite (Pty) Ltd., Purity Minerals (Pty) Ltd., Verref Mining (Pty) Ltd., and Weedon's Minerals (Pty) Ltd. Material is exported to Europe, Japan, and the United States. In Sweden, kyanite output from the new and only producer, Svenska Kyanite AB, has been running below the plant capacity of 25,000 tons per year. Production in 1989 was estimated to be 5,000 tons.

Resources

There has been no comprehensive determination of domestic kyanite reserves, but a total of 30 million tons of kyanite content is a conservative estimate. In the category of kyanite resources, the quantities of that mineral existing in several States in deposits not currently or only marginally workable at a profit are known to be large, and kyanite makes up as much as 10% of the weight of a number of extensive formations of micaceous schists and gneisses.[4]

Established kyanite reserves in Brazil were given as 3.7 million tons. Large reserves of andalusite and sillimanite were reportedly discovered in China. Reserves of andalusite in France were approximately 4 to 5 million tons of contained andalusite. In the Republic of South Africa, reserves of andalusite are 50.5 million tons.

Information on foreign reserves of kyanite-group minerals is somewhat limited; however, kyanite deposits have been reported in several countries, including Austria, Bulgaria, Canada, India, Kenya, Liberia, Spain, the U.S.S.R., and Zimbabwe.[5]

Technology

Beneficiation.—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 areal scope 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.

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LEAD

By William D. Woodbury

Mr. Woodbury is a physical scientist with the Branch of Nonferrous Metals. He had 25 years of geotechnical experience upon becoming the Bureau's lead specialist in 1982. Domestic survey data were prepared by P. Wiser and S. Hays, Nonferrous Data Section. International data tables were prepared by G. Jacarepaqua and A. Wilkes, International Data Section.

The year 1989 will be remembered within the lead industry, worldwide, as one of many records and accomplishments in several sectors. Most significantly, it was very profitable as the world price was sustained at high levels throughout the year, averaging the highest since 1981, and the fourth highest ever. Spot shortages of premium grades developed, and at yearend reported total metal stocks held by world producers, consumers, merchants, and the London Metal Exchange (LME) represented only about 3 weeks of demand.

In the United States, production at secondary lead smelter-refineries and consumption of lead for storage batteries established record highs. Recovery from old scrap also set a new record. Total primary refinery production was about the same as that in 1988. However, the Nation's oldest and largest lead smelter-refinery established record

TABLE 1

SALIENT LEAD STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Domestic ores, recoverable lead content	413,955	339,793	311,381	384,983	410,915
Value thousands	$174,008	$165,150	$246,720	$315,222	$356,476
Primary lead (refined):					
From domestic ores and base bullion	422,650	348,217	336,471	371,348	379,034
From foreign ores and base bullion	71,353	22,071	37,139	20,739	17,421
Secondary lead (lead content)	615,695	624,769	710,067	r736,401	808,589
Exports (lead content):					
Lead ore and concentrates	9,987	4,380	8,764	20,902	[1] 57,038
Lead materials, excluding scrap	37,322	19,778	13,586	29,077	[1] 43,837
Imports for consumption:					
Lead in ore and concentrates	2,649	4,604	873	20,606	[1] 5,122
Lead in base bullion	760	142	10,827	4,046	[1] 5,782
Lead in pigs, bars, reclaimed scrap	134,521	143,511	192,260	155,893	[1] 116,358
Stocks, Dec. 31:					
Primary lead[2]	84,502	20,400	21,608	15,398	15,623
At consumers and secondary smelters	93,130	83,824	88,586	r89,865	82,741
Consumption of metal, primary and secondary	1,148,298	1,125,521	1,230,373	r1,245,170	1,283,234
Price: Metals Week average, delivered, cents per pound	$19.07	$22.05	$35.94	$37.14	$39.35
World:					
Production:					
Mine thousand metric tons	r3,431.2	r3,334.9	3,428.8	p3,414.4	e3,394.9
Refinery[3] do.	r3,356.7	r3,192.6	3,204.2	p3,239.5	e3,253.8
Secondary refinery do.	r2,283.8	r2,359.3	2,517.6	p2,615.7	e2,648.9
Price: London Metal Exchange, pure lead, cash average, cents per pound	$17.84	$18.43	$26.99	$29.73	$30.63

e Estimated. p Preliminary. r Revised.

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 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.

production and output-per-worker levels, while simultaneously setting record-low injury rate and air pollutant emissions levels. Domestic mine production increased significantly, primarily because of a large mine coming on-stream in Alaska. As a result, the United States became a significant net exporter of lead concentrates for the first time, virtually all to Canada.

World mine production decreased marginally from that of 1988, and on a recoverable basis was 54% of demand. World secondary refinery production reached a record 2.65 million metric tons, and world demand increased for the seventh consecutive year, setting a record for the third consecutive year.

LEGISLATION AND GOVERNMENT PROGRAMS

In a major ruling by the Environmental Protection Agency (EPA) in September, in response to a court-ordered deadline, primary lead smelter slags were one of five mineral processing wastestreams conditionally retained in the Bevill exclusion from Federally regulated hazardous materials rules under the Resource Conservation and Recovery Act (RCRA), part B, as amended. This ruling was expected to be retained when final rules are promulgated, by court-ordered agreement, in January 1991. However, process wastewater was not retained in the exemption. The latter is only a fraction in volume of the former, however, and can be recycled effectively with best available technologies (BAT) at a cost estimated by EPA to be 0.1% to 0.2% of the 1988 value of refined metal shipments.

In a related matter, the EPA proposed in December that lead-acid batteries be prohibited from processing at Municipal Waste Combustors (MWC's) as part of an overall requirement that 25% of all recyclable materials entering the systems be salvaged. The regulation will be finalized in 12 months under MWC regulations.

At the state level, an historic occurrence with significant impact was the passage in Missouri of a new law, which, for the first time, regulates mine tailings. The industry-backed rules established a permit and fee system for lead, zinc, and iron ore tailings, set forth reclamation standards for closure, and established a trust fund administered by the State for reclaiming the tails when currently active mines permanently close. The new law is known as the Metallic Minerals Waste Management Act of 1989. In Colorado, ASARCO Inc. reached an agreement with the State and EPA on a remediation program for a portion of the Leadville Superfund site.

STRATEGIC CONSIDERATIONS

Because of its pervasive worldwide use in the transportation, communications, and electronics industries, primarily for electric power storage, lead is a strategic and critical commodity. The National Defense Stockpile holds 525,000 metric tons of lead against a goal of 998,000 tons.

Except for mines in Missouri, Morocco, and the Republic of South Africa, primary supply of lead is closely interrelated, as a result of geologic occurrence, with zinc and silver. All of these metals are recovered from the same ore in most producing countries. A strategic consideration with potentially wide-ranging impact on domestic supply resulting from these coproduct-byproduct relationships arose in 1989. This was a result of emerging and innovative environmental control strategies that are discussed later. One aspect of the pollution prevention concept, known as source reduction, could entail severe reduced allowances for the use of virgin, i.e. primary, materials in the manufacture of potentially harmful or hazardous products. In the worst-case scenario, elimination of certain products from the market place could be considered.

Implemention of such a strategy on virgin lead use in the United States could impact the domestic supply of several other metals. An analysis of domestic mine production in 1988, before a large new base and precious metal mine opened in Alaska, indicates that 23% of U.S. total zinc mine production came from a coproduct relationship with lead. These same mines also produced 100% of the bismuth, 7% of the silver, and 23% of the cadmium. Because cadmium reports with the zinc concentrates, the balance came from zinc mines in which lead is strictly a byproduct outside of Alaska. The zinc mines also were a small and only domestic source of germanium. Estimates for 1990, when the huge Red Dog zinc-lead-silver mine in Alaska is in production, are that the lead-zinc-silver coproduct relationship will supply 97% of the lead, 55% of the zinc and cadmium, and 30% of the silver. Also, as byproducts, these same mines are expected to supply all of the bismuth and indium, and about 80% of the germanium mined in the United States.

ISSUES

Because lead, its oxides, and some other lead compounds are highly toxic, especially to infants and children, whether inhaled or ingested, lead was selected during the year by the EPA for a comprehensive, highly publicized, study effort throughout the whole agency. This effort, known as The Lead Pollution Prevention Program (P4), was scheduled for completion in 1992, and involves almost all program offices in the EPA. The objective is to develop a comprehensive, cross-media (air-land-water) policy to minimize or eliminate human exposure to lead or its compounds where epidemiological evidence warrants. The new lead policy is to be framed in the context of pollution prevention rather than waste minimization, but still could utilize improved command-and-control techniques to achieve parts of the objective, including more timely, predictable, and realistic enforcement practices. The new lead policy, when finally determined, could serve as a model for tackling other major health risk problem areas as the Nation moves toward a uniform environmental code during the rest of this century. It is intended by EPA that the lead producing and consuming industries, as well as environmental and health organizations, be solicited for input and kept continuously apprised of developments during the information gathering, study, and policy framing periods. The Bureau of Mines was expected to be intimately involved with both the industrial sectors and EPA during development of the P4 program.

PRODUCTION

Mine Production

The increase in domestic mine output was exclusively from Missouri, Idaho, and a large new silver-zinc mine in Alaska. The reopening of The Doe Run Co.'s Brushy Creek Mine, closed since 1985, supplemented declining production elsewhere in Missouri. The Greens Creek Mine on Admiralty Island, AK, a joint venture of RTZ Corp. PLC (53%), Hecla Mining Co. (28%), CSX Corp. (12.6%), and Exalas Resources Inc. (6.3%), opened in February. Cominco Alaska Inc.'s planned November opening for the Red Dog Mine in the region of Kotzebue, AK, was delayed because of technical problems in the mill startup. Nine operating mines in Missouri, including Brushy Creek, plus six other mines shown on table 4, produced all but about 2,400 tons of the domestic recoverable mine output. The nine mines in Missouri accounted for 89% of the year's total. On the basis of lead in concentrates, the industry performed at only 62% of capacity (table 15) because of decreasing primary demand.

The Doe Run Co. of St. Louis, MO, the Nation's largest lead producer, operated three mine and mill divisions in Southeastern Missouri: Buick, Fletcher, and Viburnum. To take advantage of continuing high copper and zinc prices, Doe Run increased the total ore milled by 6% to 4.3 million tons, according to the annual report to stockholders of The Homestake Mining Corp., a 42.5% owner of Doe Run. This resulted in production levels of 228,000 tons of lead in concentrates, 49,000 tons of zinc concentrate, and 70,000 tons of copper concentrate. Average metal grades of the ore hoisted by Doe Run in 1989 were 5.6% lead, 0.9% zinc, and 0.6% copper. Total reserves at yearend were reported by Homestake to be 66.3 million tons, graded at 5.0% lead, 0.9% zinc, and 0.3% copper.

Asarco operated two mine and mill complexes in Southeastern Missouri, which together increased the ore milled by 40% compared with that of 1988, according to the company's annual report to stockholders. Contained lead increased by 20,700 tons, but declined by 2,000 tons at the Leadville, CO, mine operated by Asarco on a 50% equity share basis. At yearend, Asarco had the captive domestic capacity to supply all the lead concentrates required by its Glover, MO, smelter, and about one-half of the company's overall requirements. In 1984, the company's mines supplied only 5% of the company's needs, according to Asarco.

The Magmont Mine at Bixby, MO, a joint venture of Dresser Industries Inc. and Cominco American Inc., the operator, was the Nation's third largest producing lead mine in 1989. However, because of dwindling reserves and lowered average ore grades, production declined nearly 10% from 1988 to 63,000 tons of contained lead in concentrates. According to Cominco Ltd.'s annual report to stockholders, the average concentrate grade actually increased from 77.5% to 77.9%. During the year, emphasis was on mining in the area of the large 1986 groundfall, and pillar extraction exceeded that in other areas of the mine. Surface drilling yielded no additional reserves, and planning for shutdown within the next 2 or 3 years was begun. The average grade of lead ore hoisted was 6.8% compared with 7.2% in 1988, although zinc and copper grades remained at 1.0% and 0.3%, respectively.

At Cominco Alaska Inc.'s Red Dog Mine in Alaska, final assembly of the mill modules, trial runs, and commissioning of the equipment continued through December for official startup in early 1990. Construction of the port and storage facilities 52 miles away was also essentially completed. At yearend, Cominco had spent $317 million on the mine and mill complex and $170 million on the road and port facilities. The latter were financed by the State of Alaska through the Alaska Industrial Development and Export Authority. In addition, Cominco will pay an annual

TABLE 2

MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY STATE

(Metric tons)

State	1985	1986	1987	1988	1989
Alaska	—	—	—	—	W
Arizona	581	W	—	W	W
Colorado	W	W	W	W	W
Idaho	33,707	9,951	W	W	W
Illinois	W	W	W	W	W
Missouri	371,008	319,900	W	353,194	366,931
Montana	846	W	W	8,266	W
Nevada	(1)	—	—	W	—
New Mexico	W	10	W	W	W
New York	W	W	W	W	W
South Dakota	—	—	—	—	4
Tennessee	W	—	W	W	W
Total	413,955	339,793	311,381	384,983	410,915

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1] Less than 1/2 unit.

TABLE 3

MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1988	1989
January	27,771	33,553
February	28,231	31,323
March	36,080	34,840
April	32,720	33,996
May	30,346	34,885
June	32,540	36,401
July	30,424	33,509
August	36,340	38,992
September	33,157	34,601
October	34,446	35,379
November	31,098	33,116
December	31,830	30,320
Total	384,983	410,915

TABLE 4

TWENTY-FIVE LEADING LEAD-PRODUCING MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of lead
1	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
2	Fletcher	Reynolds, MO	do.	Do.
3	Magmont	Iron, MO	Cominco American Inc.	Do.
4	West Fork	Reynolds, MO	ASARCO Incorporated	Do.
5	Sweetwater	do.	do.	Do.
6	Viburnum No. 29	Washington, MO	The Doe Run Co.	Do.
7	Casteel[1]	Iron, MO	do.	Copper-lead ore.
8	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
9	Viburnum No. 28	Iron, MO	The Doe Run Co.	Copper-lead ore.
10	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Zinc ore.
11	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
12	Leadville Unit	Lake, CO	ASARCO Incorporated	Lead-zinc ore.
13	Sunnyside	San Juan, CO	Washington Mining Co.	Do.
14	Bunker Hill	Shoshone, ID	Bunker Hill Mining Co. (U.S.) Inc.	Zinc ore.
15	Sunshine	do.	Sunshine Mining Co.	Silver ore.
16	Balmat	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
17	Butte Hill	Silver Bow, MT	New Butte Mining Co. Inc.	Lead-zinc ore.
18	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
19	Great Eastern	Park, CO	J. T. Lamping	Lead ore.
20	Coeur	Shoshone, ID	ASARCO Incorporated	Silver ore.
21	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Zinc ore.
22	Camp Bird	Ouray, CO	Royal Camp Bird Inc.	Gold ore.
23	Mission	Pima, AZ	ASARCO Incorporated	Copper ore.
24	Gold King	San Juan, CO	Gold King Consolidated Inc.	Lead-zinc ore.
25	Center	Grant, NM	Mount Royal Mining & Exploration	Gold ore.

[1] Includes Brushy Creek Mill.

toll fee to the State, as well as maintenance costs.

Primary Smelter-Refinery Production

According to Homestake's annual report, the Doe Run smelter-refinery at Herculaneum, MO, produced a record 216,758 tons of refined lead as a result of improved institutional and processing control systems, yielding a record high of 1.82 tons per manshift. This was accomplished simultaneously with setting a new safety performance record of a ratio of 1.1 lost-time injuries per 200,000 manhours, compared with a national average of 7.9, according to the National Bureau of Labor Statistics. The facility, which includes a strip lead manufacturing plant, also achieved the lowest average employee blood levels ever recorded at the site, and for the first time achieved 1.1 micrograms (μg) of particulate lead emissions per cubic meter of air against the National Ambient Air Quality Standard (NAAQS) of 1.5 μg per cubic meter on an annual basis.

According to the Asarco annual report, the company produced 172,600 tons of refined lead in 1989, slightly less than in 1988 and 1987. Nearly two-thirds of the total was produced at the Glover, MO, smelter-refinery, and the balance at the Omaha, NE, refinery, which received bullion from the East Helena, MT, smelter. The Omaha plant also produced lead from purchased old and new scrap in 1989. Construction of a completely enclosed unloading, handling, and ore storage facility to mitigate environmental problems continued throughout the year at East Helena.

Secondary Smelter-Refinery Production

Domestic secondary production increased appreciably for the fourth consecutive year, achieving the highest level ever, as the industry performed at 87% of capacity, the same rate as in 1988. In spite of two closures during the year, there was a net increase in capacity of 80,000 tons from yearend 1988, a net result of one large new plant coming on-stream late in the year, several expansions, and two downgradings. Total annual secondary rated capacity for refined lead and lead alloys at yearend was estimated by the Bureau of Mines to be 930,000 tons, representing 42 companies and 50 plants, with individual capacities ranging from less than 1,000 tons per year to 120,000 tons per year. The 10 largest operated 18 plants, representing 89% of the total capacity and accounting for 86% of the production. Twenty-three small producers, including Asarco, with annual capacities averaging 1,000 tons, produced mainly specialty alloys for such uses as solders, brass or bronze ingots, and bearing metals. The most significant event of the year relative to plants was the opening of the first large new secondary smelter-refinery since 1981, that of Exide Corp. at Muncie, IN, on the site of the former Bergsoe-Boliden plant, which closed in 1983. This was a major accomplishment in light of present day environmental requirements.

During the year, Doe Run entered the secondary market by purchasing scrap batteries and tolling them elsewhere. Except for the necessary RCRA part B permit to store hazardous materials, Doe Run acquired all the necessary environmental permits for building and operating a proposed Tonolli-Engitec CX "clean technology" plant at its Buick smelter in Boss, MO. However, it expected to move forward with the project in 1990. RSR Corp. also did not break ground on any of its three proposed new

TABLE 5

REFINED LEAD PRODUCED AT PRIMARY REFINERIES IN THE UNITED STATES, BY SOURCE MATERIAL[1]

(Metric tons unless otherwise specified)

Source material	1985	1986	1987	1988	1989
Refined lead:					
From primary sources:					
Domestic ores and base bullion	422,650	348,217	336,471	371,348	379,034
Foreign ores and base bullion	71,353	22,071	37,139	20,739	17,421
Total	494,003	370,288	373,610	392,087	396,455
Calculated value of primary refined lead[2] thousands	$207,689	$180,004	$296,026	$321,039	$343,932

[1] Total refined lead: American Bureau of Metal Statistics Inc.; domestic and foreign ores: Bureau of Mines calculations.
[2] Value based on average quoted price.

TABLE 6

STOCKS AND CONSUMPTION OF NEW AND OLD LEAD SCRAP IN THE UNITED STATES, BY TYPE OF SCRAP

(Metric tons, gross weight)

Type of scrap	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1988						
Smelters, refiners, others:						
Soft lead[1]	1,855	28,548	—	28,721	28,721	1,682
Hard lead	567	5,717	—	6,093	6,093	191
Cable lead	854	3,699	—	3,668	3,668	885
Battery-lead plates	28,584	812,343	—	819,470	819,470	21,457
Mixed common babbitt	95	1,853	—	1,833	1,833	115
Solder and tinny lead	1,776	20,861	—	20,425	20,425	2,212
Type metals	172	1,808	—	1,877	1,877	103
Drosses and residues[r]	5,232	59,372	60,559	—	60,559	4,045
Total	39,135	934,201	[r]60,559	[r]882,087	942,646	30,690
1989						
Smelters, refiners, others:						
Soft lead[1]	1,682	31,260	—	31,914	31,914	1,028
Hard lead	191	8,585	—	8,585	8,585	191
Cable lead	885	9,517	—	9,381	9,381	1,021
Battery-lead plates	21,457	923,777	—	922,651	922,651	22,583
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	1,728	—	1,725	1,725	106
Drosses and residues	4,045	66,314	67,934	—	67,934	2,425
Total	30,690	1,062,932	67,934	996,303	1,064,237	29,385

[r] Revised.
[1] Includes remelt lead from cable sheathing plus other soft lead scrap processing.

"clean technology" plants announced in November 1988, but preliminary design and expansion details for the Indianapolis, IN, facility were completed by a consulting engineering firm.

In litigation actions, EPA officially declared the Nesquehoning, PA, plant site of Tonolli Corp., closed since 1985, a priority superfund site, and listed many U.S. battery manufacturers as potentially responsible parties (PRP's) liable for cleanup costs. In November, the Department of Labor proposed fines exceeding $2 million for Interstate Lead Co. of Leeds, AL, for "blatant" blood lead and air level violations. If upheld, it would be the eighth stiffest Occupational Safety and Health Administration (OSHA) fine in history. The company was appealing at yearend.

CONSUMPTION

Domestic consumption of lead was the highest since 1979 as lead-acid storage battery manufacturers used more than 1 million tons for the first time. Automotive starting-lighting-ignition (SLI) battery shipments, including exports, exceeded 80 million units for the second consecutive year. The industrial-traction and specialty battery sectors also recorded significant gains. However, lead oxides used for glass, paint, ceramics, and other chemicals, which had been the second largest use for lead on a metal equivalent basis, declined for the fifth consecutive year. This was more than offset by a significant increase in lead use for bullets and shot, the latter including use at nuclear plants. Use of sheet lead in construction and cable lead sheathing in communications also increased, the latter by 40% compared with that of 1988.

Demand for lead in industrial and traction batteries, which includes uninterruptible power supply (UPS) designed to ensure constant voltage for large computer systems at hospitals, banks, communications networks, etc., and standby power supply (SBS) for emergency lighting and some telephone systems, was estimated by the Bureau of Mines to be 174,000 tons. This was an increase of 12% over that of 1988, and represents a record high. About one-third of that was for traction batteries, i.e., electric vehicles, including in-plant fork lifts and underground mine equipment. The UPS

TABLE 7

SECONDARY METAL RECOVERED[1] FROM LEAD AND TIN SCRAP IN THE UNITED STATES

(Metric tons)

	Lead	Tin	Antimony	Other	Total
1988					
Refined pig lead[2]	367,055	—	—	—	367,055
Refined pig tin[3]	—	r545	—	—	r545
Lead and tin alloys:					
Antimonial lead	331,341	902	13,866	736	346,845
Lead-base babbitt	1,439	112	162	(4)	1,713
Solder	19,487	3,619	141	(4)	23,247
Type metal	973	70	139	(4)	1,182
Other alloys, including cable lead	1,852	29	24	—	1,905
Total	355,092	4,732	14,332	736	374,892
Tin content of chemical products	—	W	—	—	W
Grand total	722,147	r5,277	14,332	736	r742,492
1989					
Refined pig lead[2]	411,976	—	—	—	411,976
Refined pig tin[3]	—	563	—	—	563
Lead and tin alloys:					
Antimonial lead	360,570	952	13,657	725	375,904
Lead-base babbitt	1,523	116	178	(4)	1,817
Solder	16,732	3,225	128	(4)	20,085
Type metals	936	46	137	(4)	1,119
Other alloys, including cable lead	2,141	30	9	—	2,180
Total	381,902	4,369	14,109	725	401,105
Tin content of chemical products	—	W	—	—	W
Grand total	793,878	4,932	14,109	725	813,644

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] Includes remelt lead.
[3] Includes remelt tin.
[4] Included with "Antimony" to avoid disclosing company proprietary data.

market was expected to continue to increase as it is applied to smaller networked computer systems. There was also about 35,000 tons of lead used in 1989 for specialty batteries for aircraft and military applications.

STOCKS

Metal stocks at domestic primary refineries at yearend were essentially the same as a year ago, but those held by consumers declined nearly 10%. Therefore, total domestic metal stocks were at the lowest level since 1968, and reflected the worldwide tight supply-demand situation as depicted in table 17. This worldwide sensitive balance kept the world price relatively high throughout the year, which essentially has been the case since May of 1987. Stocks of lead and antimonial lead metal in the market economy countries (MEC's) reporting to the International Lead and Zinc Study Group (ILZSG), including those on the LME, were approximately 378,000 tons at yearend, only about 6% of total world demand, and 60,000 tons lower than at yearend 1988.[1] Stocks in LME warehouses declined nearly 40,000 tons to only 23,000 tons at yearend. The centrally planned economy countries (CPE's) do not report lead stock levels.

PRICES

The North American producers' price quotations, including major secondaries, which were listed in a range of 42 to 42.5 cents per pound in early December 1988, dropped to 40 cents in early January 1989, and continued to drop through April, according to Metals Week. From a low of 35 cents per pound, which held from March 2 through April 27, quotes rose steadily through August before settling in a range of 42 to 44 cents from August 31 through October 31. The range broadened to 41 to 44 cents on November 1, before dropping to 38 to 40 cents during December. Monthly average cash prices on the LME paralleled the movement in the United States through April, but dropped more slowly, which

TABLE 8

LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1988r	1989
KIND OF SCRAP		
New scrap:		
Lead-base	42,013	47,129
Copper-base	3,256	e3,600
Tin-base	5	3
Total	45,274	50,732
Old scrap:		
Battery-lead plates	623,033	678,702
All other lead-base	56,989	67,755
Copper-base	11,105	e11,400
Tin-base	—	—
Total	691,127	757,857
Grand total	736,401	808,589
FORM OF RECOVERY		
As soft lead	367,055	411,976
In antimonial lead	331,341	360,570
In other lead alloys	23,639	21,040
In copper-base alloys	14,361	e15,000
In tin-base alloys	5	3
Total	736,401	808,589
Value[1] thousands	$602,962	$701,465

e Estimated. r Revised.
[1] Value based on average quoted price of common lead.

TABLE 9

U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC code	Product	1988	1989
	Metal products:		
3482	Ammunition: Shot and bullets	52,708	62,940
	Bearing metals:		
35	Machinery except electrical	425	W
36	Electrical and electronic equipment	(1)	W
371	Motor vehicles and equipment	5,152	1,683
37	Other transportation equipment	457	W
	Total bearing metals	6,034	2,586
3351	Brass and bronze: Billets and ingots	9,994	9,610
36	Cable covering: Power and communication	16,170	22,605
15	Calking lead: Building construction	1,618	1,831
	Casting metals:		
36	Electrical machinery and equipment	r1,333	524
371	Motor vehicles and equipment	(1)	W
37	Other transportation equipment	13,474	3,395
3443	Nuclear radiation shielding	1,065	W
	Total casting metals	r15,872	16,175
	Pipes, traps, other extruded products:		
15	Building construction	11,193	8,856
3443	Storage tanks, process vessels, etc.	(2)	962
	Total pipes, traps, other extruded products	11,193	9,818
	Sheet lead:		
15	Building construction	14,009	15,900
3443	Storage tanks, process vessels, etc.	(2)	(2)
3693	Medical radiation shielding	3,449	5,087
	Total sheet lead	17,458	20,987
	Solder:		
15	Building construction	3,985	3,909
341	Metal cans and shipping containers	848	762
367	Electronic components and accessories	4,824	4,092
36	Other electrical machinery and equipment	3,052	2,029
371	Motor vehicles and equipment	6,355	6,217
	Total solder	19,064	17,009
	Storage batteries:		
3691	Storage battery grids, post, etc.	r514,694	552,308
3691	Storage battery oxides	r454,964	459,847
	Total storage batteries	r969,658	1,012,155
371	Terne metal: Motor vehicles and equipment	2,324	2,286
27	Type metal: Printing and allied industries	(3)	(3)
34	Other metal products[4]	5,290	4,564
	Total metal products	r1,127,383	1,182,566
	Other oxides:		
285	Paint	W	W
32	Glass and ceramics products	W	W
28	Other pigments and chemicals	W	10,074
	Total other oxides	62,524	57,984
2911	Gasoline additives	(5)	(5)
	Miscellaneous uses	55,263	42,684
	Grand total	r1,245,170	1,283,234

r Revised. W Withheld to avoid disclosing company proprietary data; included in appropriate totals.
[1] Included with "Other transportation equipment" to avoid disclosing company proprietary data.
[2] Included with "Building construction" to avoid disclosing company proprietary data.
[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.

caused the spread with the U.S. average to decrease from 9.6 cents per pound in January to 7.2 cents in May. The price and spread then rose slowly through October to the year's high of 34 cents per pound, the spread again reaching 9.6 cents. The LME price then took a sharp dip in November, as it did in the United States, but more so, resulting in the high spread of the year of 9.9 cents per pound. However, in December the LME rose slightly, which reflected Asian and European spot shortages of premium metal, and the spread with the average U.S. price reached the lowest of the year, 6.7 cents per pound.

The North American producer price is a delivered price in the United States. Normally, a North American producer price of 5 cents per pound above the LME to cover the tariff, insurance, ocean freight, and delivery would stimulate importation. However, the worldwide tight supply-demand balance (table 17) and occasional spot shortages of premium metal (99.99% plus), resulted in the lowest net metal domestic imports since 1982, a recession year. The average U.S and LME prices were the highest since 1980, when they were 42.5 and 41.2 cents per pound, respectively. The United States was a net pig metal exporter of 75,000 tons in that year.

TABLE 10

U.S. CONSUMPTION OF LEAD, BY MONTH[1]

(Metric tons)

Month	1988r	1989
January	98,725	111,493
February	99,320	104,013
March	107,655	106,962
April	102,222	104,901
May	106,821	108,154
June	106,492	107,353
July	95,051	98,856
August	105,332	111,328
September	105,881	107,532
October	113,441	114,945
November	106,254	108,339
December	97,976	99,358
Total[2]	1,245,170	1,283,234

r Revised.
[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.

TABLE 11

U.S. CONSUMPTION OF LEAD IN 1989, BY STATE[1]

(Metric tons)

State	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total
California	50,326	39,330	10,383	—	100,039
Florida	5,516	7,225	1,126	—	13,867
Georgia	31,798	5,858	—	—	37,656
Illinois	30,063	45,589	2,072	1,005	78,729
Kansas	20,530	16,105	11,829	—	48,464
Louisiana	6,750	3,508	1,574	—	11,832
Maryland	143	—	—	—	143
Michigan	16,415	11,046	267	—	27,728
Missouri	11,321	16,834	—	—	28,155
New York	15,892	5,048	13,428	—	34,368
Ohio	23,295	15,667	2,937	257	42,156
Pennsylvania	84,814	33,810	30,543	1,709	150,876
Tennessee	6,111	9,317	2,885	—	18,313
Texas	89,337	17,111	4,527	—	110,975
Alabama and Mississippi	18,767	—	—	2,222	20,989
Arizona and Colorado	256	176	58	—	490
Arkansas and Oklahoma	3,970	11,204	247	—	15,421
Delaware and New Jersey	44,856	7,036	3,159	248	55,299
Indiana and Kentucky	230,777	41,406	14,595	599	287,377
North Carolina and South Carolina	43,142	27,201	9,000	—	79,343
Connecticut, Massachusetts, Rhode Island	4,953	3,202	48	32	8,235
District of Columbia, Virginia, West Virginia	58	493	2,167	—	2,718
Idaho, Oregon, Washington	15,151	8,177	1,519	—	24,847
Maine, New Hampshire, Vermont	7,754	6,081	—	21	13,856
Iowa, Minnesota, Nebraska, Wisconsin	23,956	28,683	17,939	780	71,358
Total	785,951	360,107	130,303	6,873	1,283,234

[1] Includes lead that went directly from scrap to fabricated products.

TABLE 12

U.S. CONSUMPTION OF LEAD IN 1989, BY CLASS OF PRODUCT[1]

(Metric tons)

Product	Soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total
Metal products	67,637	71,161	24,740	6,873	170,411
Storage batteries	623,156	287,140	101,859	—	1,012,155
Other oxides	57,984	—	—	—	57,984
Gasoline additives	W	—	—	—	W
Miscellaneous	37,174	1,806	3,704	—	42,684
Total	785,951	360,107	130,303	6,873	1,283,234

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous."
[1] Includes lead that went directly from scrap to fabricated products.

The domestic prices for lead oxides were based on the selling price plus conversion charges for pig lead in a given period. Premium adjustments were also made by individual producers to reflect differences in manufacturing techniques, freight considerations, quality, and packaging requirements or other factors. According to American Metal Market, the quoted premiums for litharge ranged from 2 cents to 10 cents per pound in 1989, averaging about 6 cents for bags or drums in truckload lots, and 8 to 15 cents, averaging about 11 cents per pound, for 97% red lead. The premiums for leady litharge ("Bulk Battery") ranged from 1 cent to 4 cents per pound, and averaged about 2 cents.

WORLD REVIEW

According to the ILZSG statistics, consumption of soft lead and antimonial lead in the MEC's was a record 4.43 million tons in 1989, exceeding the previous high set in 1988 by about 70,000 tons.[2] Estimated world consumption of lead in all forms during 1989 increased for the seventh consecutive year to just under 6 million tons, and exceeded the 1988 previous record by more than 100,000 tons (table 17). The world demand growth since 1982 has averaged just over 2% per year, primarily because of steadily increasing SLI, UPS, SBS, traction, and load levelling battery systems. Estimated world total refinery production in 1989, including that from recycled scrap, increased only slightly from that of 1988. The production deficit shown in table 17 resulted in a continuing drawdown of world stocks, occasional spot shortages of premium metal, and sustained high prices worldwide. At yearend, supply and demand continued in delicate balance because of technical problems at smelters in Canada and Italy, mine production problems in Australia, and labor, political unrest, and sabotage in Peru.

Five new lead-producing mines came on-stream in 1989, and two small silver mines with byproduct lead were known to have closed during the year. As a result, there was 150,000 more tons of capacity operating at yearend than yearend 1988. This was the largest year-to-year increase in many years, accord-

TABLE 13

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
1985	50,475	36,374	5,770	511	93,130
1986	47,589	30,442	5,524	269	83,824
1987	55,278	27,959	5,185	164	88,586
1988	50,850	r34,108	4,756	151	r89,865
1989	48,836	29,068	4,598	239	82,741

r Revised.

TABLE 14

AVERAGE MONTHLY AND ANNUAL QUOTED PRICES OF LEAD[1]

(Cents per pound)

Month	1988		1989	
	North American producer price	London Metal Exchange	North American producer price	London Metal Exchange
January	38.00	30.21	40.17	30.62
February	34.85	29.71	37.01	28.17
March	34.00	29.39	35.07	26.69
April	34.00	29.41	35.02	27.55
May	34.57	30.27	36.34	29.15
June	36.30	30.68	39.15	30.16
July	36.50	28.06	40.29	31.32
August	36.52	27.25	41.75	31.81
September	38.41	27.63	43.63	33.00
October	39.15	29.68	43.63	34.07
November	41.38	31.33	41.26	31.39
December	42.02	33.12	38.89	32.22
Average	37.14	29.73	39.35	30.63

[1] Metals Week. Quotations for the United States on a nationwide, delivered basis. LME cash average.

ing to ILZSG, including reopenings and expansions. The largest of the new mines opened in 1989 were the Greens Creek silver-zinc mine in Alaska (12,000 tons of lead capacity) and the Hilton Mine in Australia (20,000 tons) which was integrated into the Mount Isa project in Queensland. The largest reopening was Doe Run's Brushy Creek Mine in Missouri, and the largest expansion (additional 38,000 tons) was at the Hellyer Mine on Tasmania. There were no permanent primary smelter-refinery closings in 1989. In Europe, a small rotary furnace was added to the Gailitz plant in Austria, and in Italy, Nuova Samim expanded its refinery at San Gavino by 20,000 tons. In Canada, Cominco Ltd. brought its new, larger, replacement QSL smelter on-stream.

Australia

The increase in mine production during 1989 was almost completely attributable to the new Hilton Mine coming on-stream, the Hellyer expansion project of Aberfoyle Ltd., and a full year's production from the Cadjebut open pit in Western Australia owned by BHP Minerals (58%) and Billiton Australia (42%). An expansion of the Cadjebut Mine, from 7,500 tons per year to 16,000 tons per year for lead, and from 41,000 tons per year to 65,000 tons per year for zinc, was started late in the year. Increased production from Hellyer began in March and, when at capacity, was expected to produce a million tons of ore yielding 50,000 tons of lead and 110,000 tons of zinc per year. Reserves are 16.2 million tons grading 13.0% zinc and 6.8% lead, according to Aberfoyle.

Production from the integrated Mount Isa and Hilton operations of MIM Holdings Ltd. (MIM) will raise annual output from 180,000 to 200,000 tons of lead, and from 200,000 tons to 250,000 tons of zinc. The Hilton region 20 kilometers north of Mount Isa, Queensland, is envisaged as MIM's long-term source of lead-zinc-silver, gradually replacing the mine at Mount Isa. A resource of 100 million tons was indicated, including 49 million tons of proven and probable reserves, with grades similar to the Mount Isa Mine. Deposits of similar magnitude have been discovered nearby at North Hilton, making it one of the world's largest lead-zinc-silver regions.

Also in Queensland, a decision was announced early in 1989 to proceed with development of the Thalanga zinc-lead-copper-silver-gold deposit. The project is a joint venture between the operating company, Pancontinental Mining Ltd. (50%), Outokumpu Australia Pty. Ltd. (25%), and Agip Australia Pty. Ltd. (25%). The latter's share was secured from Outokumpu during a reorgan-ization of the partnership. Reserves total 5.2 million tons grading 10.2% zinc, 3.1% lead, and 2.4% copper. At full production in 1991, when an underground decline is scheduled to replace the open pit, output is expected to reach 48,000 tons per year of zinc, 13,000 tons per year of lead, 10,000 tons per year of copper, and 33 tons per year of silver. This group continued study of a deposit at Lady Loretta near Mount Isa, publishing reserves of 6.5 million tons grading 18.8% zinc and 9.2% lead. Agip is a wholly owned subsidiary of Agip of Italy, owned by the state organization ENI, which also owns SAMIM, Italy's largest lead and zinc metal producer.

In exploration activity, MIM reached an agreement with the Northern Territory government for an 18-month drilling program, to be completed by the end of 1990, to establish the viability of mining the MacArthur River deposit. Resource estimates at yearend were 227 million tons of ore averaging 9.2% zinc and 4.1% lead. The company believes that technical problems with separating

TABLE 15

WORLD PRIMARY PRODUCTION CAPACITY

(Thousand metric tons)

	1988[r]			1989		
	Mine	Smelter	Refinery	Mine	Smelter	Refinery
North America:						
Canada	355	205	230	370	230	230
Mexico	210	300	320	210	300	320
United States	655	515	595	680	515	595
Other	10	—	—	10	—	—
Total	1,230	1,020	1,145	1,270	1,045	1,145
South America:						
Peru	205	115	110	210	115	110
Other	80	140	140	85	140	140
Total	285	255	250	295	255	250
Europe:						
Belgium	—	90	125	—	90	125
Bulgaria[e]	100	130	120	100	130	120
France	2	190	150	2	190	150
Germany, Federal Republic of	7	190	250	7	190	250
Italy	18	115	80	18	115	100
Poland	50	90	90	50	90	90
Spain	92	85	85	92	85	85
U.S.S.R.[e]	550	635	675	550	635	675
United Kingdom	—	50	160	—	50	160
Yugoslavia	115	155	155	116	155	155
Other	220	145	110	220	150	110
Total	1,154	1,875	2,000	1,155	1,880	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	200	190	350	200	190
Japan	30	270	285	30	270	285
Korea, North[e]	85	90	70	85	90	70
Other	100	95	150	100	95	150
Total	565	655	695	565	655	695
Oceania: Australia	516	445	235	575	445	235
World total	3,990	4,420	4,480	4,100	4,450	4,500

[e] Estimated. [r] Revised.

the extremely fine-grained ore can be overcome with modern autogenous direct smelting techniques. Also in the Northern Territory, the Woodcutters Joint Venture operated by Nicron Resources Ltd. completed the first full year of underground operation. Proven and probable reserves were further extended to 1.27 million tons grading 13.8% zinc and 6.4% lead. Additional drilling at depth outlined another 3 million tons of similar grades, and studies were undertaken to determine the viability of further development at the open pit-underground project.

Brazil

Companhia Paraibuna de Metais created a new subsidiary to produce high-grade lead for specialty batteries from the lead and silver residues of their electrolytic primary zinc refinery in Minas Gerais. The new company, Companhia de Chumbo e Prata do Espirito Santo (CHESA), planned to produce 24,000 tons per year at a new plant in the State of Santo by 1991. The parent company also was expected to begin construction in 1990 of a new QSL lead smelter and electrolytic refinery. The project was expected to take 3 years to complete, have a capacity of 45,000 tons per year, and to process mostly imported Peruvian concentrates. The State of Parana closed the 19,000-tons-per-year primary lead refinery of Plumbum S.A. Mineração e Metalurgia in October until process effluent filtration equipment is installed at discharge points.

Canada

Mine production of lead declined significantly in 1989 through a combination of technical difficulties, natural events, and labor problems. Cutback in hoisting capacity at Brunswick Mining and Smelting Corp. Ltd.'s Number 12 Mine in New Brunswick was a result of a shaft-deepening project. Also in New

TABLE 16

WORLD RESOURCES, 1989

(Million metric tons)

	Reserves	Reserve base[1]
Australia	14	26
United States	11	22
U.S.S.R.[e]	10	15
Canada	7	13
China[e]	6	9
Mexico	3	4
South Africa, Republic of	2	5
Total	53	94
Bulgaria[e]	2	3
Korea, North[e]	2	3
Peru	2	3
Yugoslavia	2	3
Total	8	12
Other	9	14
Grand total	70	120

[e] Estimated.

[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).

Source: International Lead Zinc Study Group, Bureau of Mines estimates, and other published sources.

Brunswick, East-West Caribou Mining Ltd. suspended production at the Caribou Mine in July to develop additional reserves, presently estimated at 15 million tons grading 11% lead and zinc combined. In July, Curragh Resources Inc. lost production temporarily at the Faro Mine, the nation's largest, in the Yukon Territory because of loss of power caused by forest fires. At Cominco Ltd.'s Sullivan Mine in British Columbia, the nation's second largest lead producer, production declined significantly because of increasing ore depth and processing problems, and cancellation of the miner's bonus formula, according to the Government's Mineral Policy Sector annual report.

In exploration and development during the year, Hudson Bay Mining and Smelting Co. Ltd. completed an expansion at its Chisel Lake Mine in Manitoba that was expected to increase lead output by 5,000 tons per year. In August, Noranda Inc. and Brunswick Mining and Smelting reopened their Heath Steel Mine near Bathurst, New Brunswick, which had been shut down since 1983. The three separate ore bodies contain 4 million tons of reserves grading 6.3% zinc and 2.5% lead. Also in New Brunswick, Marshall Minerals Corp. continued work on its Restigouche project in the north. East-West Caribou Mining planned to process the ore from the mine, which had about 1.1 million tons of reserves grading 7.71% zinc and 5.96% lead. In Nova Scotia, Westminer Canada Ltd. started work on reopening the Gays River Mine, closed by Esso Minerals Canada in 1982, at a production of 10,000 tons per year lead and 15,000 tons per year zinc. Reserves were about 1.5 million tons grading 10% zinc and 6.2% lead.

At midyear, Banco Español de Credito of Spain agreed to sell a 20% interest in Asturiana de Zinc S.A. to Curragh in exchange for a 5% share of Curragh plus a 15% interest in their Cirque deposit in northern British Columbia. That project, with 30 million tons of reserves grading 8.6% zinc and 3.5% lead, was expected to come on-stream in 1992 at 25,000 tons per year of lead.

France

Peñarroya agreed to sell its remaining lead-zinc-silver leases in France and Belgium to Nicron Resources of Australia. Remaining reserves are about 350,000 tons grading 6.5% zinc and 3.5% lead with the potential of an additional 1 million tons. Nicron will exercise the options and start production pending confirmation by exploratory drilling.

Greece

Financial problems forced the state-owned Hellenic Mining and Metallurgical Co. of Laurium S.A. (EMMEL) to close the rebuilt 20,000-tons-per-year primary smelter-refinery in June. At yearend, EMMEL had no immediate plans to reopen the facility, but late in the year the Government formed a board to examine its options.

Italy

Nuova Samim and Metallgesellschaft (MG) of the Federal Republic of Germany (FRG) agreed to merge their secondary lead activities. The two Italian plants had a capacity of 80,000 tons per year, and the German plant at Braubach, which installed the Italian Tonolli CX process in 1988 with Tonolli, had a capacity of 40,000 to 50,000 tons-per-year. In September, Nuova Samim's large primary smelter at Porto Vesme, Sardinia, was shut down because of technical problems. The Russian designed Kivcet plant had been in operation since early 1987. A planned expansion for 1990 was therefore accelerated to increase the capacity by 25% to 100,000 tons per year by midyear 1990, when the smelter was expected to reopen after correction of the problems.

Japan

Nippon Mining Co. Ltd. planned to develop a new mine on Hokkaido over the next 4 years. The deposit reportedly had reserves of 3 million tons grading 13% lead and 15% zinc with traces of indium.

Morocco

A large new underground zinc-lead-copper-silver mine was under development at Hajar by Companie Minière des Guemassa to be in full production by 1992 at about 16,000 tons per year for lead.

Saudi Arabia

The National Industrialization Corp. announced plans to construct the nation's first secondary lead smelter, capacity about 12,000 tons per year, near Jeddah. Startup is scheduled for early 1991. Late in the year, a group of Saudi private investors announced plans to construct a 25,000-tons-per-year plant near Riyadh, with MG of the FRG to be a 25% equity shareholder.

TABLE 17

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	57.5%	2% per 5,587	+54	5,641	
1886	3,335		year 5,633	−81	5,552	−181
1987	3,429		avg. 5,679	+43	5,722	
1988[p]	3,414	55%	growth 5,855	−5	5,855	
1989[e]	3,395		5,963	−60	5,903	
Total	40,781	58%	66,727	−90	66,637	[2]−90

[e] Estimated. [p] Preliminary.

[1] Recoverable content (95%) of mine production (lead in concentrates) divided by apparent consumption.

[2] Yearend stocks 1977 = 468; yearend stocks 1989 = 378 (estimated; producer, consumer, merchant, LME).

Spain

The nation's largest secondary lead producer, S.E. del Acumulador Tudor, doubled the capacity of its smelter at San Esteban de Gormaz from 20,000 tons per year to 40,000 tons per year to replace the yearend closing of its 15,000-tons-per-year plant at Zaragoza. Boliden Mineral AB of Sweden announced the significant discovery of a very large lead-zinc deposit, Los Frailes, near its Aznalcollar Mine, acquired from the Spanish company APIRSA in 1987. An estimated 50 million tons of ore grading 14% lead and zinc would make it one of Europe's largest base metal mines when developed. Pending further drilling, production could begin as early as mid-1992.

Tunisia

The Office National des Mines (ONM) and its partner, MG of the FRG, were studying the closed Bougrine Mine for possible reopening at depth. Deeper reserves are estimated to be 6 million tons grading 12% zinc and 6% lead. If approved, the mine could be on-stream within 3 years, producing 100,000 tons per year of lead and zinc concentrate. A lead-zinc deposit was discovered in the state of Kaf, estimated to contain 4 million tons of reserves, as a result of a joint-venture exploration program with BRGM of France.

United Kingdom

Britannia Refined Metals (BRM), a subsidiary of MIM of Australia, announced plans to acquire Chloride Metals' 30,000-tons-per-year secondary lead plant at Wakefield, West Yorkshire. In addition, BRM started to replace its 30,000-tons-per-year plant at Northfleet, Kent, utilizing MIM's revolutionary Isasmelt process, the first outside of Australia, and the first secondary application of the process. The process was developed with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO). The new smelter was scheduled for completion by mid-1991 at an increased capacity of 40,000 tons per year.

CURRENT RESEARCH

Recent and ongoing research relative to lead and its uses have focused

TABLE 18

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	3.8	3.6	3.6	3.6	3.6
Argentina	28.6	26.9	26.1	28.5	28.0
Australia	498.0	447.7	489.1	465.5	[3]495.0
Austria	[r]6.1	[r]4.7	5.2	2.3	2.0
Bolivia	6.2	3.1	9.0	12.5	[3]15.7
Brazil	[r]17.0	[r]13.6	11.6	14.3	14.6
Bulgaria[e]	95.0	95.0	97.0	97.0	97.0
Burma	21.9	18.2	27.1	16.7	12.0
Canada	268.3	349.3	413.7	368.4	[3]275.0
Chile	2.5	1.5	.8	1.4	1.4
China	[e]200.0	227.0	252.0	312.0	330.0
Colombia	.1	.2	.2	([4])	.1
Congo (Brazzaville)	1.5	[e]1.4	1.4	1.8	1.4
Czechoslovakia	2.7	2.9	[e]2.8	[e]2.8	2.8
Ecuador[e]	.2	.2	.2	.2	.2
Finland	2.4	2.0	[r e]2.9	[r e]1.9	1.8
France	2.5	2.5	2.2	2.0	1.1
Germany, Federal Republic of	20.5	16.7	18.8	14.3	7.8
Greece	19.8	20.9	20.6	[e]20.0	20.0
Greenland	17.8	16.2	20.5	23.1	20.0
Honduras	21.2	12.6	5.0	16.9	10.0
Hungary[e]	.7	—	—	—	—
India	27.1	37.6	36.7	30.5	32.0
Iran[e]	[3]21.6	21.6	21.6	21.6	22.0
Ireland	34.6	36.4	33.8	32.5	32.1
Italy	15.6	11.1	12.0	16.5	17.0
Japan	50.0	40.3	27.9	22.7	18.6
Kenya[e 5]	[r].6	[r].6	[r].5	[r].6	.6
Korea, North[e]	110.0	110.0	110.0	110.0	110.0
Korea, Republic of	9.7	11.9	14.0	14.5	[3]12.9
Mexico	[r]206.7	[r]182.7	177.2	171.3	[3]163.0
Morocco	106.8	76.2	75.7	72.2	67.3
Namibia	34.6	37.5	33.0	32.1	34.0
Nigeria[e]	.3	.1	[3].1	.1	.1
Norway	3.6	3.4	3.1	2.8	3.2
Peru	201.5	194.4	204.0	149.0	[3]192.2
Poland	51.3	42.5	48.8	[r e]49.0	47.0
Romania[e]	[r]30.0	[r]34.3	[r]36.3	[r]30.2	[3]37.7
South Africa, Republic of	98.4	97.8	93.6	90.2	[3]78.2
Spain	85.6	79.6	83.2	[r e]74.9	74.1
Sweden	[r]75.9	88.9	90.4	[e]91.0	89.0
Thailand	19.7	26.3	23.5	29.5	32.0
Tunisia	2.5	1.9	3.5	[e]3.5	3.5
Turkey[6]	9.8	10.4	9.5	[r e]11.0	14.8
U.S.S.R.[e]	440.0	440.0	440.0	440.0	440.0
United Kingdom	4.0	[r].6	.7	1.2	.8
United States	424.4	353.1	318.7	394.0	[3]419.3

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]	1985	1986	1987	1988[p]	1989[e]
Yugoslavia	115.1	114.6	106.7	103.3	100.0
Zambia[6]	15.0	14.9	14.5	[r e]15.0	14.0
Total	[r]3,431.2	[r]3,334.9	3,428.8	3,414.4	3,394.9

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through June 13, 1990.
[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] Pb content of ore.

TABLE 19

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina:					
Primary	15.1	15.7	16.2	[r e]16.0	16.0
Secondary	13.6	15.0	16.0	[e]16.0	16.0
Total	28.7	30.7	32.2	[r e]32.0	32.0
Australia:					
Primary	200.1	156.2	201.7	168.0	177.0
Secondary[e]	15.6	14.8	15.0	15.0	15.0
Total[e]	215.7	171.0	216.7	[r]183.0	[2]192.0
Austria:					
Primary	10.0	6.0	6.8	9.0	8.8
Secondary	15.5	19.0	16.0	16.0	15.2
Total	25.5	25.0	22.8	25.0	24.0
Belgium:					
Primary	75.3	64.5	71.1	83.2	80.0
Secondary	39.0	33.8	36.9	43.3	46.0
Total	114.3	98.3	108.0	126.5	126.0
Bolivia: Primary	.2	.2	.2	.4	[2].2
Brazil:					
Primary	29.8	32.7	29.8	29.5	[2]34.2
Secondary	51.8	52.0	58.4	68.7	[2]55.4
Total	81.6	84.7	88.2	98.2	[2]89.6
Bulgaria:[e]					
Primary	98.0	97.0	98.0	98.0	95.0
Secondary	18.0	17.0	17.0	17.0	10.0
Total	116.0	114.0	115.0	115.0	105.0
Burma: Primary	9.6	5.4	4.0	4.4	3.5
Canada:					
Primary	173.2	169.9	139.5	179.5	150.0
Secondary	68.4	87.7	91.2	89.9	83.0
Total	241.6	257.6	230.7	269.4	233.0

See footnotes at end of table.

strongly on improvements in the lead-acid battery, through all its ranges of applications, in terms of safety, capacity, dependability, and manufacturing-marketing economics.

Research performed in 1989 by Fuji Electrochemical Co. of Japan (FDK) and Isuzu Motors Ltd. of Japan, which was 38% owned by General Motors Corp. of Detroit, led to the development of a quick-charging automotive "battery" with a storage capacity 30 to 50 times greater than conventional SLI's. Commercial production was targeted for 1992. The capacitor-structured "battery," with internal resistance as low as one-hundredth of a double layer capacitor in terms of power accumulation capacity per cubic volume, can recover electric power in less than 30 seconds, with accumulation potential 10,000 times that of conventional capacitors. Individual coin-size cells can be linked in series or parallel circuitry on any irregular area, such as a car roof or bumper, for solar charging as a "key-off" or accessory supply, or to recharge a dead SLI battery. Other potential applications would be electric cars, home and industrial supplemental or load-levelling power supply, and aerospace. A coin-size cell can store power of 1 volt and 30 watts.[3]

In contract work performed for NASA's Jet Propulsion Laboratory (JPL), tile-like positive electrode squares with improved adhesion were developed to reduce flaking on the positive faces of bipolar plates, common after repeated charge-discharge cycles in conventional lead plates. This new segmented structure prevents defects from spreading across the structure. The plate body is made of fiberglass coated with conductive fluoride-doped tin oxide in epoxy resin. Lead dioxide paste, reinforced with the same conductive fibers, is then applied to the formed recesses after conditioning the body surface to improve adhesion. The negative side of the plate is then built up from epoxy and graphite, lead foil, and lead paste supported by a glass scrim.[4]

Also for JPL, performance of a conventional lead and litharge positive plate was improved from 25% to 40% efficiency to 65% to 68% efficiency by increasing the porosity of the active paste material. This was accomplished by covering the conventional grid with lead

sulfate paste blended with tin oxide-coated glass fibers. The lead sulfate, which has a large molecular volume, increases in density during charging, opening additional pores. Ironically, lead sulfate buildup and subsequent sloughing is a cause for shorting out and failure in conventional lead-acid battery construction. In preliminary tests the new cell was deeply discharged and recharged more than 2,000 times without fading.[5]

A patent was issued during the year on a range of synthetic polymeric materials exhibiting an electrochemical ionic semiconductivity previously known only in living organisms. These materials greatly enhance ion selectivity with no change in resistivity when used as plate separators in a battery system. Because they also essentially eliminate nonionic transfer, they control the mobility within electrolytes of all metals, facilitating their use as electrodes in virtually all metal-metal secondary battery systems also. Known generically as EPM materials, they can be used as electrolytic cells for the extraction of metal ions from process effluents, as nonporous breathable coatings for protective clothing or bandages, or even as a synthetic skin in burn treatment.[6]

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, Lead Development Association, London, United Kingdom.

OUTLOOK

Although overall domestic consumption of lead has grown at an average rate of about 3% per year since 1985, this rate is not expected to be sustained, primarily because of institutional factors. As the Nation pays increased attention to pollution prevention mentality instead of the present strategy of waste minimization through command and control techniques, some end uses of lead will certainly be curtailed or eliminated entirely by legislation or regulation. One of the pollution prevention strategies known as source reduction will most likely reduce the use of lead in nongrowth markets such as solders; paints and coatings (already

TABLE 19—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
China:[e]					
Primary	170.0	200.0	200.0	200.0	220.0
Secondary	40.0	40.0	40.0	45.0	50.0
Total	210.0	240.0	240.0	245.0	270.0
Colombia: Secondary[e]	3.0	4.0	4.0	4.0	3.5
Cyprus: Secondary[e]	(3)	(3)	(3)	(3)	—
Czechoslovakia: Secondary	21.4	23.6	26.0	26.0	26.0
Denmark: Secondary	4.5	.6	—	—	
Finland: Secondary	4.4	1.2	[e]1.2	[e]2.0	2.0
France:					
Primary	133.6	132.0	138.8	146.5	147.0
Secondary	90.0	98.4	107.1	109.2	108.0
Total	223.6	230.4	245.9	255.7	255.0
German Democratic Republic:[e]					
Primary	19.2	15.5	17.1	19.2	18.2
Secondary	[r]35.8	[r]29.0	[r]32.0	[r]35.8	33.8
Total	55.0	[r]44.5	[r]49.1	[r]55.0	52.0
Germany, Federal Republic of:					
Primary	181.0	182.1	167.6	176.6	182.0
Secondary	175.3	184.5	172.8	168.5	168.0
Total	356.3	366.6	340.4	345.1	350.0
Greece: Primary	13.7	19.3	2.7	[r e]5.0	5.0
Guatemala: Secondary	.1	.1	.1	.1	[2].2
Hungary: Secondary[e]	.1	.1	.1	.1	.1
India:					
Primary	15.6	19.9	20.7	18.8	19.0
Secondary	[e]10.0	11.3	12.1	14.0	15.0
Total	[e]25.6	31.2	32.8	32.8	34.0
Iran: Secondary[e]	7.5	8.0	10.0	10.0	10.0
Ireland: Secondary	9.0	10.2	9.6	[e]10.0	10.0
Italy:					
Primary	[r]29.5	[r]29.3	62.3	72.2	72.5
Secondary	96.7	[r]101.7	111.4	111.6	112.0
Total	[r]126.2	[r]131.0	173.7	183.8	184.5
Jamaica: Secondary[e]	1.0	1.0	1.0	1.0	1.0
Japan:					
Primary	233.7	232.7	218.8	217.7	[2]207.7
Secondary	133.3	128.7	119.5	122.3	[2]124.6
Total	367.0	361.4	338.3	340.0	[2]332.3
Kenya: Secondary[e]	2.0	[r]2.0	[r]2.0	[r]2.0	1.0
Korea, North: Primary[e]	95.0	95.0	95.0	95.0	95.0
Korea, Republic of:[e]					
Primary	11.0	32.1	52.5	[r]46.0	36.8
Secondary	9.2	27.5	30.0	[r]44.0	44.1
Total	20.2	59.6	82.5	[r]90.0	80.9
Malaysia: Secondary	14.6	13.8	11.8	[e]12.4	12.5

See footnotes at end of table.

TABLE 19—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Mexico:					
Primary	r203.0	r182.0	177.0	168.1	2160.9
Secondary[e]	31.0	33.0	235.0	35.0	35.0
Total[e]	r234.0	r215.0	212.0	203.1	195.9
Morocco:					
Primary	59.5	60.0	62.5	e62.5	62.5
Secondary[e]	2.0	2.0	2.0	2.0	2.0
Total[e]	61.5	62.0	64.5	64.5	64.5
Namibia: Primary	38.5	40.0	40.6	44.4	45.0
Netherlands: Secondary[e]	25.0	33.0	35.7	39.5	40.0
New Zealand: Secondary[e]	6.0	4.0	23.6	3.0	5.0
Nigeria: Secondary	.8	1.0	.3	e.5	.5
Pakistan: Secondary[e]	1.0	1.0	2.0	2.0	2.0
Peru:					
Primary	81.9	66.4	71.3	53.6	70.0
Secondary[e]	5.0	5.0	5.0	5.0	5.0
Total[e]	86.9	71.4	76.3	58.6	75.0
Philippines: Secondary[e]	7.0	7.0	7.0	7.0	7.0
Poland:					
Primary[e]	61.1	63.3	64.5	r61.0	61.0
Secondary[e]	26.2	25.0	25.0	r36.0	20.0
Total	87.3	88.3	89.5	r97.0	81.0
Portugal: Secondary[e]	7.0	6.0	6.5	6.5	6.5
Romania:[e]					
Primary	38.6	36.0	233.2	r38.0	45.0
Secondary	10.0	15.5	10.0	10.0	15.0
Total	48.6	51.5	r43.2	r48.0	60.0
South Africa, Republic of: Secondary	32.8	40.5	38.3	37.4	236.0
Spain:					
Primary	112.8	88.0	71.4	r e68.8	75.0
Secondary	43.3	42.0	51.3	r e52.0	50.0
Total	156.1	130.0	122.7	r e120.8	125.0
Sweden:					
Primary	43.2	r49.2	61.2	e60.0	58.0
Secondary	25.9	r27.8	30.2	e30.0	28.0
Total	69.1	r77.0	91.4	e90.0	86.0
Switzerland: Secondary	2.0	r2.5	2.5	1.5	1.4
Taiwan: Secondary[e]	r48.7	53.5	r66.4	r67.3	67.2
Thailand: Secondary	7.5	9.1	11.4	15.6	16.0
Trinidad and Tobago: Secondary[e]	2.0	2.0	1.8	1.8	1.8
Tunisia:					
Primary	2.0	2.2	e2.2	e2.2	2.2
Secondary[e]	.5	.5	.5	.5	.5
Total[e]	2.5	2.7	2.7	2.7	2.7

See footnotes at end of table.

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 an average range of 0.5% to 1.0% per year in the decade of the 90's as the storage battery sector becomes even more dominant. The lower average 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 lead-acid batteries for peak-power, load-levelling applications become widely accepted for households and commercial facilities.

World demand for lead, including the United States., has grown at an average rate of about 2% through 1989 since the low recession year of 1982 (table 17). Lower growth domestic demand, which is currently about 21% of the total, will undoubtedly lower the overall 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 as 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 alone, 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 discussed in the following section. 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 geo-

TABLE 19—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Turkey:[e]					
Primary	6.5	7.0	7.0	7.3	9.8
Secondary	2.5	2.6	3.0	3.7	1.0
Total	[r]9.0	[r]9.6	10.0	[r]11.0	10.8
U.S.S.R.:[e]					
Primary	[r]485.0	[r]485.0	[r]475.0	[r]447.0	455.0
Secondary	265.0	270.0	275.0	280.0	280.0
Total	[r]750.0	[r]755.0	[r]750.0	[r]727.0	735.0
United Kingdom:					
Primary	148.1	156.1	137.5	172.2	160.0
Secondary	179.1	172.5	200.7	201.6	200.0
Total	327.2	328.6	338.2	373.8	360.0
United States:					
Primary	494.0	370.3	373.6	392.1	396.5
Secondary	615.7	624.8	710.2	736.4	808.6
Total	1,109.7	995.1	1,083.8	1,128.5	1,205.1
Venezuela: Secondary[e]	18.0	16.0	17.0	18.5	17.0
Yugoslavia:					
Primary	[r]60.0	[r]75.0	76.4	70.9	78.0
Secondary	40.0	[r]38.0	36.0	[e]39.0	41.0
Total	[r]100.0	[r]113.0	112.4	109.9	119.0
Zambia: Primary	8.9	6.6	8.0	6.4	7.0
Grand total of which:	[r]5,640.5	[r]5,551.9	5,721.8	5,855.2	5,902.7
Primary	[r]3,356.7	[r]3,192.6	3,204.2	3,239.5	3,253.8
Secondary	[r]2,283.8	[r]2,359.3	2,517.6	2,615.7	2,648.9

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through June 13, 1990. 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] Revised to zero.

logic relationships of the three metals in the primary production sector.

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. The reasons, whether market-driven, technology-driven, environmentally driven, or combinations thereof, are discussed in the following section.

BACKGROUND

Industry Structure

Since the development of the last major lead-producing region in 1968, the first year of significant production from the Viburnum Trend in Southeast Missouri, large-scale structural changes have occurred worldwide in both the producing and consuming sectors of the lead industry. Most apparent, as illustrated in table 17, is the decline in primary demand, which has accelerated downward in recent years and is expected to continue this trend at a similar rate into the next century. The milestone year was 1984 when world mine production dropped to a 15-year low. As the world economy pulled out of recession, resource recycling was emphasized as world demand accelerated. A proliferation of new secondary plants has appeared together with expansion of capacity at older plants and environmental concerns for improved performance forcing technologic retrofitting. This was especially noticeable by 1988 when world supply and demand were almost in balance (table 17). However, at yearend 1989, world metal stocks were extremely low relative to demand as world demand again outstripped production, as was the case in 1986. Although world secondary refinery production was an estimated record 2.65 million tons in 1989, mine production was estimated to be about the same level as 1978, in spite of significant increased production from new mines and increasing productivity at some old mines, especially in China.

Although increasing worldwide environmental awareness will continue to force an increasingly greater share of demand to be supplied from secondary sources, this will not alleviate the tight supply problem, regardless of the rate of recycling increase, without a considerable revolutionary (as opposed to evolutionary) technology shift. Basically, this will require electrowinning and/or eletrorefining to obtain premium metal (99.99% plus), the occasional spot shortages of which have led to market "tightness" in the fourth quarters of 1988 and 1989. Conventional primary smelters fed by virgin ores can achieve this, especially with electrorefining (nearly 99.999%), but the best on average that conventional secondary smelter refineries can achieve is 99.985% purity. Premiums for the purer product have kept average prices artificially high the past 2 years. Eventually, a rationalization of worldwide environmental codes will alleviate this problem by forcing optimum recycling in conjunction with clean technology reprocessing.

Ironically, the demand for high-purity lead has been fed by evolutionary changes in the worldwide demand pattern itself and not simply the volume increase. Original equipment automotive batteries and some large UPS system batteries that are continuously on-line as voltage regulators and not subject to drawdown are more amenable to the use of high-purity calcium lead alloys. This is especially critical for the mass-production automobile industry. Replacement "hybrid" type low antimonial lead batteries, which are superior in electrical charge recovery cyclability but are more expensive to make, can carry a premium not associated with the cost of buying a new car. However, because of the greater volume

necessary (5 out of 6 in the United States) compared with the original equipment battery market, discounts can often offset this to the consumer, especially when the market is saturated.

What all this has led to in recent years is a massive worldwide restructuring and rationalization of the industry. In some cases retrenchment; in others vertical integration, often through multi-national mergers, especially on the primary side; in still others, lateral merging for more flexible marketing; and, in other cases, joint ventures, divestiture, or expansion depending on capital availability and its cost or simple conviction or lack thereof to remain competitive under continuously changing and evolving conditions.

One of the best examples of multinational restructuring through mergers on the primary side to increase vertical integration for some parties, facilitate cash-flow for investment for others, and ensure flexible marketing for all involved Asarco, one of the two remaining domestic primary lead metal producers. According to its 1989 annual report, Asarco, which is essentially a custom smelting company, has substantial interests in three of the world's major mining companies: an 18.7% stake in MIM of Australia, a 52.3% ownership of Southern Peru Copper Corp. (SPCC), and a 34% holding in Mexico Desaraollo Industrial Minero, S.A. de C.V. (MEDIMSA). MIM, which in return has a 24.9% interest in Asarco, is a partially integrated producer of copper, silver, gold, lead, zinc, and coal. SPCC operates two large copper mines and a copper smelter in Peru. MEDIMSA is a holding company for several, not necessarily integrated, companies in Mexico engaged in the mining, milling, smelting and refining of nonferrous metals, including the large integrated copper producer Mexicana de Cobre, S.A. de C.V. All these associated companies accounted for about 11% of the market economy countries' mine production of copper, 17% of silver, 14% of lead, and 10% of zinc in 1989, according to Asarco. In addition, MIM owns a secondary lead plant in Taiwan, and Asarco is presently considering reentering that sector in the United States, representing lateral integration within one commodity, following the leadership of Doe Run. Other examples would be SAMIM's involvement in both primary and secondary sectors in Italy, with MG of the FRG as previously discussed, and Brittania Metals in the United Kingdom, a subsidiary of MIM.

The total merger of Peñarroya of France with Preussag AG of the FRG in late 1987 into Metaleurop is an example of multilayer restructing and merger on a grand scale. In late 1989, MG, in an attempt to expand its base production and raw material reserves on a global scale, hiked its share in MIM from 4% to 10.5%. MIM has a 3% interest in MG and a 9% interest in Cominco Ltd. of Canada, one of the world's leading base metal producers, in which MG has a 37% share through its Canadian holding company, Metall Mining Co. Ltd. Mitsubishi Mining and Smelting Co. Ltd. of Japan also has a small interest in Cominco, and they jointly own and operate a primary lead smelter that also utilizes secondary feed at Noashima called Mitsubishi Cominco Smelting Co. Ltd.

In the United States, there are two prime examples of divestiture in recent years, as both AMAX Inc. and Kennecott have gotten out of the lead business because of environmental risks and uncertain future markets. AMAX's interests, the Buick Mine and Boss Smelter-refinery, were eventually folded into The Doe Run Co. along with its partner, the Homestake Lead Mining Co. of Missouri. The interests of Kennecott's Ozark Lead Co. were acquired by Asarco.

Doe Run's pending lateral movement into the secondary sector utilizing "clean processing technology" will allow them market flexibility by, ironically, reopening the Buick conventional refinery only. Pyrometallurgical refineries can be made environmentally sound by retrofitting, not yet proven for conventional smelters, and extremely doubtful if stricter emission standards are applied. However, by combining the two processes, Doe Run will be better able to compete in the antimonial lead market, almost exclusively the domain of secondary producers in the United States. RSR Corp., which is about equal to Doe Run in lead production, on the other hand has chosen to convert to electrowinning with electrorefining of the metallic portion of the scrap to penetrate the premium market, now controlled by the primary producers in the United States.

On the consuming side, in the battery sector, multinational mergers and joint-producing ventures have also become common in recent years as new automated manufacturing technologies and new environmental codes spread rapidly, requiring increasing new capital investment. Recent examples of this in the United States have been Dunlop of Australia's acquisition of Chloride Inc., a former U.S. subsidiary of the Chloride Group of the United Kingdom, to form Pacific Chloride Inc., and then acquiring GNB Inc., the Nation's third largest battery company, renamed Pacific Dunlop Inc. Exide Corp., the Nation's largest battery manufacturer, has formed joint ventures with Yuasa Electric Storage Battery Co. Ltd., one of Japan's largest, to manufacture batteries for Japanese car manufacturers in the United States and also to manufacture replacement motorcycle batteries. The joint-venture plant at Reading, PA, adjacent to Exide's large secondary smelter-refinery-plastics complex, is the Nation's largest motorcycle battery plant, according to Exide.

Costs

In 1987 the Bureau of Mines investigated the domestic primary and secondary lead smelting and refining industries to determine the economic impacts of then existing and proposed environmental, health, and safety regulations. The impacts were assessed in terms of capital and operating costs for existing and alternative smelting-refining technologies. For the primary sector, the estimated capital cost to rehabilitate the three Missouri smelter-refineries by replacing the present sinter plant-blast furnace operations with dryers, flash smelting, continuous drossing, and double-contact acid plants was estimated to be $1,000 per annual ton of capacity, or $400 million 1987 dollars. The estimated capital expenditure for a single 400,000 ton replacement "green field" flash smelter in Missouri, optimally located, was estimated to be $750 per annual ton of capacity, or $300 million 1987 dollars. That plant would incorporate all BAT, including total ambient ventilation, and collection of airborne particulates from all plant areas. A second option analyzed was that for three QSL-type bath furnaces at a single location, estimated capital cost about the same as that for

rehabilitation of the existing three separate plants. Over 90% of the costs in all three scenarios were attributed to the requirements for improved airborne particulate (on-site and offsite) and SO_2 emission controls.

The average investment cost required for the 24 secondary plants processing batteries in 1987 to achieve existing regulatory compliance was estimated to average $124 per annual ton of plant capacity for those studied. An average additional cost of about $400 per annual ton of capacity was estimated and would be required to meet the most probable new lead NAAQS of 0.5 $\mu g/m^3$. The latter cost was purely an estimate based on secondary industry responses to the Bureau of Mines for probable equipment requirements.

None of the foregoing estimates imply that investing the necessary capital expenditures would guarantee full compliance with all EPA, OSHA, or State requirements, in either the primary or secondary sectors.

With respect to basic operating costs only, the Bureau found that in 1987, these averaged 22 cents per pound for the secondary plants studied and 20.8 cents for the primary plants, allowing for 11.9 cents per pound byproduct credits in the latter case. After including taxes, capital recovery, and a 15% discounted cashflow return on investment, total costs were 23.1 cents and 23.8 cents, respectively.

Raw material feed costs, in recoverable metal terms, averaged 14.2 cents per pound for the primary plants and were assumed to be 9 cents for the secondary plants. Regulatory costs for these plants, on average, were 2.75 cents for primary and 3 cents for secondary at that time, but none of the plants in either sector were in full compliance with all EPA and OSHA or State regulations. An additional average cost per plant to meet the then existing regulations would have been 5.5 cents per pound for the primaries, only by complete rehabilitation, and 3.8 cents for the secondaries, requiring extensive retrofitting. The additional 5.5 cents for the primary case allowed for an additional (to 11.9 cents) estimated attendant 0.7 cent per pound increase in the deductible byproduct credit because of improved recovery (12.6 cents). Total required upgrading to meet the existing 1987 regulations, including taxes and return on investment, would have resulted in total average costs of 29.3 cents per pound for the primaries and 27.2 cents for the secondaries. Updating these costs to 1989 would require an additional average of 3 to 5 cents per pound in recoverable metal feed costs for secondary plants because of higher prices for battery scrap during 1988 and 1989. On the primary side, however, the mine and mill average costs have probably decreased at captive mines as a result of improved productivity, resulting in a slight reduction of raw material feed costs to the smelters. Some additional retrofitting costs at the smelters since 1987 were probably offset by improved productivity resulting primarily from institutional changes at Doe Run, discussed earlier.

It was estimated by the Bureau in 1987 that an additional average retrofit operating cost of at least 2 cents per pound on top of the capital requirements would be necessary for secondary plants to meet a probable NAAQS of 0.5 $\mu g/m^3$. The proposed revised drinking water standard, which will directly impact plant discharges and process effluents, could double that additional cost or more. For primary plants, it is virtually certain that neither total rehabilitation nor new BAT plants, flash or bath, could meet such a NAAQS revision. It was estimated in 1987 that a new flash plant would operate at 28.2 cents per pound, including capital recovery and return on investment and discounting improved byproduct recovery credits of 12.8 cents per pound. The comparable figure estimated for a new bath plant (QSL-type), was 29.4 cents. Although the latter has an inherent lower functional processing cost as the feedstock does not have to be dried, the capital recovery costs included are estimated to be 1.7 cents per pound greater than that for a flash plant (Outokumpu-type).[7]

[1] International Lead and Zinc Study Group (London). Lead and Zinc Statistics. ILZSG Mon. Bull., v. 30, No. 9, Sept. 1990, p. 18.

[2] Page 33 of work cited in footnote 1.

[3] American Metal Market. Apr. 18, 1990.

[4] NASA Tech. Briefs. Apr. 1990, p. 22.

[5] ——. May 1990, p. 34.

[6] Advanced Battery Technology. July 1989, p. 5.

[7] Isherwood, R. J., Smith, R. C., Kiehn, O. A., and Daley, M. R. Impact of Existing and Proposed Regulations on the Domestic Lead Industry. BuMines OFR 55-88, Aug. 1988, 33 pp.

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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	1988				1989			
	Production		Shipments		Production		Shipments	
	Gross weight[r]	Lead content[r]	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	83,719	77,747	84,065	$91,828,401	78,733	73,000	81,684	$82,655,677
Leady oxide	467,736	444,350	NA	NA	472,112	448,507	NA	NA
Total	551,455	522,097	NA	NA	550,845	521,507	NA	NA

[r] Revised. 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.

TABLE 21

U.S. IMPORTS FOR CONSUMPTION OF LEAD PIGMENTS AND COMPOUNDS, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
1988		
White lead	219	$297
Red lead	804	756
Litharge	11,494	8,325
Chrome yellow	3,999	7,720
Other lead pigments	1,202	2,830
Other lead compounds	1,724	2,363
Total	19,442	22,291
1989[1]		
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

[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.

Source: Bureau of the Census.

TABLE 22

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):				
Australia	23	$9	—	—
Belgium	1,035	445	1,114	$345
Canada	5,735	2,308	38,706	12,773
Germany, Federal Republic of	332	100	—	—
India	99	41	3,959	1,764
Japan	6,609	4,694	1,646	759
Korea, Republic of	370	144	733	308
Mexico	72	21	944	303
Netherlands	711	287	109	58
Spain	1,224	577	7,788	6,383
Taiwan	3,557	1,523	748	243
U.S.S.R.	—	—	485	303
United Kingdom	741	336	441	125
Venezuela	27	8	—	—
Other	367	185	365	152
Total	20,902	10,678	57,038	23,516
Ash and residues (lead content):[2]				
Austria	16	41	—	—
Belgium	14,637	7,892	9,560	5,221
Canada	314	225	18	19
France	19	204	—	—
Germany, Federal Republic of	34	50	179	200
Hong Kong	20	23	—	—
India	—	—	68	18
Japan	17	20	—	—
United Kingdom	418	318	125	140
Other	r8	r35	10	14
Total	15,483	8,808	9,960	5,612
Unwrought lead and lead alloys (lead content):				
Australia	202	222	87	133
Belgium	5	10	25	61
Canada	2,365	2,286	4,017	3,500
Chile	132	165	250	280
China	(3)	3	978	776
Dominican Republic	88	89	7	6
Germany, Federal Republic of	64	345	19	30
Haiti	10	13	65	233
Honduras	22	26	—	—
Hong Kong	8	14	108	100
Indonesia	—	—	18	18
Israel	478	377	3,377	2,579
Italy	61	147	29	49
Japan	99	123	1,619	1,873

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought lead and lead alloys (lead content)—Continued				
Korea, Republic of	1,043	850	4,384	4,777
Malaysia	—	—	3,005	2,114
Malta	54	65	3	13
Mexico	1,103	1,743	689	660
Netherlands	14	12	1,597	1,774
Peru	—	—	80	149
Philippines	18	26	60	79
Saudi Arabia	22	76	—	—
Singapore	77	48	4,010	3,409
South Africa, Republic of	73	79	9	54
Sudan	608	549	170	169
Taiwan	886	600	3,518	6,312
Trinidad	5	20	159	100
United Kingdom	31	36	127	575
Venezuela	7	33	—	—
Other	r71	r132	102	268
Total	7,546	8,089	28,512	30,091
Wrought lead and lead alloys (lead content):				
Antigua	—	—	18	$25
Argentina	(3)	$2	6	24
Australia	—	—	7	73
Barbados	1	5	10	51
Belgium	(3)	2	11	33
Bermuda	—	—	5	7
British Virgin Islands	—	—	10	8
Canada	2,734	2,178	1,994	2,748
Chile	10	45	2	18
Colombia	(3)	2	29	111
Dominican Republic	30	38	4	25
Ecuador	4	7	27	63
Egypt	—	—	5	2
Finland	—	—	18	100
France	77	179	62	430
Germany, Federal Republic of	4	14	516	808
Guatemala	7	7	10	35
Haiti	7	61	21	72
Hong Kong	6	37	115	410
India	—	—	121	231
Israel	8	11	37	164
Italy	8	11	19	119
Jamaica	49	59	10	24
Japan	174	260	312	1,255
Korea, Republic of	78	190	61	329
Malta	—	—	12	83

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead and lead alloys (lead content)—Continued				
Mexico	2,533	3,899	1,110	2,999
Netherlands	71	116	193	428
Paraguay	23	35	—	—
Philippines	121	240	34	223
Saudia Arabia	—	—	49	145
Singapore	7	41	59	829
Spain	—	—	167	747
Sweden	1	20	14	94
Taiwan	1	15	58	240
Thailand	—	—	21	267
United Arab Emirates	—	—	5	7
United Kingdom	23	19	148	402
Venezuela	60	288	23	102
Other	r11	r49	42	382
Total	6,048	7,830	5,365	14,113
Grand total	49,979	35,405	100,875	73,332
Scrap (gross weight):				
Bahamas	—	—	380	45
Belgium	107	31	1,173	291
Brazil	16,112	4,171	4,559	1,550
Canada	12,480	3,900	10,646	4,658
Chile	—	—	105	10
China	398	89	3,054	703
France	160	35	549	146
Germany, Federal Republic of	2,788	579	1,618	363
Honduras	—	—	50	5
India	2,417	687	5,768	2,623
Ireland	266	154	—	—
Israel	820	614	—	—
Japan	120	290	1,296	4,060
Korea, Republic of	3,198	960	3,655	4,601
Mexico	11,112	2,221	10,755	2,854
Netherlands	391	108	3,010	728
Netherlands Antilles	—	—	89	46
Panama	—	—	96	26
Philippines	99	24	26	5
Saudi Arabia	—	—	1,573	288
Singapore	—	—	272	159
South Africa, Republic of	2,692	962	877	377
Spain	4,720	1,116	6,155	690
Taiwan	10,036	2,446	997	654
Thailand	65	8	—	—
United Arab Emirates	98	24	91	21
United Kingdom	6,731	2,719	2,232	886

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Scrap (gross weight)—Continued				
Venezuela	6,972	2,034	739	174
Other	r128	r40	144	202
Total	81,910	23,212	59,909	26,165

r Revised.
[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, export categories for 1989 are not necessarily comparable with those in 1988.
[2] Before 1989, title was "Drosses and residues, including flue dust."
[3] Less than 1/2 unit.

Source: Bureau of the 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)
1987	3,367	$3,181	984	$1,741	5,686	$6,910	79	$113	52,823	$15,670	3,470	$2,589
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

[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 are not necessarily comparable with those in 1987 and 1988.

Source: Bureau of the Census.

TABLE 24

U.S. IMPORTS[1] OF LEAD, BY COUNTRY

(Lead content)

Country	1987		1988		1989[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates:[3]						
Australia	1,724	$456	1,431	$631	1,910	$1,306
Bolivia	—	—	377	191	36	12
Canada	201,165	50,683	221,785	72,976	189,907	62,387
Chile	3,231	985	3	1	—	—
China	3,568	2,203	—	—	—	—
Honduras	—	—	—	—	21	12
Mexico	1,070	628	—	—	40	27
Peru	19,098	10,309	11,436	6,077	12,888	5,293
Total	229,856	65,264	235,032	79,876	204,802	69,037
Base bullion:						
Belgium-Luxembourg[4]	1,414	955	999	737	—	—
Canada	—	—	50	33	37	31
China	—	—	34	15	345	173
France	1,699	1,136	249	170	—	—
Germany, Federal Republic of	350	258	—	—	—	—
Italy	1,250	904	—	—	—	—
Japan	1,800	1,165	—	—	—	—
Korea, Republic of	17	10	76	49	—	—
Mexico	881	278	1,213	779	5,400	4,334
Morocco	—	—	376	267	—	—
Netherlands	1,749	1,276	—	—	—	—
Peru	—	—	501	354	—	—
Spain	1,200	886	—	—	—	—
Sweden	—	—	2,002	1,498	—	—
United Kingdom	401	284	999	660	—	—
Other	66	87	r50	r33	—	—
Total	10,827	7,239	6,549	4,595	5,782	4,538
Pigs and bars:						
Australia	63	37	6,719	3,981	—	—
Belgium-Luxembourg[4]	4,950	3,299	499	310	41	25
Bolivia	2	12	36	22	52	48
Brazil	—	—	(5)	2	1,510	974
Canada	92,643	61,384	104,815	77,207	90,479	61,951
China	574	357	653	403	6	5
France	3,193	2,102	299	94	—	—
Germany, Federal Republic of	8,824	5,755	1,212	1,446	144	269
Italy	1,800	1,232	1,800	1,139	1,731	1,238
Japan	906	704	—	—	—	—
Macao	403	298	—	—	—	—
Mexico	42,635	28,457	30,937	21,580	19,178	13,232
Morocco	1,500	1,001	—	—	—	—
Mozambique	87	66	—	—	—	—
Netherlands	6,317	3,939	—	—	—	—
Peru	350	189	—	—	4,316	2,913
Poland	2,500	1,535	—	—	—	—
Spain	5,999	3,887	—	—	—	—

See footnotes at end of table.

TABLE 24—Continued

U.S. IMPORTS[1] OF LEAD, BY COUNTRY

(Lead content)

Country	1987		1988		1989[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Pigs and bars—Continued						
Sweden	9,086	5,887	—	—	—	—
Switzerland	201	141	58	40	—	—
United Arab Emirates	—	—	8	44	296	510
United Kingdom	4,039	3,180	88	161	—	—
Venezuela	—	—	—	—	126	81
Yugoslavia	1,020	634	—	—	277	319
Zambia	903	612	—	—	—	—
Other	r81	r134	r(6)	r(6)	—	—
Total	188,076	124,842	147,124	106,429	118,156	81,565
Reclaimed scrap, including ash and residues:[7 8]						
Canada	3,062	1,600	2,854	1,230	487	182
Costa Rica	2	1	52	28	—	—
Hong Kong	48	31	—	—	—	—
Japan	323	185	16	90	(5)	4
Malaysia	38	23	—	—	—	—
Mexico	3,034	1,230	4,202	1,845	—	—
Netherlands Antilles	—	—	22	3	332	169
Panama	44	23	92	53	—	—
Philippines	17	10	—	—	—	—
United Arab Emirates	—	—	25	78	—	—
Other	19	25	26	12	—	—
Total	6,587	3,128	7,289	3,339	819	355
Grand total	435,346	200,473	395,994	194,239	329,559	155,495

r Revised.
[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 are not necessarily comparable with those in 1987 and 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] For 1987, Belgium and Luxembourg combined, data not available to separate; 1988 and 1989 are data for Belgium only.
[5] Less than 1/2 unit.
[6] Revised to zero.
[7] Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).
[8] 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	1987		1988		1989[1]	
	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	—	—
Canada	696	$231	8,171	3,995	2,124	$830
Honduras	—	—	1,396	1,016	21	11
Mexico	177	77	—	—	40	27
Peru	—	—	4,383	2,705	2,937	1,107
Total	873	308	20,606	11,224	5,122	1,975
Base bullion (lead content):						
Belgium-Luxembourg[3]	1,414	955	999	737	—	—
Canada	—	—	50	33	37	31
China	—	—	34	15	345	173
France	1,699	1,136	249	170	—	—
Germany, Federal Republic of	350	258	—	—	—	—
Italy	1,250	904	—	—	—	—
Japan	1,800	1,165	—	—	—	—
Korea, Republic of	—	—	76	49	—	—
Mexico	881	278	1,213	779	5,400	4,334
Morocco	—	—	376	267	—	—
Netherlands	1,749	1,276	—	—	—	—
Spain	1,200	886	—	—	—	—
United Kingdom	401	284	999	660	—	—
Other	83	97	r50	r33	—	—
Total	10,827	7,239	4,046	2,743	5,782	4,538
Pigs and bars (lead content):						
Australia	63	37	6,719	3,981	—	—
Belgium-Luxembourg[3]	4,950	3,299	499	310	41	25
Bolivia	2	12	36	22	52	48
Brazil	—	—	(4)	2	1,510	974
Canada	92,643	61,384	104,815	77,207	90,479	61,951
China	574	357	653	403	6	5
France	3,193	2,102	299	94	—	—
Germany, Federal Republic of	7,325	4,682	2,713	2,519	144	269
Italy	1,800	1,232	1,800	1,139	1,731	1,238
Japan	906	704	—	—	—	—
Macao	403	298	—	—	—	—
Mexico	42,635	28,457	30,916	21,562	18,703	12,900
Morocco	1,500	1,001	—	—	—	—
Mozambique	87	66	—	—	—	—
Netherlands	6,317	3,939	—	—	—	—
Peru	350	189	—	—	2,316	1,543
Poland	2,500	1,535	—	—	—	—
Spain	5,999	3,887	—	—	—	—
Sweden	9,086	5,887	—	—	—	—
Switzerland	201	141	58	40	—	—
United Arab Emirates	—	—	8	44	296	510
United Kingdom	4,039	3,180	88	161	277	319
Venezuela	—	—	—	—	126	81

See footnotes at end of table.

TABLE 25—Continued

U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1987		1988		1989[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Pigs and bars (lead content)—Continued						
Yugoslavia	1,020	634	—	—	—	—
Other	r80	r134	r(5)	r(5)	—	—
Total	185,673	123,157	148,604	107,484	115,681	79,863
Reclaimed scrap, including ash and residues (lead content):[6 7]						
Canada	3,062	1,600	2,854	1,230	345	113
Costa Rica	2	1	52	28	—	—
Hong Kong	48	31	—	—	—	—
Japan	323	185	16	90	(4)	4
Malaysia	38	23	—	—	—	—
Mexico	3,034	1,230	4,202	1,845	—	—
Netherlands Antilles	—	—	22	3	332	169
Panama	44	23	92	53	—	—
Philippines	17	10	—	—	—	—
United Arab Emirates	—	—	25	78	—	—
Other	19	25	26	12	—	—
Total	6,587	3,128	7,289	3,339	677	286
Grand total	203,960	133,832	180,545	124,790	127,262	86,662
Wrought lead, all forms, including wire and powders (gross weight):[8]						
Belgium-Luxembourg[3]	18	38	32	65	68	181
Canada	352	414	283	472	770	1,257
China	—	—	—	—	279	719
Germany, Federal Republic of	256	827	199	494	244	837
Italy	55	110	39	87	50	160
Japan	128	2,338	3	76	37	393
Mexico	180	121	2,285	1,280	2,539	1,797
Peru	622	360	40	28	1,284	927
Spain	118	140	45	101	7	117
Taiwan	6	12	7	18	248	658
United Kingdom	1,047	895	478	586	406	989
Other	r11	r46	r34	r73	136	1,041
Total	2,793	5,301	3,445	3,280	6,068	9,076

r Revised.

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable with those in 1987 and 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] For 1987 Belgium and Luxembourg combined, data not available to separate; 1988 and 1989 data are for Belgium only.

[4] Less than 1/2 unit.

[5] Revised to zero.

[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, etc."

[8] 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)
1987	182,852	$119,444	13,648	$10,952	2,483	$2,768	310	$2,533	6,088	$2,805	499	$323
1988	137,598	97,565	15,052	12,662	3,331	3,101	114	179	6,938	3,094	351	245

Year	Blocks, pigs, anodes, etc.				Wrought lead and lead alloys (gross weight)						Scrap		Ash and residues	
	Unwrought[2]		Unwrought alloys		Strip, sheets, plates, and foil		Bars, rods, tubes, pipe, wire, fittings		Powders and flakes					
	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

[1] Lead content, unless otherwise specified.
[2] Includes bullion.
[3] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable with those in 1987 and 1988.

Source: Bureau of the 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)
1986	1,016	517	$3,810
1987	970	515	4,185
1988	1,623	992	8,838
1989[2]	1,789	852	11,908

[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 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 12 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.

Total lime sold or used by domestic producers, including that from Puerto Rico, remained essentially unchanged at 17.2 million tons in 1989. These products, valued at over $856 million, included quicklime and hydrated lime for commercial sale or captive consumption. Commercial sales increased for the third straight year and were at their highest level since 1979. Captive consumption decreased to the lowest level since the Bureau of Mines first collected accurate data on captive production in 1958.

DOMESTIC DATA COVERAGE

Domestic production data for lime are developed by the Bureau of Mines from two separate voluntary surveys of U.S. operations. The survey used to prepare this report is the annual "Lime" survey. Of the 116 operations to which the annual survey request was sent, 114 responded, representing 98% of the total sold or used by producers shown in table 2. Production for the two nonrespondents was estimated using reported prior-year production figures.

LEGISLATION AND GOVERNMENT PROGRAMS

Section 3001 of the Resource Conservation and Recovery Act (RCRA), enacted on October 21, 1976, mandated that the Environmental Protection Agency (EPA) "promulgate regulations identifying characteristics of hazardous waste, and listing particular hazardous wastes which shall be subject to the provisions of this subtitle." In 1980, RCRA was amended (the Bevill Amendment) to exclude "solid waste from the extraction, beneficiation, and processing of ores and minerals" from regulation as hazardous waste under subtitle C of RCRA, pending completion of certain studies by EPA. In a 1988 reinterpretation of the Bevill exclusion, EPA proposed to include "air pollution control dust from lime kilns" within the exclusion, which would then be studied in a report to Congress and be subject to a subsequent regulatory determination pursuant to section 3001 of RCRA. However, on September 1, 1989, in response to a Federal Appeals Court directive, EPA published a final rule to narrow the exclusion as it applies to mineral processing wastes. Title 40 Code of Federal Regulations Part 261—Identification and Listing of Hazardous Wastes, § 261.4 Exclusions, was amended to include a revised definition of "beneficiation" in paragraph (b)(7): "Solid waste from the extraction, beneficiation, and processing of ores and minerals. . . ." The definition of "beneficiation" was revised to include the following activity: "calcining to remove water and/or carbon dioxide." Calcining at lime plants is designed to drive off carbon dioxide, and EPA has ruled that lime kiln dust now falls within the definition of solid waste from beneficiation and is therefore excluded from regulation under RCRA.[1]

TABLE 1

SALIENT LIME STATISTICS

(Thousand short tons unless otherwise specified)

	1985	1986	1987	1988[r]	1989
United States:[1]					
Number of plants	115	116	116	115	115
Sold or used by producers:					
Quicklime	12,997	11,850	12,979	13,773	14,065
Hydrated lime	2,314	2,199	2,468	2,531	2,461
Dead-burned dolomite	378	424	285	748	625
Total[2]	15,690	14,474	15,733	17,052	17,152
Value[3] thousands	$809,000	$757,867	$786,125	$817,893	$852,113
Average value per ton	$51.56	$52.36	$49.96	$47.96	$49.68
Lime sold	13,409	12,097	13,105	14,736	15,016
Lime used	2,281	2,377	2,628	2,317	2,135
Exports[4]	19	16	13	15	32
Imports for consumption[4]	194	201	178	210	218
Consumption, apparent[5]	15,865	14,658	15,898	17,248	17,337
World: Production	[r]135,446	[r]135,496	139,393	[p]146,308	[e]149,184

[e] Estimated. [p] Preliminary. [r] Revised.

[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.

PRODUCTION

The term "lime," as used throughout this chapter, refers primarily to six chemicals produced by the calcination of high-purity calcitic or dolomitic limestone followed by hydration where necessary. They are: (1) quicklime, calcium oxide (CaO); (2) hydrated lime, calcium hydroxide ($Ca(OH)_2$); (3) dolomitic quicklime (CaO•MgO); two types of dolomitic hydrate, (4) type N ($Ca(OH)_2$•MgO) and (5) type S ($Ca(OH)_2$•$Mg(OH)_2$); and (6) dead-burned dolomite. Nondolomitic quicklime and hydrated lime are also called high-calcium lime. Lime can also be produced from a variety of calcareous materials such as aragonite, chalk, coral, marble, and shell. Lime is also regenerated; that is, produced as a byproduct, by paper mills, carbide plants, and water treatment plants; however, regenerated lime is beyond the scope of this report.

Total U.S. lime production from limestone, including that of Puerto Rico, was essentially unchanged. Commercial lime sold by producers increased by 282,000 tons from the previous year. Captive lime used by producers decreased by 182,000 tons or nearly 8% compared with the previous year.

In 1989, 72 companies produced lime. Leading producing companies, in descending order, were Dravo Lime Co. with two plants in Kentucky, one plant in Alabama, and one plant in Texas (subsequently sold); 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 California and Nevada and one each in Arizona and Utah; Martin Marietta Corp. in Ohio; APG Lime Co. with one plant each in Texas and Virginia; Allied Lime Co. with two plants in Alabama; Chemical Lime Southwest with two plants in Texas; Continental Lime Inc. with one plant each in Montana, Nevada, Utah, and Washington; and Wimpey Minerals PA Inc. (formerly Broyhill and Associates) with two plants in Pennsylvania. These 10 companies operated 28 plants and accounted for 57% of total lime production.

Domestic lime plant capacity is based on 365 days minus the average

TABLE 2

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1988[r]					1989				
	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	159	1,291	1,450	$66,576	5	162	1,319	1,481	$70,361
Arizona	3	66	607	674	29,637	3	W	W	W	W
Arkansas, Louisiana, Oklahoma	4	59	201	259	14,325	3	71	214	286	15,548
California	11	W	W	458	20,242	11	W	W	395	24,503
Colorado, Nevada, Wyoming	8	W	W	290	21,152	9	W	W	357	24,136
Hawaii, Oregon, Washington	5	W	W	409	26,431	4	W	W	393	26,348
Idaho	3	—	W	W	W	3	W	W	W	W
Illinois, Indiana, Missouri	8	412	3,190	3,602	163,051	8	458	3,196	3,654	168,979
Iowa, Nebraska, South Dakota	4	W	W	W	W	4	W	W	W	W
Kentucky, Tennessee, West Virginia	5	110	1,668	1,777	84,334	5	117	1,529	1,624	89,859
Maryland	1	3	3	6	329	—	—	—	—	—
Massachusetts	2	16	W	W	W	2	W	W	W	W
Michigan	8	75	639	714	36,088	8	W	W	621	32,479
Minnesota and Montana	7	—	W	W	W	7	W	W	W	W
North Dakota	3	86	22	108	7,094	3	85	22	107	5,439
Ohio	9	W	W	2,065	87,431	9	W	W	1,888	94,157
Pennsylvania	10	298	1,343	1,641	91,214	10	300	1,360	1,660	92,139
Puerto Rico	1	25	—	25	3,802	1	26	—	26	3,800
Texas	7	484	708	1,192	55,935	8	367	937	1,304	60,829
Utah	4	W	W	365	17,252	4	W	W	373	17,974
Virginia	5	143	598	741	33,875	5	170	650	821	38,353
Wisconsin	3	122	329	452	23,986	4	120	317	437	18,129
Other[3]	(4)	497	3,923	849	38,938	(4)	611	5,146	1,750	72,880
Total[2]	116	2,555	14,522	17,077	821,695	116	2,487	14,690	17,178	855,913

[r] Revised. 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.

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 75% of commercial lime plants. A weighted average for capacity utilization was calculated from specific plant capacity data and the percentage of capacity utilized at each plant. Based on these calculations, the domestic lime industry operated at 78% of capacity in 1989.

New Plants, Expansions, and Changes

Continental Lime Co., a wholly owned subsidiary of Continental Lime Ltd. of Canada, opened its new Pilot Peak lime plant at Wendover, NV. A used F.L. Smidth rotary kiln with a preheater of Continental design was installed. The plant has a capacity of 120,000 tons per year. St. Clair Lime Co. added a 10-ton-per-hour hydrating system to its Marble City plant in eastern Oklahoma. The system's major component is an Italian Cimprogetti three-stage hydrator, the first of its kind in North America. Germany Valley Limestone at Riverton, WV, announced plans to construct a new preheater lime kiln to replace two existing kilns. Startup was expected to be in the spring of 1990.

Allied Products Co. of Birmingham, AL, sold its lime division to Chemical Lime Co. of Fort Worth, TX. The Alabaster and Montevallo plants in Shelby County, AL, were renamed Allied Lime Co. Dravo Lime Co. sold its Round Rock division, located 60 miles southwest of Dallas, TX, to Texas Lime Co. of Cleburne, TX. The sale included the Blum lime plant and 1,200-acre limestone quarry. Broyhill and Associates was sold to George Wimpey Plc., a large construction company based in the United Kingdom. The sale included the limestone quarries and lime plants in Hanover and Annville, PA. USG Corp. sold its lime plant in Genoa, OH, to a management group from Bellefonte Lime Co. of Bellefonte, PA. Continental Lime Ltd. sold its precipitated calcium carbonate (PCC) plants in St. Helens, OR, and Prince Albert, Saskatchewan, to Georgia Kaolin Co., a subsidiary of Combustion Engineering Inc. Continental retained ownership of its PCC plant in Takoma, WA.

TABLE 3

LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY SIZE OF PLANT

Size of plant	1988[r]			1989		
	Plants	Quantity (thousand short tons)	Percent of total	Plants	Quantity (thousand short tons)	Percent of total
Less than 10,000 tons	14	89	1	12	74	([2])
10,000 to 25,000 tons	20	338	2	19	318	2
25,000 to 50,000 tons	13	512	3	15	585	3
50,000 to 100,000 tons	16	1,202	7	21	1,496	9
100,000 to 200,000 tons	22	3,099	18	20	2,883	17
200,000 to 400,000 tons	22	5,537	33	21	5,844	34
More than 400,000 tons	9	6,299	36	8	5,979	35
Total[3]	116	17,077	100	116	17,178	100

[r] Revised.
[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.

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, 22% for environmental uses, 8% for construction uses, and less than 4% for refractory dolomite. Captive lime was used mainly in sugar refining and in the production of steel in basic oxygen furnaces.

In steel refining, quicklime was used as a flux to remove impurities such as phosphorus, silica, and sulfur. Dolomitic lime was often substituted for a fraction of the high-calcium lime to extend refractory life. Dead-burned dolomite, also called refractory lime, was used to line the bottom of open-hearth steel furnaces to extend the life of the brick lining. Dead-burned dolomite was a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption for raw steel production decreased 5% to 5.0 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 flue gas desulfurization 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 Bureau of Mines on an f.o.b. plant basis, increased to $49.83 per ton (revised 1988 value was $48.12). Average values were $48.17 per ton for chemical and industrial lime (revised 1988 value was $46.46), $61.30 for construction lime, $55.43 for lime used in agriculture, and $65.10 for refractory dolomite.

The average value of quicklime sold increased to $47.42 per ton. Average values per ton were $47.01 for chemical lime (revised 1988 value was $45.88), $43.66 for construction lime, $44.76 for lime used in agriculture, and $60.99 for refractory dead-burned dolomite.

The average value of hydrated lime sold increased to $62.16 per ton. Average values were $56.60 for chemical lime (revised 1988 value was $58.45), $69.75 for lime used in construction, and $59.66 for lime used in agriculture.

Traditionally lime has been a low-priced commodity. Its average annual price 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 increased dramatically. This increase continued into the 1980's, although in recent years prices have

TABLE 4

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1988[r]			1989		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lime	Total[2]
Alabama	479	45	524	483	47	529
Alaska	1	1	2	3	1	3
Arizona	371	92	463	257	70	326
Arkansas	98	21	119	183	31	214
California	579	110	689	479	127	606
Colorado	98	8	107	61	11	72
Connecticut	15	5	20	18	10	27
Delaware	14	7	21	12	4	16
District of Columbia	16	28	44	15	26	41
Florida	413	22	435	392	18	410
Georgia	264	80	344	314	81	395
Hawaii	(3)	3	3	—	—	—
Idaho	118	3	120	137	2	139
Illinois	538	110	648	575	144	719
Indiana	1,564	26	1,590	1,527	30	1,557
Iowa	113	16	129	70	22	92
Kansas	70	18	88	72	24	96
Kentucky	472	20	493	482	27	510
Louisiana	252	111	363	272	98	370
Maine	(3)	1	1	(3)	1	1
Maryland	354	22	376	328	19	347
Massachusetts	135	13	148	148	12	160
Michigan	1,091	83	1,174	1,138	40	1,178
Minnesota	175	149	324	157	145	301
Mississippi	180	8	188	175	6	182
Missouri	182	63	245	183	55	237
Montana	121	17	139	132	13	145
Nebraska	57	5	61	66	76	142
Nevada	133	25	158	212	37	249
New Hampshire	1	1	2	—	1	1
New Jersey	112	26	138	101	22	123
New Mexico	95	15	110	187	33	220
New York	88	37	125	71	41	112
North Carolina	239	31	270	191	36	228
North Dakota	127	90	217	123	88	211
Ohio	1,668	154	1,821	1,369	139	1,508
Oklahoma	124	8	132	104	6	111
Oregon	123	25	148	115	25	141
Pennsylvania	1,686	234	1,920	1,826	233	2,059
Rhode Island	(3)	1	1	2	2	4
South Carolina	154	16	170	218	23	241
South Dakota	19	1	21	24	2	26
Tennessee	177	57	235	183	55	238
Texas	716	501	1,217	947	369	1,316
Utah	201	8	209	224	18	242
Vermont	(3)	1	1	—	1	1

See footnotes at end of table.

TABLE 4—Continued

DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons)

State	1988[r]			1989		
	Quicklime	Hydrated lime	Total[2]	Quicklime	Hydrated lime	Total[2]
Virginia	133	87	220	151	40	191
Washington	250	18	268	250	21	271
West Virginia	438	35	473	471	51	522
Wisconsin	115	50	165	112	47	159
Wyoming	71	20	90	68	19	87
Total[2]	14,440	2,528	16,970	14,628	2,449	17,076
Exports:						
Canada	31	6	36	35	13	48
Other countries[4]	45	26	71	28	26	54
Total	76	32	107	63	39	102
Grand total[2]	14,516	2,560	17,077	14,691	2,488	17,178

[r] Revised.
[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.

leveled off in the range of $48 to $50 per ton. When comparing prices over the past 20 years, based on constant 1989 dollars, two trends become evident. From 1970 to 1979 prices increased steadily, finishing the decade up 52%. From 1980 to 1989 prices decreased steadily, finishing the decade down 24%.

FOREIGN TRADE

Exports and imports of lime both increased in 1989. Exports increased by 116% to 32,241 tons, and imports increased by about 4% to 217,656 tons. Most U.S. trade was with Canada, which accounted for over 85% of the U.S. imports and exports of lime.

On September 11, 1984, the U.S. Department of Commerce published a countervailing duty order on lime from Mexico. The order established rates of 55.89% for Sonocal S.A. de C.V. and 1.21% for all others subject to the order. After the purchase of Sonocal by a private cooperative (Sociedad Cooperativa E.E.R.R. Bomintzha, S.C.L.) in 1986, Commerce initiated a changed circumstances administrative review of the countervailing duty order following a request from the Government of Mexico on July 21, 1988. As a result of the review, on November 30, 1989, the Department of Commerce published a notice of final results revoking the 55.89% countervailing duty on imports of Mexican lime from Bomintzha, retroactive to August 24, 1986.[2]

WORLD REVIEW

In October 1989, the National Lime Association hosted the Executive Committee meeting of the International Lime Association in Williamsburg, VA. Final plans were discussed for the Seventh International Lime Association Congress, to be held in Rome, Italy, September 12–14, 1990. The Congress will include presentation of about 20 technical papers and an exhibit by lime and limestone equipment manufacturers.

Brazil[3]

It is estimated that Brazil produced over 6 million tons of lime in 1989. Over 75% of production came from the states of Minas Gerais, São Paolo, and Paraná. Although there were two to three hundred companies involved in lime production in Brazil, roughly two-thirds of the total production came from 20 companies. The two largest producers were Ical-Indústria de Calcinocao S.A. and Itaú N. Granja-Arcos, which together produced over 1 million tons of quicklime and hydrate. Lime was consumed by the domestic iron and steel industry, for construction, and in paper and pulp manufacture. These three markets accounted for over 70% of consumption.

Canada[4]

Energy, Mines and Resources Canada reported production in 1989 from 13 producers operating 18 plants. The major end uses for quicklime were steelmaking (53%), environmental uses (16%), pulp and paper manufacture (13%), and chemicals (8%). The major end uses of hydrate were environmental uses (60%) and in construction (11%).

The Canadian lime industry will grow significantly in the next few years. Plans have been announced for expansion projects or for new plant construction in New Brunswick, Quebec, Ontario, Alberta, and British Columbia. These projects will involve the following companies: the Havelock Lime division of Dickenson Mines Ltd. in New Brunswick, the Domlim and Jolichaux divisions of Graybeck Inc. in Quebec, the Société Dolo-Mine Inc. in Quebec, Beachvilime Ltd. in Ontario, Dymond Clay Products Ltd. in Ontario, Summit Lime Works Ltd. in Alberta, and the Texada Lime division of BP Resources Canada Ltd. in British Columbia. Most of this new capacity should come on-line during 1990 and 1991.

Germany, Federal Republic of

The West German lime industry continued to benefit from a strong economy. Expansion by the construction and iron and steel industries buoyed lime sales, despite increased competition from both Eastern and Western Europe. The Federal Republic of Germany ranked fifth in the world in lime production.

Sweden

The Swedish lime industry consisted of three commercial producers of quicklime and hydrate and three cap-

FIGURE 1

TRENDS IN MAJOR USES OF LIME

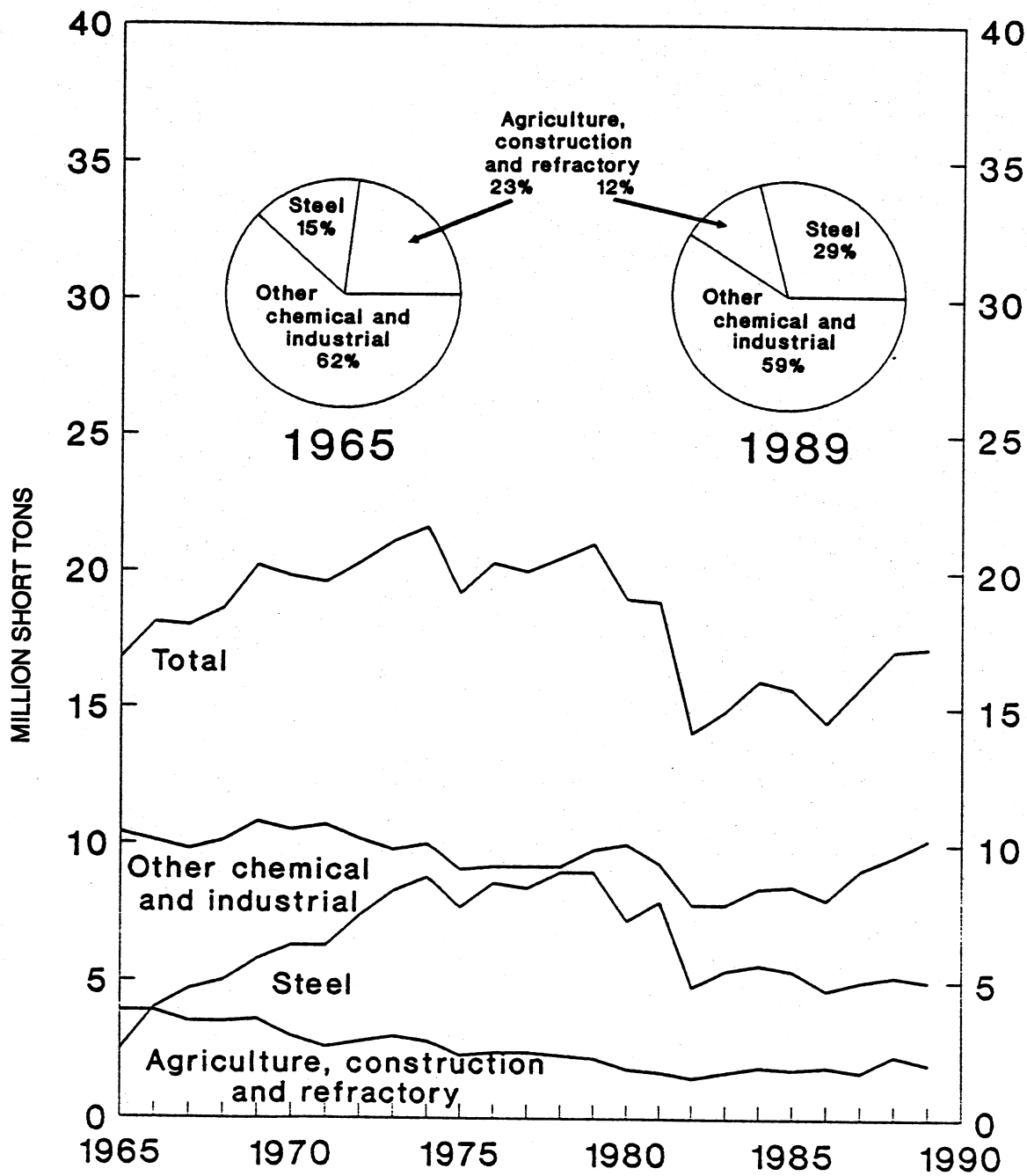

TABLE 5

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

(Thousand short tons and thousand dollars)

Use	1988[r]				1989			
	Sold	Used	Total[2]	Value	Sold	Used	Total[2]	Value
Agriculture	50	—	50	2,956	56	—	56	3,077
Chemical and industrial:								
Acid water, mine or plant	398	—	398	18,788	251	—	251	11,332
Alkalies	W	W	101	5,370	W	W	164	8,452
Aluminum and bauxite	171	—	171	7,617	169	—	169	8,383
Copper ore concentration	W	W	682	28,988	W	W	419	18,821
Food products, animal or human	25	—	25	1,222	28	—	28	1,534
Glass	131	—	131	6,420	130	—	130	6,418
Magnesia from seawater or brine	W	W	482	22,190	W	W	646	32,214
Metallurgy	W	—	W	316	W	—	W	W
Oil well drilling	W	—	W	445	W	—	W	474
Ore concentration, other	364	—	364	17,377	W	—	W	W
Oil and grease	24	—	24	1,122	18	—	18	889
Paper and pulp	W	W	1,260	59,781	W	W	1,178	56,997
Sewage treatment	424	1	424	21,965	404	—	404	18,494
Steel, BOF	W	W	4,239	182,911	W	W	3,928	180,720
Steel, electric	948	—	948	44,534	W	W	979	46,294
Steel, open-hearth	50	—	50	2,190	64	—	64	2,877
Sugar refining	37	649	686	31,254	40	642	682	34,214
Sulfur removal from stack gases	1,388	—	1,388	67,046	1,485	—	1,485	70,792
Tanning	W	W	32	1,764	W	W	55	3,765
Water purification	1,055	—	1,055	49,571	1,030	—	1,030	49,134
Other[3]	7,652	1,488	2,345	116,044	9,567	1,343	3,540	178,958
Total[2]	12,667	2,138	14,805	686,915	13,186	1,985	15,171	730,762
Construction:								
Soil stabilization	831	—	831	40,265	667	—	668	33,999
Finishing lime	183	—	183	17,479	207	—	207	22,372
Mason's lime	W	W	160	16,842	W	W	111	8,320
Other[4]	451	—	300	11,982	444	—	342	16,667
Total[2]	W	W	1,474	86,568	W	W	1,327	81,358
Refractory dolomite	W	W	748	45,256	W	W	625	40,716
Grand total[2]	14,760	2,317	17,077	821,695	15,042	2,135	17,178	855,913

[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, explosives, ferroalloys, fiberglass, glue, insecticides, ladle desulfurizing, magnesium metal, manganese, pelletizing, pharma ceuticals, petrochemicals, precipitated calcium carbonate, rubber, silica brick, soap, wire drawing, and uses indicated by symbol W in "Chemical and industrial" lime only.

[4] Includes asphalt antistripping.

tive producers of quicklime. The major commercial uses were for steelmaking, paper and pulp manufacture, building materials, and environmental purposes. Annual commercial sales were about 465,000 tons and captive consumption about 275,000 tons. Two steel plants were to close down at the end of 1989, decreasing demand by 45,000 tons to 55,000 tons per year. In April 1989, a new lime kiln came on-stream, intended to replace an older kiln. The new kiln, operated by Kalkproduktion Storugns AB and jointly owned by Swedish, Danish, and Finnish producers, will produce about 165,000 tons per year.

United Kingdom

Lime producers in the United Kingdom belonging to the trade association, British Aggregate Construction Materials Industries (BACMI), formed the British Lime Association (BLA) in November 1989. The BLA will function within BACMI and be affiliated with the International Lime Association. Its major aims will be to promote the development of new applications in the United Kingdom and to represent the lime industry on matters concerning the Government.

TABLE 6

TIME-PRICE RELATIONSHIPS FOR LIME[1]

Year	Average annual price, dollars per ton	
	Actual price	Based on constant 1989 dollars
1970	14.53	43.69
1971	15.78	44.89
1972	16.78	45.58
1973	17.42	44.45
1974	22.02	51.50
1975	27.46	58.49
1976	30.19	60.43
1977	33.50	62.87
1978	36.76	64.30
1979	41.26	66.30
1979	44.50	65.58
1981	47.01	63.16
1982	49.47	62.48
1983	51.10	62.12
1984	51.12	59.95
1985	51.69	58.87
1986	52.50	58.27
1987	50.11	53.91
1988	r48.12	50.10
1989	49.83	49.83

r Revised.
[1] Includes Puerto Rico.

TABLE 7

U.S. EXPORTS OF LIME

	Quantity (short tons)	Value[1] (thousands)
1986	16,448	$4,500
1987	12,644	2,971
1988	14,908	3,113
1989	32,241	3,893

[1] Customs value.

Source: Bureau of the Census.

CURRENT RESEARCH[5]

The Construction Research Center of the University of Texas at Arlington conducted a study of the comparative performances of Portland cement lime (type S lime) mortars and equivalent masonry cement mortars produced to American Society of Testing and Materials (ASTM) specifications. This study was initiated as result of concerns voiced by certain groups in the building

TABLE 8

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)
1986	57,842	$4,108	142,865	$8,129	200,707	$12,237
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

[1] Customs value.

Source: Bureau of the Census.

TABLE 9

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	45	45	45	45	45
Australia[e 3]	[4]1,326	1,210	1,210	r1,210	1,300
Austria	1,434	1,405	1,519	re1,703	1,650
Belgium	1,997	1,971	1,944	2,086	2,100
Botswana	3	([5])	([5])	([5])	([5])
Brazil	5,255	5,411	5,842	e6,060	6,060
Bulgaria	1,467	1,799	1,409	1,570	1,540
Burundi	1	([5])	([5])	([5])	([5])
Canada	2,438	2,472	2,458	2,776	[4]2,812
Chile[e]	[4]882	880	830	830	830
China[e]	r8,800	r9,900	r12,100	r14,300	17,600
Colombia[e]	1,430	1,430	1,430	1,430	1,430
Costa Rica[e]	11	11	11	11	11
Cuba	187	192	204	197	200
Cyprus	9	8	8	8	8
Czechoslovakia	3,557	3,670	3,569	e3,640	3,530
Denmark (sales)	142	147	132	148	150
Dominican Republic[e]	37	37	40	40	39
Egypt[e]	107	105	105	105	105
Ethiopia	e2	2	3	3	([4 5])
Fiji Islands	4	3	([6])	—	—
Finland (sales)	278	288	e300	224	234
France	3,417	3,200	e3,300	3,405	3,400
German Democratic Republic	3,932	3,908	3,724	3,835	3,750
Germany, Federal Republic of	7,545	7,139	6,736	e7,940	8,100
Guatemala	68	41	88	79	83
Hungary	883	916	916	938	937
India[e]	550	660	770	r830	830
Iran[e]	700	700	700	700	700
Ireland	93	97	85	107	100
Israel[e]	55	55	55	55	55
Italy[7]	r4,350	r3,969	4,292	re4,300	4,300
Jamaica	95	101	99	88	88
Japan (quicklime only)	8,217	7,404	7,435	8,516	8,700
Jordan	e250	5	4	e4	4
Kenya	31	14	29	e28	[4]30

See footnotes at end of table.

TABLE 9—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Korea, Republic of[e]	220	220	220	250	250
Kuwait	58	63	69	[e]72	72
Lebanon[e]	11	11	11	11	11
Libya[e]	290	290	290	290	290
Malawi	2	3	3	[e]3	3
Malta[e]	6	6	6	6	6
Martinique[e]	6	6	6	6	6
Mauritius[e]	8	8	8	8	8
Mexico	[r]5,614	[r]6,112	6,889	6,614	6,610
Mongolia[e]	105	105	105	110	110
Mozambique[e]	11	11	11	11	11
Nepal	[8]8	1	1	23	24
New Zealand[e]	175	175	175	165	110
Nicaragua[e]	[4]4	4	4	4	4
Norway[e]	110	110	110	110	110
Paraguay	88	97	102	94	114
Peru[e]	40	40	[4]14	[r]14	14
Philippines	52	42	[r e]20	4	5
Poland	4,546	4,576	4,697	[e]4,520	4,520
Portugal[e]	220	220	220	220	220
Romania[e]	[4]4,097	4,100	4,000	3,900	3,600
Saudi Arabia[e]	13	13	13	13	13
South Africa, Republic of (sales)	2,220	2,143	1,744	2,112	[4]2,138
Spain[e]	1,200	1,300	1,300	1,300	1,380
Sweden	715	723	650	740	740
Switzerland	41	39	44	[e]46	44
Taiwan	116	[e]120	116	117	110
Tanzania[e]	[4]3	3	3	3	3
Tunisia[e]	660	720	720	720	720
Turkey[e]	1,100	1,200	1,200	1,600	1,200
Uganda[e]	1	1	1	1	1
U.S.S.R.	32,190	33,204	33,203	[r e]33,200	33,100
United Arab Emirates[e]	50	50	50	50	50
United Kingdom[e]	2,750	2,750	3,100	3,100	3,100
United States including Puerto Rico (sold or used by producers)	15,713	14,498	15,758	17,077	[4]17,178
Uruguay	10	11	14	11	11
Venezuela[e]	2	2	2	2	2
Yugoslavia	2,984	[r]2,906	2,754	2,197	2,200
Zaire	127	150	109	[e]110	110
Zambia	282	268	259	263	265
Total	[r]135,446	135,496	139,393	146,308	149,184

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through June 6, 1990.
[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] Data are for years ending June 30 of that stated.
[4] Reported figure.
[5] Less than 1/2 unit.
[6] Revised to zero.
[7] Includes hydraulic lime.
[8] Data for year ending mid-July of that stated.

industry about the revised ASTM Standard Specification for Mortar for Unit Masonry (C-270-86) and Uniform Building Code, which allowed masonry cement to be used alone to produce any listed mortar type for either reinforced or unreinforced masonry. The concerns focused on whether mortars produced using masonry cements were equivalent to Portland cement lime mortars with respect to masonry assemblage characteristics such as masonry water tightness, masonry bond, masonry shear strength, and masonry compressive strength.

A testing program was developed to compare the two types of mortars. The program involved two phases: (1) tests on laboratory mortars and (2) tests on jobsite mortars. Eight masonry cement mortars and three Portland cement lime mortars were studied. The studies concluded that the properties of the mortars produced using either masonry cement or Portland cement lime were equivalent. However, the study also concluded that the masonry assemblage properties of Portland cement lime mortars were significantly better with respect to water tightness, flexural bond strength, and shear strength, and equivalent in compressive strength.

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. Over the past 20 years lime consumed for steelmaking averaged 6,790,000 tons per year or 39% of total consumption. In 1989, consumption dipped to 4,971,000 tons or 29% of total consumption. The dip in 1989 reflects a trend of decreasing consumption by the steel 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, impacts of new clean air legislation are unknown, 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 1991 through 1994 and be followed by a strong recovery in 1995 and 1996. Based on this forecast and the decreasing trend in flux consumption, lime consumption for steelmaking could easily drop to 4.0 to 4.5 million tons per year by the early 1990's. This translates to a loss in consumption of up to 1.0 million 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 9% of total consumption, although environmental uses when grouped together account for 22%. It is in this sector of the lime market that growth potential exists. The four major environmental uses for lime are: (1) sulfur removal from stack gases or flue gas desulfurization (FGD), (2) water purification, (3) Sewage treatment, and (4) acid water treatment. According to Bureau of Mines statistics, during the 1980's the total consumption for these uses actually declined by nearly 12%, despite FGD use doubling. Other environmental uses consume over 600,000 tons per year.

New environmental legislation and a resurgence in environmental awareness and concern by the public will have an impact on environmental markets. Consumption for FGD should continue to increase, despite strong competition from limestone and other nonlime FGD systems. Consumption for stabilization of sewage sludge to tie up heavy metals and reduce odor should increase. Lime's ability to tie up heavy metals and neutralize acid water makes it useful in treating tailing ponds at active mining operations and in treating the runoff from abandoned mines. This should lead to increased consumption in the Western United States, where increased attention is being directed at the problems of acidification and heavy metal pollution of streams and rivers from past mining. 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.

The outlook for lime consumption in other chemical and industrial uses depends on the general health of the economy and the health of specific sectors, such as construction, paper and pulp, and mining. 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 in the pulping chemical market is forecast to grow by 6% per year. Lime consumption for precipitated calcium carbonate (PCC) production should increase dramatically as the push to build satellite PCC plants near paper mills continues. If base and precious metals prices remain steady or increase, lime consumption by the mining industry could increase. It is an important chemical in the recovery, smelting, and refining of copper, gold, silver, and other nonferrous metals.

BACKGROUND

Definitions and Specifications[6]

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 is over 2.5 inches in diameter. Although sizes can vary, the typical size is 5 x 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, rail cars, and in 50-pound paper bags. As a result of the hydration process, it is of fine particle size. A typical product size passes 85% or more through a No. 200 sieve, and a few special applications may require a product passing 95% to 98% through a No. 325 sieve.

Because of the differences in limestones, a rigid standardization of lime material specifications is impossible. Few plants manufacture lime with exactly the same properties, as a result, lime specifications are by necessity quite general in their provisions. A typical analysis is shown in table 10.

Technology[7]

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

TABLE 10

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.

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 around 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 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.

[1] Federal Register. Environmental Protection Agency. 40 CFR Part 261, Mining Waste Exclusion; Final Rule. V. 54, No. 169, Sept. 1, 1989, pp. 36592-36642.

[2] ——. International Trade Administration/Import Administration (Dep. Commerce). Lime From Mexico; Final Results of Changed Circumstances Countervailing Duty Administrative Review and Revocation of Countervailing Duty Order. V. 54, No. 229, Nov. 30, 1989, pp. 49324-49330.

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LITHIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 12 years industry and 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 Peter J. Roetzel, international data assistant.

The United States led the world in lithium mineral and compound production and consumption. Estimated consumption increased slightly, and world production also grew. Sales increased for domestic producers, who announced price increases for the third 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 upon the end use. Most lithium compounds were consumed in the production of ceramics, glass, and primary aluminum.

DOMESTIC DATA COVERAGE

The 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. The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on lithium in units most consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

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 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. Because of mercury contamination, DOE delayed the proposed disposal of lithium hydroxide until an environmental impact study was complete.

PRODUCTION

The two companies that produced lithium in the United States in 1989 did so from two different types of deposits. Both firms mined spodumene, (a lithium-aluminum-silicate ore) from large hard-rock deposits in North Carolina using open pit methods. Geothermal brines were a source for lithium in Nevada. Pumps remove the brine from underground deposits into evaporation ponds. Extraction processes separate lithium from the concentrated brines.

Cyprus Foote Mineral Co. produced lithium carbonate at its brine deposit in Silver Peak, NV, and produced small quantities of spodumene concentrate at its mine in Kings Mountain, NC. It operated processing facilities for downstream lithium products and metal in Frazer, PA; Sunbright, VA; and New Johnsonville, TN. The company continued to maintain its lithium carbonate plant at Kings Mountain in a care-and-maintenance status as it had since mid-1986.

Lithium Corp. of America (Lithco), a subsidiary of FMC Corp., 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

TABLE 1

SALIENT LITHIUM STATISTICS

(Metric tons of contained lithium)

	1985	1986	1987	1988	1989
United States:					
Production[1]	W	W	W	W	W
Producers' stock changes[1]	W	W	W	W	W
Imports[2]	370	610	820	1,000	630
Shipments of Government stockpile surplus[3]	1	2	4	2	—
Exports[e 4]	2,300	1,800	1,800	2,300	3,000
Consumption:					
Apparent	W	W	W	W	W
Estimated	2,300	2,400	2,400	2,700	2,700
Rest of world: Production[e 1]	3,400	3,600	3,600	4,200	4,900

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.

compounds, at a chemical plant located near the mine.

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 increased slightly in 1989. Ceramics and glass production and aluminum smelters were the largest consumers of lithium 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 petalite and spodumene, two lithium ores, were a source of lithium used to improve the physical properties of container and bottle glass and as a source of alumina (Al_2O_3), 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, reduce power consumption, or increase current efficiency.

The multipurpose grease industry was the third largest end use for lithium in 1988. Lithium-based 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.

Nearly all major battery manufacturers marketed lithium batteries in some configuration, and research and development continued for further substitution in applications that implement more conventional alkaline batteries. Although they represent a small percentage of total lithium consumption, sales of these batteries remained a favorable growth area for lithium consumption. Lithium batteries offer improved performance over alkaline batteries, at a slightly higher cost. Lithium batteries were used in watches, microcomputers, and cameras, and, more recently, in small appliances, electronic games, and toys. The military purchased large and small lithium batteries for a variety of military applications.

Aircraft manufacturers in several countries continued to test aluminum-lithium alloys for wing and fuselage skin and structural members of new aircraft. Use of aluminum-lithium alloys can reduce the weight of the aircraft by more than 10%, allowing significant fuel savings over 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 with those of conventional aluminum alloys. These alloys face direct competition, however, from composite materials consisting of boron, graphite, or aramid fibers imbedded in polymers.

Small quantities of other lithium compounds were important to many industries. Butyllithium was a catalyst in synthetic rubber production. 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

For the third consecutive year, both domestic companies increased prices for nearly all lithium products. Prices were about 6% higher in 1989 than the

TABLE 2

DOMESTIC YEAREND PRODUCERS' AVERAGE PRICES OF LITHIUM AND LITHIUM COMPOUNDS

	1988		1989	
	Dollars per pound	Dollars per kilogram	Dollars per pound	Dollars per kilogram
Lithium bromide, 54% brine: Truckload lots, delivered in drums	4.55	10.03	4.82	10.63
Lithium carbonate, technical: Truckload lots, delivered	1.63	3.59	1.73	3.81
Lithium chloride, anhydrous, technical: Truckload lots, delivered	3.42	7.54	3.20	7.05
Lithium fluoride	5.65	12.46	5.99	11.97
Lithium hydroxide monohydrate: Truckload lots, delivered	2.07	4.56	2.19	4.83
Lithium metal ingot, standard-grade: 1,000-pound lots, f.o.b	26.70	58.86	28.30	62.39
Lithium sulfate, anhydrous	3.69	8.14	3.90	8.60
N-butyllithium in n-hexane (15%): Truckload lots, delivered	15.85	34.94	16.80	37.04

Source: U.S. lithium producers.

previous year. The close balance between supply and demand worldwide has been instrumental in improving the price situation. Although installed production capacity remained in excess of demand, the chemical plant at Kings Mountain remained inactive, and supply and demand were balanced sufficiently to maintain strong prices.

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 new codes, import and export categories for lithium and its chemicals changed, and some formerly listed details were no longer available. International trade information will no longer be available for lithium ore concentrates or lithium metal from the Bureau of the Census. Import categories identified as lithium carbonate and lithium oxides and hydroxides replaced lithium salts and compounds. For this reason, comparisons between 1988 and 1989 trade data are not valid.

The Federal Republic of Germany, Japan, and United Kingdom were the largest importers of lithium compounds from the United States. Imported lithium ore concentrates entered the United States, but no data were available. Reports from concentrate producers and consumers indicated that U.S. imports decreased in 1989.

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, the U.S.S.R., and Zimbabwe. Argentina, Brazil, and Namibia produced smaller quantities; production primarily consisted of ore concentrates. Portugal and Zaire have produced lithium mineral concentrates in the past.

The U.S.S.R. and China produced significant quantities of lithium car-

TABLE 3

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1988		1989	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate:				
Argentina	—	—	1,041	$3,729
Austria	—	—	1,873	6,709
Australia	84,785	$280,588	18,960	77,385
Belgium	—	—	19,958	55,000
Brazil	28,939	91,448	34,336	111,114
Canada	472,416	1,597,289	362,663	1,422,124
China	38,399	84,656	—	—
Germany, Federal Republic of	2,274,105	6,237,532	2,882,128	8,506,932
India	88,684	259,180	4,542	14,169
Japan	1,633,772	4,985,716	1,429,825	4,662,880
Korea, Republic of	460,345	1,477,147	137,732	417,594
Mexico	36,836	124,211	76,699	318,681
Netherlands	171,138	502,432	362,946	1,036,790
New Zealand	1,297	14,195	36	1,585
Singapore	—	—	8,642	89,865
South Africa, Republic of	13,013	47,326	29,808	100,991
Spain	—	—	59,874	165,000
Taiwan	267,977	845,816	8,990	30,027
United Kingdom	1,512,397	4,500,385	1,708,728	4,801,594
Venezuela	3,992	13,200	336,723	1,138,668
Total [1]	7,088,096	21,061,121	7,485,504	22,960,837
Lithium carbonate U.S.P. [2]				
Australia	—	—	123,854	296,165
Belgium	—	—	4,301	31,289
Canada	—	—	41,211	549,534
El Salvador	—	—	320	9,300
Germany, Federal Republic of	—	—	5,388	68,375
Honduras	—	—	328	8,727
India	—	—	25,242	100,666
Japan	—	—	386,512	1,202,469
Korea, Republic of	—	—	270,415	810,908
Mexico	—	—	12,994	8,557
New Zealand	—	—	1,498	18,685
South Africa, Republic of	—	—	1,700	60,264
Sweden	—	—	5,648	11,454
Taiwan	—	—	239,472	708,039
United Kingdom	—	—	1,107	23,220
Venezuela	—	—	440,238	1,345,378
Total	—	—	1,560,228	5,253,030
Lithium hydroxide:				
Argentina	87,381	352,973	146,044	559,459
Australia	—	—	70,778	286,205
Austria	68,402	263,730	—	—
Belgium	—	—	110,369	384,065
Brazil	495,156	1,858,444	332,244	1,478,515
Canada	103,418	414,976	63,326	300,382

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1988		1989	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium hydroxide—Continued				
Chile	43,199	$172,951	18,129	$68,871
Colombia	19,033	77,386	32,114	127,308
Ecuador	9,891	36,619	5,000	23,326
Egypt	19,958	77,000	—	—
France	—	—	2,164	5,819
Germany, Federal Republic of	478,852	1,695,173	1,121,636	3,625,447
Guinea	—	—	572	183,960
India	425,514	1,721,493	345,276	1,325,356
Indonesia	—	—	22,680	104,600
Israel	28,772	105,871	14,984	69,485
Italy	—	—	1,683	4,496
Japan	873,152	3,588,531	892,290	3,823,441
Korea, Republic of	167,868	674,637	113,148	462,802
Malaysia	2,000	8,159	2,599	12,608
Mexico	84,030	669,011	216,640	1,033,320
Netherlands	172,385	690,843	237,698	754,827
New Zealand	5,000	22,400	7,500	35,249
Nigeria	—	—	35,599	107,624
Pakistan	15,300	64,460	28,341	123,254
Peru	—	—	17,387	73,404
Philippines	25,401	100,240	14,337	55,807
Saudi Arabia	26,000	106,600	—	—
Singapore	51,891	192,400	77,126	311,917
South Africa, Republic of	90,844	348,062	96,218	225,569
Sweden	—	—	36,580	138,920
Taiwan	8,981	36,570	21,763	73,244
Thailand	18,688	74,367	58,722	262,566
United Arab Emirates	7,983	31,504	18,414	74,435
United Kingdom	418,208	1,515,839	518,632	1,746,624
Uruguay	1,000	4,938	998	4,920
Venezuela	40,000	164,000	11,000	46,530
Total	3,788,307	15,069,177	4,691,991	17,914,355
Lithium metal:[3]				
Australia	—	—	350	—
Belgium	—	—	4,989	—
Brazil	—	—	190	—
Germany, Federal Republic of	—	—	155,920	—
India	—	—	3,079	—
Israel	—	—	4,712	—
Japan	—	—	115,982	—
Saudi Arabia	—	—	90	—
Singapore	—	—	50,131	—
South Africa, Republic of	—	—	178	—
Taiwan	—	—	1,730	—
Turkey	—	—	78	—

See footnotes at end of table.

bonate and other lithium compounds, but specific information on the operations was limited. Companies in the Federal Republic of Germany, France, Japan and the United Kingdom produced downstream lithium compounds from imported lithium carbonate, but no minerals or brines were produced in those countries.

Capacity

The data in table 5 are rated capacity for mines and refineries 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 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 nearly 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.

Australia

Lithium Australia Ltd. (LAL), a subsidiary of Greenbushes Ltd., mined high-grade, low-iron spodumene at its mine in Greenbushes, Western Australia. LAL produced two ore 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

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1988		1989	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium metal[3]—Continued				
United Kingdom	—	—	201,128	—
Total	—	—	537,557	—
Other:				
Argentina	7,943	$15,904	—	—
Australia	85,406	217,572	—	—
Belgium	50,517	63,231	—	—
Brazil	123,302	206,387	—	—
Canada	1,357,388	2,132,539	—	—
China	—	—	—	—
Colombia	3,115	6,074	—	—
Denmark	—	—	—	—
Ecuador	11,000	20,500	—	—
France	94,520	91,761	—	—
Germany, Federal Republic of	210,198	399,073	—	—
India	3,000	5,505	—	—
Iraq	1,789	3,181	—	—
Ireland	440	2,260	—	—
Israel	353	12,091	—	—
Italy	30	1,980	—	—
Jamaica	9,830	25,409	—	—
Japan	87,109	830,872	—	—
Jordan	—	—	—	—
Korea, Republic of	1,533	17,343	—	—
Mexico	400,179	927,616	—	—
Netherlands	189,739	369,826	—	—
Nigeria	—	—	—	—
Pakistan	29,608	55,756	—	—
Philippines, Republic of	20,000	14,910	—	—
Saudi Arabia	12,641	22,531	—	—
Singapore	36,125	75,358	—	—
South Africa, Republic of	50,603	94,060	—	—
Sweden	—	—	—	—
Switzerland	7,714	13,500	—	—
Taiwan	92,189	311,104	—	—
Trinidad	62,200	141,791	—	—
Turkey	110	16,390	—	—
United Arab Emirates	32,000	15,500	—	—
United Kingdom	379,088	953,413	—	—
Venezuela	44,398	135,062	—	—
Yugoslavia	284	92,359	—	—
Total	3,404,351	7,290,858	—	—

[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.

Source: Bureau of the Census.

manufacture of black and white television picture tube glass and pyroceramics in the Pacific rim countries and Europe. LAL sold to the same countries glass grade concentrate with lower lithium content for consumption in container glass. Sales and production continued to expand significantly, as they have every year since production began in 1982.[1]

Bolivia

Industria Minera Tierra Ltda., a Bolivian company, and a U.S. company expressed interest in developing the Salar de Uyuni, the world's largest salt flat. Early in the year, Industria Minera Tierra requested permission from the Bolivian Government to build a pilot plant for the production of 40 tons of lithium carbonate per year. The Government showed interest in joint-venture arrangements by announcing plans to call for international bids. At yearend, the Government of Bolivia and Lithco were negotiating for a joint-venture operation in the Salar. Lithco's plans included an exploration program and, possibly, a 37,000-ton-per-year plant for recovery of lithium carbonate from the evaporated brines. Preliminary studies of the Salar de Uyuni, which is more than 3,600 meters above sea level, indicated reserves of 5.5 million tons of lithium, 110 million tons of potassium, and 3.2 million tons of boron.[2]

Canada

Tantalum Mining Corp. (Tanco) has been mining spodumene concentrates at its mine near Bernic Lake in southeastern Manitoba. Since mining began in 1984, Tanco has grown to become the largest supplier of lithium ore 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.

Chile

Cyprus Foote Mineral Co. bought the remaining shares of its lithium brine operation at the Salar de Atacama, Sociedad Chilena de Litio Ltda. (SCL) to become the sole owner. Cyprus Foote, formerly Foote Mineral Co., has produced lithium carbonate

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF LITHIUM-BEARING MATERIALS, 1988

(Kilograms and thousand dollars)

	Compound							
	Lithium ores		Lithium compounds		Lithium salt		Lithium metal	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	4,425,085	413	231	10	—	—	—	—
Canada[2]	15,975,570	1,667	—	—	—	—	—	—
Chile	—	—	7,102,102	6,259	—	—	—	—
China	—	—	39,683	83	—	—	—	—
France	—	—	5,078	125	13,200	9	8,571	17
Germany, Federal Republic of	—	—	30,336	388	—	—	—	—
Japan	—	—	3,739	122	55	2	—	—
Luxembourg	—	—	65	1	—	—	—	—
Mexico	—	—	218	23	—	—	—	—
Namibia	905,962	24	—	—	—	—	—	—
United Kingdom	—	—	9,075	97	252	3	6,687	14
Zaire	79,808	2	—	—	—	—	—	—
Zimbabwe	10,273,839	943	—	—	—	—	—	—
Total	31,660,264	3,049	7,190,527	7,108	13,507	14	15,258	31

[1] Customs value.
[2] Spondumene concentrate.

Source: Bureau of the Census.

from the brines from this Salar since 1984. The project originated as a joint venture between Foote and Corporación de Fomento de la Producción (CORFO), a Chilean Government agency. Production capacity for lithium carbonate increased steadily from a 6,300-ton-per-year capacity to reach the current level of 9,100 tons per year. SCL expanded the evaporation ponds prior to another expansion at the carbonate plant. Further capacity expansion to 11,800 tons per year should be completed in 1990.[3]

Minera Salar de Atacama Ltda., 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 a decision from AMAX to pursue the project was expected in 1990.[4]

Namibia

Southwest Africa (SWA) Lithium Mines produced petalite concentrate at its Rubicon Mine near Karibib. Low-grade ores were beneficiated through a flotation process, while high-grade ores were hand picked. Small amounts of two other lithium ores, lepidolite and amblygonite, were other products. The Federal Republic of Germany imported most of these ores. High-grade lepidolite was handpicked at the company's Helicon Mine for export to Western Europe and Japan.[5]

Zimbabwe

Bikita Minerals Ltd. mined petalite, another lithium ore, 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 over 1 million tons that could be recovered with a significant savings in mining

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF LITHIUM-BEARING MATERIALS, 1989

(Kilograms and thousand dollars)

	Compound			
	Lithium carbonate		Lithium hydroxide	
	Quantity	Value[1]	Quantity	Value[1]
Chile	3,236,541	6,337	—	—
Germany, Federal Republic of	52	4	2,888	22
India	17,500	81	—	—
Japan	127	26	9,401	57
Sweden	—	—	545	27
Switzerland	72,000	175	10,348	58
United Kingdom	25	6	—	—
Total	3,326,245	6,629	23,182	164

[1] Customs value.

Source: Bureau of the Census.

TABLE 6

WORLD LITHIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY[1]

(Metric tons of contained lithium)

North America:	
United States[2]	5,600
Canada	500
Total	6,100
South America:	
Argentina[e]	10
Brazil[e]	290
Chile	1,700
Total[e]	2,000
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.

TABLE 7

LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina (minerals not specified)	35	184	178	119	120
Australia, spodumene	11,835	12,703	22,279	[r e]30,000	40,000
Brazil:					
Amblygonite	159	49	52	[e]50	50
Lepidolite	26	30	([3])	([3])	—
Petalite	1,323	1,614	2,946	[r e]1,700	2,000
Spodumene	107	366	505	[e]400	400
Canada, spodumene[e 4]	4,600	7,500	11,500	14,000	14,000
Chile, carbonate from subsurface brine	4,508	4,458	6,139	7,332	8,000
China (minerals not specified)[e 5]	15,000	15,000	15,000	15,000	15,000
Namibia:					
Amblygonite	49	52	106	147	150
Lepidolite	71	52	61	18	20
Petalite	1,753	751	749	1,477	1,200
Portugal, lepidolite	4	[e]27	—	—	—
U.S.S.R. (minerals not specified)[e 5]	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)	27,910	32,760	14,959	15,073	15,500

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing proprietary data.
[1] Table includes data available through Apr. 9, 1990.
[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] Revised to zero.
[4] Estimates based on imports by the United States.
[5] 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.

costs after installation of the new device. Hand sorting continued to be used only for special small orders of minerals other than petalite.[6]

CURRENT RESEARCH

Research continued in areas believed to possess the greatest potential for the lithium industry. Martin Marietta Corp. of Baltimore, MD, developed a new family of aluminum-lithium (Al-Li) alloys, named Weldalite, targeted for use in aerospace applications, and, specifically, space launch systems. The alloys were the strongest known wrought aluminum products available, according to Martin Marietta. Reynolds Metals Co. received the license for exclusive production. During testing, Weldalite maintained superior strength over the wide range of temperatures required for space applications. The alloys were lightweight due to the lithium content, and weldable, making them attractive for use in fuel and oxidizer tanks for space vehicles. Reynolds planned to produce ingot, sheet, plate, and extrusions of Weldalite at its new casting facilities in McCook, IL. The McCook facilities were upgraded to prepare Reynolds to become a leading supplier to the aerospace industry.[7]

Because forged metal parts have been preferred to castings or machined parts due to superior tensile strength and toughness, techniques have been developed for forging Al-Li alloys. Boeing Commercial Aircraft Co. tested tow fittings forged from Al-Li 2090 alloy that should withstand the high load stress of towing and the extensive environmental exposure during takeoffs and landings on aircraft. Huntington Alloys International developed two powder metallurgy Al-Li alloys for forgings. The company tested its 905XL hot-die forgings in aircraft components because of its low density and high strength. It considered its 9052 alloy for torpedo bodies and hulls because of its good corrosion resistance.[8]

Several organizations improved existing battery technology or developed new products. Long-life thermal batteries have powered weapons and spacecraft since World War II. These batteries can remain inactive for 30 years without discharge, and upon activation when the electrolyte melts, produce power for a few minutes to 1 hour. In the late 1970's, Sandia National Laboratories developed a lithium-silicon alloy and iron disulfide battery to replace the original calcium-calcium chromate thermal battery. The new design weighed 75% less than the calcium battery, but experienced troublesome voltage spikes. By addition of lithium oxide to the cathode material, control of heat input to the battery, and puri-

fication of the iron disulfide, the laboratory eliminated the voltage spikes.[9]

Researchers at the University of California at Berkeley developed a new battery that reportedly could make electric vehicles practical. The new battery, which could produce up to 30% more power per ounce than current systems and weighs significantly less, consisted of thin films of lithium, polyethylene film, and a disulfide polymer that are sandwiched together. A series of thin cells could be layered together to form larger batteries. The improved design reduced temperature requirements for electric vehicle batteries. The polymer battery could lower the operating temperature requirements from 700° F to between 176° F and 212° F. Coin cells like the ones found in watches and calculators should be available in 2 years using the new technology; larger size cylinders and vehicle batteries were expected to be available later.[10]

Sanyo Energy Corp. began offering a rechargeable lithium/manganese dioxide (Li/MnO_2) battery. The new product possessed a low self-discharge rate and high voltage in relation to size. One Li/MnO_2 battery should replace two nickel/cadmium batteries and provide two to three times the energy density.[11]

Research continued in other areas, which, if developed, hold potential for requiring large amounts of lithium. Integrated, or waveguide, optics are the optical equivalent of the electronic integrated circuits. As more information is transported via optical fibers, devices will be developed to process that information through optical rather than electronic means. Lithium niobate has been identified as a prime material for integrated optic substrates.[12] Lithium should be an important material in the development and operation of nuclear fusion reactors. Westinghouse Hanford Co., in Richland, WA, developed a device called the Materials Open Test Assembly (MOTA) to test different materials for use in fusion reactors. Samples of material would be placed in a reactor plant and irradiated for more than 1 year. Tests would determine tritium recovery rates from lithium oxide test canisters. Other fusion materials will be tested in other canisters.[13]

OUTLOOK

The aluminum industry experienced a slowdown in 1984, and, as a result, domestic lithium consumption decreased dramatically that year. Since that time, lithium consumption has expanded at an average of about 5% per year. 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 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 average 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

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MAGNESIUM

Domestic magnesium production hit its highest level since the beginning of the decade because strong demand continued for magnesium for aluminum alloying, casting applications, and iron and steel desulfurization. Because demand could not be completely met with primary production, particularly in the first half of the year, inventory levels dropped rapidly to reach a 20-year low by midyear. Demand slowed in the second half of 1989, and producers replenished their stocks. Magnesium exports increased significantly, and imports declined from the high level in 1988. The United States remained a net exporter of magnesium.

World production of magnesium reached a record-high level in 1989, and production capacity was expected to increase significantly within the next year. Two new plants in Canada planned to bring a total of 52,500 metric tons of annual capacity on-stream in 1990, and a small capacity expansion was planned in Brazil. Preliminary investigations were underway to construct new primary magnesium plants in Australia, Colombia, India, Norway, and the Republic of South Africa.

Legislation and Government Programs

In September, the Environmental Protection Agency issued a final ruling on the criteria to evaluate mineral processing wastes for exclusion from regulation under subtitle C of the Resource Conservation and Recovery Act (RCRA). Wastewater from the anhydrous process for magnesium recovery was a candidate for exclusion under the original criteria in 1988. This waste passed the high-volume, low-toxicity criteria established in the final ruling and was conditionally excluded under RCRA. Final subtitle C regulation of the process wastewater was to be determined by January 1990.[1]

Production

U.S. primary magnesium production was at the highest level since 1980 and was at 95% of rated yearend capacity. In April, AMAX Magnesium Corp. announced that it had sold its Rowley, UT, facility, but the sale was not finalized until September. Renco Group Inc. purchased the primary magnesium plant, which was renamed Magnesium Corp. of America (MagCorp). MagCorp planned to increase its capacity to 38,000 tons in 1990. The company also began drawing brine in 1989 from its new solar ponds in the west desert that replaced the solar ponds destroyed in a 1986 flood of the Great Salt Lake. MagCorp estimated that the new ponds have a 10- to 15-year supply of brine.

In May, Dow Chemical Co. announced that annual capacity at its Freeport, TX, magnesium plant was increased by 5,000 tons to 90,000 tons. This represented the fourth capacity increase at the facility since late 1987. The capacity increase was in response to low stock levels and growing demand in the automotive diecasting and desulfurization sectors. Dow's three previous capacity increases involved restarting idled electrolytic cells, but the fourth increase involved improvements in the production process.

Northwest Alloys Inc., a subsidiary of Aluminum Co. of America (Alcoa), planned to increase magnesium production at its Addy, WA, plant by

TABLE 1

SALIENT MAGNESIUM STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Primary magnesium	135,728	125,639	124,396	141,983	152,066
Secondary magnesium	41,298	41,807	45,164	50,207	51,200
Exports	36,580	39,909	44,182	49,802	56,631
Imports for consumption	8,411	8,355	10,851	14,407	12,289
Consumption, primary	r83,752	r78,961	r94,620	100,793	105,226
Price per pound	$1.48–$1.53	$1.53	$1.53	$1.58–$1.63	$1.63
World: Primary production	r325,183	r322,408	323,930	p334,372	e343,548

e Estimated. p Preliminary. r Revised.

making proprietary improvements in its processing methods. Reportedly, two-thirds of Northwest Alloys' production is used by Alcoa for aluminum alloying. Alcoa used to purchase all of Northwest Alloys' production, but although aluminum can production has increased significantly, increased recycling rates have lowered Alcoa's consumption of primary magnesium.

Consumption

Spectrulite Consortium Inc. purchased Dow's magnesium rolled products business citing the need to strengthen the company's market position. In past years, Dow had purchased Spectrulite's rolled products, and Spectrulite also supplied Dow with extrusion billet for Dow's operations in Aurora, CO.

Frontier Foundries Inc. opened a new magnesium investment casting facility in its complex in Titusville, PA. The company's investment casting process can produce castings with precise size tolerance, smooth surface finish, and intricate detail. Also, Thompson Castings Inc. announced the development of a new casting process that yields near-net-shape prototype components for automotive testing requirements. Components can be produced in a wide variety of shapes and in sizes from a few ounces to a few pounds. Castings can be produced by the new process with interlocking cores with thin-wall passages for pneumatic and hydraulic components.

Several new applications for die-cast magnesium in the automotive industry were announced. The Cadillac Motor Div. of General Motors Corp. planned to substitute magnesium valve covers for aluminum on the V-8 engines used in most of its cars. Also, magnesium was planned to be used for the main structural front seat parts in the 1989 Mercedes Benz SL Roadster, for Audi's V-8 die-cast instrument panel, and for wheels in some of Honda Motor Corp.'s automobiles. A review of magnesium applications in the automotive industry outlined additional uses.[2]

Usage of magnesium continued to increase in the computer industry for both die-cast and extruded components in housings and internal applications. Because computer components change more quickly than those in other industries, extrusions may be preferable to castings. Extrusions have relatively low-cost tooling and economical short-run capabilities compared to diecasting, although the secondary costs may be higher.[3]

Stocks

Consumer stocks of primary magnesium declined from 6,860 tons at yearend 1988 to 5,350 tons at yearend 1989. Magnesium alloy ingot stocks increased slightly from 838 tons at yearend 1988 to 849 tons at yearend 1989.

Producers' primary magnesium stocks declined to their lowest level in nearly 20 years by the end of the second quarter. However, by the end of the year, stocks increased substantially to 20,133 tons and also increased from yearend 1988 stocks of 17,087 tons.

Prices

Producers' quoted magnesium prices were unchanged during 1989. Both Dow and MagCorp quoted a price for primary metal ingot at $1.63 per pound

TABLE 2

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1985	1986	1987	1988	1989
KIND OF SCRAP					
New scrap:					
Magnesium-base	1,510	991	845	2,641	3,951
Aluminum-base	16,252	17,822	20,867	19,926	19,278
Total	17,762	18,813	21,712	22,567	23,229
Old scrap:					
Magnesium-base	4,630	3,958	3,857	3,882	4,269
Aluminum-base	18,906	19,036	19,595	23,758	23,702
Total	23,536	22,994	23,452	27,640	27,971
Grand total	41,298	41,807	45,164	50,207	51,200
FORM OF RECOVERY					
Magnesium alloy ingot [1]	3,838	3,925	4,001	3,930	4,494
Magnesium alloy castings	438	551	447	438	795
Magnesium alloy shapes	—	31	—	1,065	635
Aluminum alloys	35,797	37,293	40,711	43,827	43,125
Zinc and other alloys	8	3	W	W	W
Chemical and other dissipative uses	3	W	W	943	W
Cathodic protection	1,214	W	—	W	W
Total	41,298	41,807	45,164	50,207	51,200

W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."
[1] Includes secondary magnesium content of both secondary and primary alloy ingot.

TABLE 3

U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1985	1986	1987	1988	1989
For structural products:					
Castings:					
Die	2,229	3,646	3,710	4,383	5,627
Permanent mold	825	748	1,121	943	811
Sand	1,482	1,373	1,454	1,743	1,017
Wrought products:					
Extrusions	7,036	6,285	6,804	6,907	6,712
Other[1]	3,804	3,938	3,884	5,719	5,326
Total	15,376	15,990	16,973	19,695	19,493
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	37,059	36,804	49,784	51,183	51,436
Other	7	5	8	7	9
Cathodic protection (anodes)	4,307	6,342	5,537	6,234	5,474
Chemicals	3,469	1,449	1,047	780	594
Iron and steel desulfurization	e8,000	e9,000	e10,000	W	10,463
Nodular iron	1,540	1,622	1,811	2,037	1,635
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	7,372	5,235	5,286	8,467	10,798
Other[2]	6,622	2,514	4,174	12,390	5,324
Total	r68,376	r62,971	r77,647	81,098	85,733
Grand total	r83,752	r78,961	r94,620	100,793	105,226

e Estimated. r Revised. 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 4

U.S. STOCKS AND CONSUMPTION OF NEW AND OLD MAGNESIUM SCRAP[1]

(Metric tons)

	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1988	960	5,610	1,901	3,882	5,783	787
1989	787	7,233	3,052	4,269	7,321	699

[1] Cast scrap, solid wrought scrap, borings, turnings, and drosses.

and diecasting alloy price at $1.43 per pound throughout the year. A compilation of U.S. magnesium prices from 1915 to 1988 was published by the Bureau of Mines.[4]

Foreign Trade

Because of implementation of the Harmonized Tariff System (HTS) beginning in 1989, trade data for 1989 may not be comparable with those of previous years. Exports of magnesium increased significantly compared with those in 1988. The Netherlands, 27%; Canada, 24%; and Japan, 21%, were the principal destinations for U.S. exports. Magnesium imports declined from the high level in 1988. Norway was the source of 51% of domestic imports, mainly primary metal and alloy. Canada supplied 32%, mainly waste and scrap, and Mexico supplied 9% of U.S. imports.

World Review

World primary magnesium production reached a record-high level in 1989, and world inventory levels dropped significantly during the year. According to the International Magnesium Association, world inventories dropped to a 5-year low in June, but recovered to end the year at 35,000 tons. Yearend stocks represented 52 days of average daily demand during 1989 and were 7,800 tons above those at yearend 1988.

Australia.—Queensland Metals Corp. announced that it was seeking a partner to construct a 60,000-ton-per-year primary magnesium plant in Gladstone. The company was developing a magnesite mine and magnesia production plant nearby and expected to use magnesite for the metal plant feed material.

Brazil.—Cia. Brasileira do Magnesio S.A. (Brasmag) reportedly received a $10 million loan from a pool of regional banks to increase its annual primary magnesium capacity to 10,600 tons in 1990. The expansion included installation of a series of electric-reduction vacuum furnaces. Brasmag planned to increase production capacity further in the mid-1990's if the Government approves the company's proposal to construct its own hydroelectric powerplant. When the initial expansion is completed, Brasmag plans to export one-fourth of its production

TABLE 5

U.S. EXPORTS AND IMPORTS FOR CONSUMPTION OF MAGNESIUM

Year	EXPORTS							
	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	1,406	$3,286	43,233	$123,509	3,849	$15,495	8,143	$28,084
	IMPORTS FOR CONSUMPTION							
	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	3,773	$7,856	3,879	$12,373	3,829	$14,702	808	$2,928

Source: Bureau of the Census.

to Mexico and other Latin American countries; the bulk of the magnesium is planned for domestic consumption. Brazil's magnesium consumption, mostly from the automotive industry and estimated to be 9,600 tons in 1988, was partially met with imported metal.

Canada.—Small-scale magnesium production at Norsk Hydro A/S's Becancour, Quebec, plant began in November. The company planned to reach the plant's full production capacity of 40,000 tons per year by the first quarter of 1990. Total construction costs were about $180 million greater than the $340 million originally budgeted. Included in the total investment were the costs necessary to expand gradually the plant's annual capacity to 60,000 tons.

In November, Magnesium Co. of Canada Ltd. (MagCan) announced the startup of 12,500 tons of annual capacity at its new magnesium plant in High River, Alberta, would be delayed until January 1990. The company cited problems in getting the necessary labor to complete plant construction. MagCan planned to add two 25,000-ton-per-year capacity increments to reach a total annual capacity of 62,500 tons by 1994.

Colombia.—Industrial Minera de Colombia was seeking foreign partners to share the construction costs for a $200 million magnesium complex in the Guajira peninsula. Annual production of the proposed electrolytic plant would be 30,000 tons. In addition to the electrolytic plant, the magnesium complex would include a desalination facility, limestone mine, powerplant, and chlorine gas and caustic soda plant.

India.—Ispat Alloys Ltd. announced that it would construct a 4,000-ton-per-year primary magnesium plant near Agartala, Tripura, at a cost of about $37.5 million. This area is rich in dolomite and natural gas, both necessary for operating a silicothermic plant. Annual demand for magnesium in India was estimated to be about 2,000 tons. No timetable was set for plant construction.

Japan.—In February, Nichiju A.M. announced an increase in its annual magnesium production by 1,200 tons to 4,800 tons at its plant in Takaoku, Toyama. In addition, Ube Industries Ltd. announced that it would increase magnesium production at its plant in Ube City to 8,000 tons per year by mid-1989. Ube planned to restart idled furnaces to achieve the additional production because all the company's operating furnaces were at capacity. With the closure of Furakawa Magnesium Co. Ltd.'s Oyama City, Tochigi, plant in March, total magnesium production capacity in Japan was 13,000 tons by yearend.[5]

Norway.—Norsk Hydro announced that it would close 10,000 tons of annual magnesium production capacity at its Porsgrunn complex when its Canadian plant comes on-stream. The closure was announced late in the year after Norsk Hydro reported that annual production capacity at the plant had been increased by 3,000 tons to 51,000 tons. The incremental increase was achieved by channeling additional electric power through existing facilities. Capacity that was closed in 1988 because of environmental problems was expected to remain closed for at least 5 years.

Elkem A/S planned to build a 20,000-ton-per-year primary magnesium plant if it could come to terms with the Government on electrical supplies. Elkem would take advantage of a power-rate cut offered to a new power-intensive industry. Two economically depressed cities, Fauske and Mo i Rana, were considered as possible plant sites.

South Africa, Republic of.—Anglo American Corp. reportedly began a feasibility study on recovering magnesium from a dolomite deposit in the Transvaal. The dolomite would be used to feed a 10,000-ton-per-year plant operated in a joint venture between Anglo American and Cape Lime Corp., the owner of the dolomite deposit.

United Kingdom.—Norsk Hydro reportedly acquired a majority share of Kirk Precision Ltd., a manufacturer of magnesium bicycle frames, and planned to establish a robotic facility capable of producing 200,000 frames annually. Kirk Precision was believed to have the largest hot-chamber, high-pressure diecasting machinery in existence. This machinery may be adaptable for production of large magnesium diecastings for other applications, particularly in the automotive industry.[6]

TABLE 6

U.S. EXPORTS OF MAGNESIUM, BY COUNTRY 1989

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)
Argentina	—	—	483	$1,652	—	—	26	$136
Australia	—	—	2,143	6,871	—	—	215	915
Austria	29	$65	51	169	—	—	—	—
Bahrain	—	—	125	356	—	—	—	—
Belgium	—	—	1	17	—	—	159	705
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	—	—	—	—
Colombia	—	—	10	38	9	32	47	206
France	—	—	22	331	—	—	(1)	17
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
Ireland	—	—	—	—	—	—	—	—
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
New Zealand	—	—	65	246	—	—	2	142
Norway	—	—	1,211	3,485	2	5	—	—
Peru	—	—	24	95	—	—	—	—
Singapore	—	—	—	—	20	66	(1)	5
South Africa, Republic of	—	—	98	331	35	119	88	509
Spain	—	—	738	2,446	—	—	—	—
Sweden	—	—	42	395	(1)	4	21	119
Taiwan	—	—	512	1,692	20	68	44	123
Turkey	20	40	—	—	—	—	—	—
United Kingdom	19	41	202	1,171	30	126	124	1,526
Venezuela	17	70	61	133	—	—	228	767
Other	9	21	300	1,551	457	1,343	97	868
Total	1,406	3,286	43,233	123,509	3,849	15,495	8,143	28,084

[1] Less than 1/2 unit.

Source: Bureau of the Census.

Current Research

Mintek, of the Republic of South Africa, patented a process to produce magnesium in a plasma-arc furnace. In the new process, a plasma-arc furnace replaced the submerged-electrode furnace normally used in the Magnetherm process, and the process was done at atmospheric pressure rather than under a vacuum. The reaction, in which magnesium vapor is generated from dolomite and ferrosilicon, was the same as that of the Magnetherm process. Mintek claimed that capital costs for the new process were less than those for the Magnetherm process, and it could be adapted to continuous or semicontinuous operation.[7]

Magnesium Elektron Ltd. introduced a magnesium casting alloy, designated WE43, a high-strength alloy containing yttrium for use at temperatures up to 300° C. The alloy was cast by a novel process called differential-pressure sand casting, which provides thin-walled castings with improved properties and increases metal utilization. Corrosion resistance of WE43 was reported to be comparable with that of high-strength aluminum alloys. Potential applications for WE43 are aerospace engines, helicopter transmissions, and missiles. Allied-Signal Inc. also developed a new magnesium casting alloy suitable for applications in the aerospace and automotive industries. The magnesium-aluminum-zinc-neodymium alloy was reported to match the corrosion resistance of 2024 aluminum alloys. It also

TABLE 7

WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1989, BY CONTINENT AND COUNTRY

(Metric tons)

	Capacity
North America:	
United States	160,000
Canada	9,000
Total	169,000
South America: Brazil	6,000
Europe:	
France	14,000
Italy	10,000
Norway	51,000
U.S.S.R.	95,000
Yugoslavia	6,000
Total	176,000
Asia:	
China	9,000
Japan	13,000
Total	22,000
World total	373,000

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

showed superior resistance to pitting, compared with conventional magnesium casting alloys, while retaining equivalent mechanical properties. The new alloy can be formed by rapid-solidification-processing techniques.

A new company, Thixomat Inc., was formed to commercialize a process to fabricate near-net-shape metal and metal-matrix composite parts. The process, developed by Dow, combines elements of diecasting with injection molding, and developmental work was done with magnesium alloys and magnesium metal-matrix composites. In the one-step patented process, granules of magnesium alloy were fed into a reciprocating-screw-injection system, heated to 580° C to form a semisolid slurry, and injected quickly into a mold. Components produced from thixotropic magnesium were reported to have 50% lower porosity and greater dimensional stability than die-cast components.[8]

Outlook

The International Magnesium Association, in its annual review of magnesium supply and demand, projected an average annual growth rate in consumption of 3% from 1989 to 1993 throughout market economy countries. Most of this growth was projected to occur in North American diecasting applications, with all other applications exhibiting small growth. Continued recycling of aluminum beverage cans, the largest market for magnesium, coupled with reduced can weight, contributed to a slow growth forecast in this application. But, if aluminum food cans are proven technically feasible and aluminum beverage cans are accepted in Europe, the slow growth forecast could change dramatically.

Worldwide magnesium production was expected to increase over the same period, but as significant additional capacity comes on-stream in Canada, capacity utilization was expected to decline. As part of the decrease in capacity utilization, higher cost magnesium producers were expected to take small capacity increments offline when inventories increase to an acceptable level.[9]

MAGNESIUM COMPOUNDS

Overall U.S. magnesium compounds production decreased in 1989, although caustic-calcined magnesia production increased. Imports continued to supply a significant share of U.S. demand, but the dramatic annual increases in imports that occurred in the mid-1980's appeared to have stabilized.

Refractories were the principal use for dead-burned magnesia, and caustic-calcined magnesia was used primarily in

TABLE 8

MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Brazil	2,615	4,356	5,488	5,865	6,200
Canada[e]	7,200	5,100	8,800	7,600	7,200
China[e]	[r]3,000	[r]3,000	[r]3,000	[r]3,200	3,200
France	13,639	13,361	13,601	13,800	13,900
Italy	7,863	[r]12,417	7,626	5,436	[2]2,770
Japan	8,456	8,116	8,180	9,012	[2]11,385
Norway	54,704	56,522	56,907	50,300	[2]49,827
U.S.S.R.[e]	87,000	89,000	90,000	91,000	91,000
United States	135,728	125,639	124,396	141,983	[2]152,066
Yugoslavia	4,978	4,897	5,932	6,176	6,000
Total	[r]325,183	[r]322,408	323,930	334,372	343,548

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through June 22, 1990.
[2] Reported figure.

TABLE 9

MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Brazil	2,006	1,767	1,376	[e]1,500	1,500
Japan	20,894	14,415	10,284	10,020	12,000
U.S.S.R.[e]	8,000	8,000	8,000	8,000	8,000
United Kingdom[e]	900	1,000	1,000	1,000	1,000
United States	41,298	41,807	45,165	50,207	[2]51,200
Total	73,098	66,989	65,825	70,727	73,700

[e] Estimated. [p] Preliminary.
[1] Table includes data available through June 22, 1990.
[2] Reported figure.

animal feed and chemicals. Seawater and brines were the main raw materials for magnesium compound production, accounting for more than 60%, with dolomite, magnesite, and olivine as the other source materials.

Many world producers of magnesia were upgrading their facilities to produce higher grade materials rather than increasing their capacity. Demand from the refractories users, such as the iron and steel industry, for better-quality, longer-lasting refractories resulted in this shift from higher quantity to higher quality.

Production

Caustic-calcined magnesia production increased for the third year in a row, and dead-burned magnesia production declined, reversing a 2-year trend. Production of olivine declined by 9%, and average value decreased by 16%.

Early in 1989, a partnership formed between managers of Merck & Co. Inc.'s magnesium chemicals business and C. P. Hall Co. purchased the assets of Merck's magnesium chemicals business. Although Merck sold the San Francisco, CA, plant to Genentech Inc. in 1988, the partnership, named Marine Magnesium Co., negotiated an open-ended lease with Genentech to continue operations at the plant for at least 3 years. C. P. Hall, a purchaser and reseller of specialty magnesias, was expected to continue to be Marine Magnesium's largest customer. National Refractories & Minerals Corp. announced in July that it completed an expansion of capacity for production of 50% magnesium hydroxide slurry. This expansion would triple magnesium hydroxide slurry capacity at its Moss Landing, CA, seawater plant to 400,000 tons per year.

Consumption and Uses

Refractories for use in iron and steel, nonferrous metals, glass, and cement production facilities were the dominant use for dead-burned magnesia. Caustic-calcined magnesia was used in a wide variety of applications. Animal feed, representing 27% of U.S. caustic-calcined magnesia shipments, was the largest consuming industry. Chemical uses accounted for 24% of domestic shipments. The following uses, in declining order, accounted for 24% of caustic calcined magnesia shipments: rayon manufacture, refractories, fertilizer, and fuel additive. The remaining 25% of domestic shipments was consumed by the following industries, in declining order: stack-gas scrubbing, rubber, electrical, water treatment, ceramics, medicine and pharmaceuticals, oxychloride and oxysulfate cements, sugar, pulp and paper, uranium processing, insulation and wallboard, candies, foundry, and winemaking.

Magnesium carbonate and magnesium sulfate were used principally in the pharmaceutical industry, with smaller use for chemicals and fertilizers. Magnesium carbonate also was used in the rubber industry, and magnesium sulfate was used for animal feed. Magnesium chloride brines were used primarily in chemical applications, with smaller uses in ceramics and dust control. Pulp and paper was the main consuming industry for magnesium hydroxide. Smaller quantities were used in the chemical and water

TABLE 10

SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	91	86	103	124	135
Value	$33,772	$33,969	$27,565	$36,500	$39,529
Exports, value[3]	$9,773	$13,295	$14,167	$13,322	$2,263
Imports for consumption, value[3]	$10,407	$11,493	$4,575	$2,371	$13,657
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	263	249	296	371	348
Value	$81,149	$73,172	$80,760	$103,400	$97,673
Exports, value	$5,529	$5,488	$3,240	$9,262	$10,685
Imports for consumption, value	$29,767	$36,718	$41,333	$42,885	$38,555
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	341	385	259	748	533
Value	$24,454	$27,789	$21,766	$45,256	$38,208
World production (magnesite)	r12,168	r12,299	11,753	p11,936	e12,003

e Estimated. p Preliminary. 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.

TABLE 11

U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	123,905	$36,500	134,641	$39,529
Magnesium hydroxide [100% $Mg(OH)_2$][1]	392,743	76,031	341,933	70,260
Magnesium sulfate (anhydrous and hydrous)	61,505	19,185	63,432	19,819
Precipitated magnesium carbonate[1]	2,877	655	2,332	641
Refractory magnesia	371,296	103,400	348,316	97,673

[1] Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

treatment industries. Magnesium chloride was used for chemicals and oxychloride and oxysulfate cements.

The bulk of U.S. olivine shipments, 68%, was used as foundry sands. Refractories represented 18% of olivine shipments, and the remaining 14% was used for slag control, soil conditioning, and unspecified applications.

Prices

Yearend magnesium compound prices, published in the Chemical Marketing Reporter, have remained unchanged since 1987. Yearend prices were as follows:

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.	.14

Foreign Trade

Because of the implementation of the HTS beginning in 1989, trade data for 1989 are not comparable with those of the previous years. For magnesium compounds, additional data on exports of crude magnesite and various magnesium compounds were separated that were previously included in categories containing other materials.

Trade data for olivine were combined with other trade data by the Bureau of the Census and could not be separately identified. According to the Journal of Commerce Port Import/Export Reporting Service, 205,090 tons of olivine was imported from Norway, and the United States exported 4,491 tons, mainly to Chile and Peru.

World Review

Australia.—After completing a feasibility study in June, the joint-venture partners in the Queensland Magnesia Project planned to begin construction of a magnesia plant by yearend. The new plant, in Kunwarara, was expected to have an annual capacity of 150,000 tons of dead-burned magnesia and 25,000 tons of fused magnesia. Initial production was planned for mid-1991, with product shipments beginning in September. The magnesite deposit that will serve as the feed for the plant was estimated to contain 400 million tons of magnesite. Two areas, designated KG1 and KG2 and representing 13% of the total deposit, were targeted for initial mining operations at a rate of between 1.75 and 2 million tons per year.

Brazil.—Magnesita S.A., the largest magnesite producer in the country, also produces refractory brick and planned to install a new shaft kiln, with a capacity of 50,000 tons of brick per year at its plant in Minas Gerais. The new kiln,

TABLE 12

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989 Quantity (metric tons)	1989 Value (thousands)
Caustic-calcined magnesia:		
Canada	2,228	$1,022
Germany, Federal Republic of	199	128
Mexico	871	306
Netherlands	858	536
Other	219	271
Total	4,375	2,263
Dead-burned and fused magnesia:		
Australia	1,027	316
Belgium	417	138
Canada	11,574	5,960
France	2,626	676
Korea, Republic of	482	249
Mexico	5,357	2,804
Taiwan	585	298
Venezuela	206	59
Other	251	185
Total	22,525	10,685
Other magnesia:		
Australia	311	456
Brazil	102	91
Canada	505	282
Colombia	180	309
France	187	77
Germany, Federal Republic of	2,273	1,206
Israel	1,942	643
Italy	190	63
Mexico	548	747
Panama	116	11
Spain	2,023	1,016
Sweden	302	100
Taiwan	159	103
Thailand	123	63
United Kingdom	141	84
Venezuela	6,319	2,743
Other	422	1,219
Total	15,843	9,213
Natural magnesite:		
Australia	124	117
Belgium	185	331
Brazil	394	906
Canada	1,365	668
Germany, Federal Republic of	433	542

TABLE 12—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989 Quantity (metric tons)	1989 Value (thousands)
Natural magnesite—Continued		
Greece	180	$226
Italy	1,214	1,119
Korea, Republic of	215	109
Mexico	4,583	2,757
Netherlands	217	277
Romania	165	98
Spain	468	389
Taiwan	255	194
Other	582	566
Total	10,380	8,299
Calcined dolomite:		
Canada	22,109	6,323
Colombia	1,046	185
Mexico	9,330	1,977
Peru	1,500	476
Spain	2,000	659
Trinidad	956	163
Venezuela	2,500	847
Other	198	53
Total	39,639	10,683

Source: Bureau of the Census.

TABLE 13

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

Source: Bureau of the Census.

expected to be operational by 1991, was designed to produce a high-density, 98% magnesia brick. In addition, one of Magnesita's subsidiaries, Refratec-Productos Electrofundidos Ltd., planned to construct a 2,400-ton-per-year plant to produce a high-temperature grade of fused magnesia. Both of these new operations were part of Magnesita's program to develop new refractory products for basic-oxygen furnaces and electric arc furnaces.[10]

Canada.—Baymag officially opened a 14,000-ton-per-year fused magnesia plant in September in Exshaw, Alberta. Baymag produced caustic-calcined magnesia at its nearby plant as the raw material for the fused magnesia plant. To maintain feedstock supply, Baymag announced that it would construct a 50,000-ton-per-year facility for caustic-calcined magnesia at the new plant site. Because of the high degree of automation in the new plant, the entire operation reportedly could be run by six people. Depending on market strength, Baymag planned to double the plant's capacity by adding two electric arc furnaces.[11] In addition to its production of fused and caustic-calcined magnesia, Baymag was expected to supply magnesite for a new magnesium metal plant scheduled to begin operation in 1990.

India.—Tamilnadu Magnesite Products Ltd. reportedly was constructing a

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989	
	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:		
Canada	56,069	$10,996
China	7,569	808
Greece	6,456	789
Mexico	3,203	416
Turkey	2,108	534
Other	179	114
Total	75,584	13,657
Dead-burned and fused magnesia:		
Canada	9,746	4,582
China	61,382	4,914
Czechoslovakia	12,159	948
Greece	45,346	7,800
Hong Kong	4,230	414
Ireland	13,551	4,467
Israel	1,122	404
Japan	11,384	2,955
Mexico	25,050	7,832
Netherlands	3,186	1,056
United Kingdom	15,484	3,107
Other	150	76
Total	202,790	38,555
Other magnesia:		
Canada	390	123
Germany, Federal Republic of	60	86

TABLE 14—Continued

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989	
	Quantity (metric tons)	Value (thousands)
Other magnesia—Continued		
Japan	4,226	$7,591
Mexico	335	156
United Kingdom	370	394
Other	493	844
Total	5,874	9,194
Crude magnesite:		
Canada	1,077	225
China	6,344	645
France	158	66
Germany, Federal Republic of	55	8
India	5	3
Italy	259	127
Japan	424	250
Mexico	21	8
Taiwan	1	10
United Kingdom	28	12
Total	8,372	1,354
Calcined dolomite:		
Canada	20,854	2,755
Germany, Federal Republic of	194	41
Ireland	10	4
Mexico	730	71
Total	21,788	2,871

Source: Bureau of the Census.

TABLE 15

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

Source: Bureau of the Census.

30,000-ton-per-year plant to produce dead-burned magnesia. The new plant, scheduled to come on-stream in 1991, will use technology patented by Sulzer Brothers Ltd. of the Federal Republic of Germany to beneficiate low-grade magnesite to dead-burned magnesite containing greater than 99% magnesia. High-grade magnesia produced at the plant was expected to be used for refractory bricks in the country's growing steel industry. Tamilnadu Magnesite also produced caustic-calcined magnesia for export.

South Africa, Republic of.—Chamotte Holdings (Pty.) Ltd. installed kilns to produce caustic-calcined magnesia for use in animal feed and fertilizers at its operation in Malelane. The company has produced refractory magnesia, and installation of the new kilns was expected to reduce the Republic of South Africa's import dependence on caustic-calcined magnesia. Chamotte Holdings also completed a 6,000-ton-per-year magnesium sulfate plant, with the output destined primarily for paper, agricultural, and other smaller markets. A third project involved the installation of a plant to produce 75,000 tons per year of magnesium carbonate fines.

Outlook

Because the largest use for magnesium compounds is in the manufacture of refractories, this industry segment has had the greatest influence on overall magnesium compounds demand. Following the contraction of the iron and steel industry in the mid-1980's, magnesia refractories demand declined to historic lows. However, a combination of retrenchment and processing changes in the iron and steel industry led to stronger demand for magnesia refractories in the latter part of the 1980's. Growth for magnesia refractories in the early 1990's was expected to continue, but at a slower pace than in the late 1980's. Changes in steel furnace technology led to the substitution of magnesia refractories in place of other types of refractories. But at the same time, development of longer-lived magnesia refractories lengthened the amount of time between furnace relinings.

Although total demand for magnesium compounds has increased significantly from its low point in the mid-1980's, magnesia production in the United States has not increased as significantly. When the industry was depressed, cheaper imports of magnesia, particularly from China and Greece, began to increase dramatically. Import reliance for magnesium compounds rose from 4% in 1982 to 25% in 1985 and has remained above 20% since then. Even though import reliance has leveled off somewhat, the United States was expected to continue to rely on imported material to supply about 20% of domestic magnesium compounds demand.

TABLE 16

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand metric tons, MgO equivalent)

Country	Raw material	
	Magnesite	Seawater or brines
North America:		
Canada	160	—
Mexico	—	170
United States	100	913
Total	260	1,083
South America: Brazil	345	—
Europe:		
Austria	576	—
Czechoslovakia	700	—
France	—	30
Greece	612	—
Ireland	—	100
Italy	—	125
Netherlands	—	120
Norway	—	25
Poland	10	—
Spain	205	—
Turkey	285	—
U.S.S.R.	2,100	100
Yugoslavia	240	—
Total	4,728	500
Africa:		
Kenya	170	—
South Africa, Republic of	84	—
Zimbabwe	2	—
Total	256	—
Asia:		
China	1,000	10
India	229	—
Israel	—	70
Japan	—	485
Korea, North	1,250	—
Korea, Republic of	—	50
Nepal	125	—
Total	2,604	615
Oceania: Australia	10	—
Grand total	8,203	2,198

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

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 to specify magnesium alloys are E for rare-earth metals and M for manganese.

Although many minerals contain magnesium, magnesite, dolomite, brucite, and olivine are the only minerals from which magnesium is recovered commercially. Magnesite, or magnesium carbonate ($MgCO_3$), has a theoretical magnesia content of 47.6%. Dolomite is a calcium carbonate-magnesium carbonate mineral ($CaCO_3 \cdot MgCO_3$) that has a theoretical magnesia content of 22%. Brucite, magnesium hydroxide [$Mg(OH)_2$] contains up to 69% magnesia, and olivine ($Mg_2Fe_2SiO_4$) contains up to 19% magnesium. Of these minerals, magnesite and dolomite are the largest sources of magnesium.

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 78% of the magnesium metal production capacity uses seawater or brines as a raw material.

Various magnesia products are made by calcining magnesium carbonate or

TABLE 17

MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia	57,535	41,441	53,941	56,446	55,000
Austria	1,255,043	1,084,360	946,943	1,121,585	1,200,000
Brazil[2]	[r]260,754	[r]296,792	390,182	404,000	400,000
Canada[e 3]	136,000	144,000	150,000	150,000	150,000
China[e]	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Colombia	14,230	14,936	[e]15,000	[e]15,000	15,000
Czechoslovakia	654,000	666,000	671,000	630,786	600,000
Greece	845,888	884,373	841,000	930,000	900,000
India	417,412	422,000	430,000	460,000	465,000
Iran[e 4]	5,000	5,000	5,000	5,000	5,000
Kenya[e]	300,000	300,000	([5 6])	([5 6])	—
Korea, North[e]	1,900,000	1,900,000	1,900,000	1,900,000	1,900,000
Mexico	19,299	7,530	7,351	7,531	7,500
Nepal	19,851	63,190	38,388	45,000	40,000
Pakistan	2,113	1,757	3,740	3,081	3,000
Philippines[e]	[5]676	650	650	650	700
Poland	19,200	20,900	22,300	23,000	23,000
South Africa, Republic of	28,898	61,186	74,961	74,088	74,000
Spain[e]	[5]692,196	700,000	710,000	710,000	720,000
Turkey	1,128,961	1,313,763	1,185,904	1,161,416	1,200,000
U.S.S.R.[e]	1,975,000	1,925,000	[r]1,875,000	[r]1,825,000	1,825,000
United States	W	W	W	W	W
Yugoslavia	417,000	423,000	403,000	383,000	390,000
Zimbabwe	19,385	22,649	28,991	30,121	30,000
Total	[r]12,168,441	[r]12,298,527	11,753,351	11,935,704	12,003,200

[e] Estimated. [p] Preliminary. [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 2, 1990.

[2] Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1985—623,330; 1986—648,752; 1987—860,163; 1988—810,837; and 1989—850,000 (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.

[6] Revised to zero.

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 recovered from seawater or brines is called synthetic magnesia.

Standards for magnesia 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 then 50% of domestic 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 wide variety of applications, including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, each containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys.

Magnesium and its alloys are used as structural components in automobiles, trucks, aircraft, computers, and power tools. Many of these applications use magnesium because of its light weight and its 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 iron and steel in 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 lining materials principally for use in the 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 myriad of applications in the agriculture, 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 also is important in manufacturing paper, rayon, and rubber.[12]

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 industry. Fused magnesia is mainly used 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 buildings and bridges and in incinerators.[13]

Industry Structure

U.S. producers of primary magnesium and magnesium compounds are shown in tables 18 and 19. 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. Olivine operates one mine and one processing plant in Washington.

Norway, the U.S.S.R., and the United States, with large electrolytic plants, represent 82% of the world's magnesium metal production capacity. Smaller thermal plants are located in Canada, China, France, Italy, Japan, and Yugoslavia. Canada is expected to replace Norway as the third largest producer in 1990 when two new electrolytic facilities come on-stream.

In the rest of the world, the largest magnesite production facilities are located in the centrally planned economies of China, North Korea, and the U.S.S.R. Together, these three countries account for 53% of the world's magnesite production capacity. Japan and the United States account for nearly 64% of the capacity for magnesium compounds production from seawater and brines. Fused magnesia is produced in France, Israel, Japan, the United Kingdom, and the United States.

Norway is the world's largest producer of olivine, and, in addition to supplying domestic needs, Norway's production is exported throughout the world. Countries with smaller output are Austria, Italy, Japan, Mexico, Spain, and the United States.

Technology

Two thermal processes currently are in use to recover magnesium metal

TABLE 18

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1989

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	90,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			160,000

TABLE 19

U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1989

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	68,000
Marine Magnesium Co.	South San Francisco, CA	15,000
National Refractories & Minerals Corp.	Moss Landing, CA	130,000
Total		1,013,000

from dolomite—the Pidgeon process and the Magnetherm process. Both utilize 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 silicon to produce magnesium vapor, which is cooled and condensed in a separate section of the retort. Plants in Canada, Italy, and Japan use this process to recover magnesium.

In the Magnetherm process, calcined dolomite, ferrosilicon, and alumina are heated under a vacuum. Alumina reduces the melting point of the slag produced by the dolomite-ferrosilicon reaction to make resistance heating practical. Magnesium vapor is cooled and condensed in a condensing chamber. The Magnetherm process is used by plants in Brazil, France, Japan, the United States, and Yugoslavia.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that is prepared from seawater or brines. Two types of magnesium chloride can be prepared—hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow, 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 fed directly to electrolytic cells.

MagCorp and Norsk Hydro 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, the brine is further concentrated and dehydrated in a spray dryer. The resulting powder is melted and purified to yield an anhydrous material. 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 are usually 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 collected and recycled or sold.[14]

Mineral Process Licensing Corp. developed a one-step process for producing anhydrous magnesium chloride from magnesite that was expected to be used in the MagCan plant in Canada. 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 the electrolytic cells.[15]

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 the 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 kilns.

In producing synthetic magnesia, seawater or brines are treated either with a small quantity of lime or sulfuric

TABLE 20

U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1989	Non-MFN Jan. 1, 1989
Magnesium:			
Unwrought magnesium	8104.11.0000	8.0% ad val.	100% ad val.
Unwrought magnesium alloys	8104.19.0000	6.5% ad val.	60.5% ad val.
Wrought magnesium	8104.90.0000	14.8¢/kg on Mg content + 3.5% ad val.	88¢/kg on Mg content + 20.0% ad val.
Magnesium waste and scrap	8104.20.0000	Free	Free.
Magnesium compounds:			
Crude magnesite	2519.10.0000	Free	$10.33/ton.
Dead-burned and fused magnesia	2519.90.1000	0.4¢/kg	1.7¢/kg.
Caustic-calcined magnesia	2519.90.2000	$2.07/ton	$20.70/ton.
Magnesia, other	2519.90.5000	Free	15.4¢/kg.
Calcined dolomite	2518.20.0000	6% ad val.	30% ad val.
Kieserite, natural	2530.20.1000	Free	Free.
Epsom salts, natural	2530.20.2000	3.7% ad val.	20% ad val.
Magnesium hydroxide and peroxide	2816.10.0000	3.1% ad val.	25% ad val.
Magnesium chloride	2827.31.0000	1.5% ad val.	5% ad val.
Magnesium sulfate	2833.21.0000	3.7% ad val.	20% ad val.

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 upon the feed material and the process used. Operating costs for magnesium production range from $309 to $2,283 per ton, with energy costs as the largest component of the total operating cost. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending upon source material and processing techniques. Operating costs range from $24 to $425 per ton for magnesium compound production, with seawater as the most costly source. Energy costs also represent the largest component of operating costs.[16]

Tariffs for magnesium and magnesium compounds are shown in table 20. 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).

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TABLE 21

MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION											
United States:											
Nonmetal	909	727	690	512	567	574	420	412	464	622	544
Metal	[1]147	[1]153	140	93	104	144	136	125	124	142	152
Total	1,056	880	830	605	671	718	556	537	588	764	696
Rest of world:											
Nonmetal	4,558	4,726	4,668	4,371	4,777	4,676	4,807	4,845	4,688	[p]4,790	[e]4,760
Metal	160	162	169	161	156	184	189	196	200	[p]192	[e]192
Total	4,718	4,888	4,837	4,532	4,933	4,860	4,996	5,041	4,888	[p]4,982	[e]4,952
World total	5,774	5,768	5,667	5,137	5,604	5,578	5,552	5,578	5,476	[p]5,746	[e]5,648
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	909	727	690	512	567	574	420	412	464	622	544
Primary metal	147	153	140	93	104	144	136	125	124	142	152
Secondary metal (old scrap)	13	16	22	21	23	24	24	23	23	28	28
Imports:											
Nonmetal	54	46	50	39	61	115	134	160	164	198	171
Metal	5	4	6	5	5	9	8	8	11	14	12
Industry stocks, metal, Jan. 1	45	40	44	57	42	25	32	39	39	28	25
Total U.S. supply	1,173	986	952	727	802	891	754	767	825	1,032	932
Distribution of U.S. supply:											
Exports:											
Nonmetal	55	59	32	20	15	27	25	25	20	34	26
Metal	49	52	32	36	43	44	36	40	44	50	57
Industry stocks, metal, Dec. 31	40	44	57	42	25	32	39	39	28	25	26
Industrial demand[2]	1,029	831	831	629	719	788	654	663	733	923	823
U.S. DEMAND PATTERN											
Nonmetal:											
Refractories	817	629	609	446	508	531	402	376	453	583	484
Chemicals	91	85	99	85	105	131	127	171	155	203	205
Total	908	714	708	531	613	662	529	547	608	786	689
Metal:											
Cans and containers	17	19	20	17	19	23	23	22	39	39	42
Transportation	40	36	38	25	31	36	38	33	38	38	36
Machinery	35	34	34	33	34	29	22	27	19	20	17
Chemicals	10	7	8	6	7	8	5	3	2	1	1
Nonferrous metal production	8	10	13	7	6	9	12	9	5	11	12
Iron and steel foundries	5	5	5	4	3	4	3	3	2	3	2
Other[3]	6	6	5	6	6	17	22	19	20	25	24
Total	121	117	123	98	106	126	125	116	125	137	134
Total industrial demand	1,029	831	831	629	719	788	654	663	733	923	823
Total U.S. primary demand[4]	1,016	815	809	608	696	764	630	640	710	895	795
Total U.S. demand for primary metal[5]	108	101	101	77	83	102	101	93	102	109	106

[e] Estimated. [p] Preliminary.

[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] Includes iron and steel desulfurization from 1984 to 1989.

[4] Total U.S. demand less U.S. recovery from secondary metal.

[5] U.S. demand for metal less U.S. recovery from secondary metal.

MANGANESE

By Thomas S. Jones

Dr. Jones, a physical scientist with 31 years industry and Bureau of Mines experience, has been the commodity specialist for manganese since 1982. Domestic survey data were prepared by Sherwood Jordan, mineral data assistant, and international data tables were prepared by Giovanni Jacarepaqua, international data assistant.

World production of manganese ore increased nominally, according to preliminary data.

The price of metallurgical-grade ore advanced about 60% on international markets to another record. Prices also rose significantly for manganese alloys.

Developments in the United States included a slight decline in usage rate for manganese in steelmaking. The total of contained manganese imported into the United States for the year was the greatest since 1981, and imports of silicomanganese again set a record. The Government's program of upgrading ore into high-carbon ferromanganese was extended through 1991.

TABLE 1

SALIENT MANGANESE STATISTICS

(Thousand short tons, gross weight)

	1985	1986	1987	1988	1989
United States:					
Manganese ore (35% or more Mn):					
Exports	56	42	63	68	57
Imports for consumption	387	463	341	512	639
Consumption[e]	545	500	533	554	616
Stocks, Dec. 31: Consumers[e]	589	455	456	458	518
Manganiferous ore (5% to 35% Mn):					
Production (shipments)	20	14	W	W	W
Ferromanganese:					
Exports	7	4	3	3	9
Imports for consumption	367	396	368	531	476
Consumption	466	376	409	468	440
Stocks, Dec. 31: Consumers and producers	100	93	48	91	75
World:					
Production of manganese ore	[r]27,948	[r]27,545	26,134	[p]26,300	[e]26,483

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

LEGISLATION AND GOVERNMENT PROGRAMS

The Minerals Management Service of the U.S. Department of the Interior issued final regulations governing the second and third parts of a three-tiered regulatory program for marine mining on the U.S. Outer Continental Shelf of all leasable minerals other than oil, gas, and sulfur (54 FR 2042).

STRATEGIC CONSIDERATIONS

Security of Supply

Manganese, for which there is no economical substitute, is essential to steelmaking. Steel producers in the market economy countries (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. 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 sizable stockpile of manganese materials built up by the Government following World War II still represented a reserve of nearly 2 million tons[1] of contained manganese as of the end of 1989. On September 29, 1989, the Defense Logistics Agency (DLA) progressed with the latest phase of the program of upgrading metallurgical-grade ore in the National Defense Stockpile. A contract was made with Elkem Metals Co. to convert about 265,000 tons of ore into about 148,000 tons of high-carbon ferromanganese in 1990 and 1991 at a cost of approximately $82.3 million. In March, DLA accepted into inventory 55,034 tons of high-carbon ferromanganese to bring its stocks of that ferroalloy to 812,157 tons. The only excess stockpile manganese materials sold in 1989 consisted of 336 tons of nonstockpile-grade metallurgical ore. These developments, plus a small accounting adjustment for natural battery ore, are summarized in the following table.

Material	Short tons, gross weight		
	Sales		Change in yearend inventory
	Stockpile grade	Nonstockpile grade	
Natural battery ore	—	—	+52
Metallurgical ore	—	336	−78,198
High-carbon ferromanganese	—	—	+55,034

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 of 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.[2] In so doing, OTA discounted ocean mining for the present.

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, such as in the event sanctions disrupt supplies from the Republic of South Africa.

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. Publication of shipments data was precluded to avoid disclosing proprietary data.

Ferroalloys and Metal

Publication of statistics was precluded to avoid disclosing proprietary data.

TABLE 2

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR MANGANESE MATERIALS IN 1989

(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	62,000	169,511	33,425	202,936	787	203,723
Synthetic manganese dioxide	25,000	3,011	—	3,011	—	3,011
Chemical ore	170,000	171,717	89	171,806	417	172,223
Metallurgical ore	2,700,000	1,940,696	911,408	2,852,104	13,310	2,865,414
High-carbon ferromanganese	439,000	812,157	—	812,157	—	812,157
Medium-carbon ferromanganese	—	29,057	—	29,057	—	29,057
Silicomanganese	—	23,574	—	23,574	—	23,574
Electrolytic metal	—	14,172	—	14,172	—	14,172

TABLE 3

DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1989

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.
SKW Alloys Inc.	Calvert City, KY	—	X	—	—	Electric furnace.

[1] FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO_2, synthetic manganese dioxide.

CONSUMPTION, USES, AND STOCKS

Metallurgical applications accounted for most manganese consumption, about 90% for steelmaking. Relatively small quantities of manganese were used for alloying with nonferrous metals, chiefly aluminum. Nonmetallurgical applications included dry cell batteries, plant fertilizers, animal feed, brick coloring, and manganese chemicals.[3]

Ironmaking and Steelmaking

The average rate of consumption of manganese as manganese ore in making pig iron or equivalent hot metal stayed at 1.2 pounds per ton of raw steel, as calculated from a reported consumption of 135,000 tons of manganese ore in production of 97.9 million tons of raw steel.

For reported consumption in production of 99.1 million tons of raw steel and steel castings, the pounds of manganese consumed per ton of raw steel was 6.7 as ferromanganese, 1.3 as silicomanganese, and 0.1 for metal. The total of 8.1 was 6% less than in 1988.

Battery and Miscellaneous Industries

Production of alkaline batteries began in the latter part of the year at the Columbus, GA, plant of the joint venture between the Ultra Technologies Inc. subsidiary of Eastman Kodak Co. and Japan's Matsushita Battery Industrial Co. Ltd. In Wisconsin, Rayovac Corp. announced a major expansion of alkaline battery facilities at its Fennimore, WI, plant, to occur over a 4-year period.

Bankruptcy of Burgess Inc., Freeport, IL, once one of the larger domestic sources of carbon-zinc batteries, exemplified the trend for carbon-zinc cells, based on natural manganese dioxide, to decrease in popularity in favor of alkaline cells, based on synthetic dioxide.

Through U.S. subsidiaries, Sweden's ESAB AB acquired the worldwide operations of L-TEC Welding and Cutting Systems. L-TEC's activities have included a plant at Niagara Falls, NY, where manganese materials are used in making welding fluxes.

TABLE 5

U.S. CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF MANGANESE FERROALLOYS AND METAL IN 1989

(Short tons, gross weight)

End use	Ferromanganese			Silico-manganese	Manganese metal
	High carbon	Medium and low carbon	Total		
Steel:					
Carbon	244,493	84,261	328,754	71,684	945
Stainless and heat-resisting	12,509	(1)	12,509	4,849	2,274
Full alloy	33,371	8,956	42,327	16,290	733
High-strength, low-alloy	29,849	5,219	35,068	6,785	(1)
Electric	(1)	(1)	(1)	(1)	(1)
Tool	318	(1)	318	(1)	74
Unspecified	181	690	871	213	65
Total steel[2]	320,721	99,126	419,847	99,821	4,091
Cast irons	12,631	979	13,610	1,712	—
Superalloys	W	—	W	—	170
Alloys (excluding alloy steels and superalloys)	954	W	954	W	[3]18,689
Miscellaneous and unspecified	5,252	245	5,497	2,815	491
Total consumption	339,558	100,350	439,908	[4]104,348	23,441
Total manganese content[5]	265,000	80,000	345,000	69,000	23,000
Stocks, Dec. 31: Consumers and producers	66,505	8,581	75,086	10,393	4,086

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 4

U.S. CONSUMPTION AND INDUSTRY STOCKS OF MANGANESE ORE,[1] BY USE

(Short tons, gross weight)

Use	Consumption		Stocks, Dec. 31	
	1988	1989	1988	1989
Manganese alloys and metal	W	W	127,205	W
Pig iron and steel	e138,000	135,000	e130,000	167,000
Dry cells, chemicals, miscellaneous[2]	W	W	201,252	W
Total[e]	554,000	616,000	458,457	518,000

[e] Estimated. 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.

PRICES

Manganese Ore

The price of metallurgical manganese ore rose by about 60%, an even bigger percentage increase than in 1988, to a new record high for price in commercial transactions. Factors cited as being behind ore price increases were increased demand and price for man-

ganese ferroalloys, increased Japanese demand for ore for direct steelmaking, continued imports by East European countries and China that were estimated to total about 1 million tons, and limited international sourcing.

The average price, c.i.f. U.S. ports, for metallurgical ore containing 48% manganese was assessed as $2.80 per long ton unit, compared with $1.78 in 1988. Corresponding 1989 and 1988 prices were $2.76 and $1.75 per metric ton unit, and 12.5 and 7.9 cents per pound of manganese in ore. The price trend for manganese in metallurgical ore during the past two decades is given in the accompanying table.

TABLE 6

TIME-PRICE RELATIONSHIPS FOR MANGANESE IN METALLURGICAL ORE

Year	Average annual U.S. price, dollars per long ton unit	
	Actual price	Based on constant 1982 dollars
1969	0.50	1.26
1970	.54	1.29
1971	.60	1.35
1972	.60	1.29
1973	.65	1.31
1974	.90	1.67
1975	1.38	2.33
1976	1.45	2.30
1977	1.48	2.20
1978	1.40	1.94
1979	1.40	1.78
1980	1.70	1.98
1981	1.72	1.83
1982	1.58	1.58
1983	1.38	1.33
1984	1.42	1.32
1985	1.43	1.29
1986	1.34	1.18
1987	1.29	1.10
1988	1.78	1.47
1989	2.80	2.22

Manganese Ferroalloys

Based on quotations for imports, the general price trend for manganese ferroalloys was upward in the first part of 1989 and then downward, ending with a firming of prices in December. A relative advance in year-average price of nearly 40% for silicomanganese was almost double that of 21% for high-carbon ferromanganese. Increasing ore costs and strong demand from steelmakers were credited for the ferroalloy price increases.

For high-carbon ferromanganese containing 78% manganese, the price of imported material, f.o.b. Pittsburgh or Chicago warehouse, continued in 1989 at $600–$615 per long ton of alloy, rose to a record peak of $660–$680, receded to $570–$595, and closed the year at $620–$645. The domestic producer price listed by Elkem Metals, f.o.b. plant or warehouse, followed a somewhat different course by carrying over from 1988 at $615, increasing first to $680 as of February and then to $695 as of mid-June, and remaining at $695 for the rest of 1989.

For silicomanganese with 2% carbon, the price in cents per pound of alloy, f.o.b. Pittsburgh or Chicago warehouse, started at yearend 1988's level of 35–36.25, advanced to 44–45.5, and then fell to 24–26 before closing at 26–28. The price for domestic material from Elkem Metals, similar basis, started the year at 36.5, increased to 45, and ended the year at 35.

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 for all or the last three quarters of 1989, respectively.

FOREIGN TRADE

For ore, unit values indicated exports to Canada, the majority of exports to countries other than Canada and Mexico, and reexports of 1,384 tons (all to Canada) were metallurgical ore. Virtually all reported ore exports to Mexico appeared to have been transshipments of Gabonese ore.

The overall quantity of manganese units imported rose slightly to the greatest total since 1981. Average grade of imported ore decreased to 46.7%, the least since 1982. Imports of ore from Ghana were officially recorded for the first time since 1974. Average manganese content of all ferromanganese imports again declined, to 77.8%, the lowest average since 1981. Record imports of silicomanganese included shipments from China, the only such during the 1980's. Reported imports of spiegeleisen were 276 tons.

Imports of manganese dioxide, all apparently synthetic except 10 tons from Morocco, dropped 70%. Receipts, total and from Japan, were the lowest since a separate tariff category was established in 1978. Imports of potassium permanganate advanced to a record, especially because of Chinese material. Listed under imports classified as "Other sulfates," which includes manganese sulfate, were 8,091 tons from Mexico valued at $3.9 million.

Tariffs

Effective January 1, 1989, the Harmonized Tariff Schedule (HTS) replaced the Tariff Schedules of the United States as the basis of foreign trade categories and import duties. Duties that otherwise would have applied to imports from Canada under HTS were modified under the United States-Canada Free-Trade Agreement by Presidential Proclamation 5923 (53 FR 50638).

Imports on or after November 14, 1988, of electrolytic manganese dioxide (EMD) from Greece and Japan became liable for assessment of antidumping duties of 37% for EMD from Greece and ranging from 72% to 77% for EMD from Japan. The International Trade Administration of the U.S. Department of Commerce announced imposition of the antidumping duties on April 17 (54 FR 15243).

WORLD REVIEW

Capacity

The rated capacity data in table 9 are as of December 31, 1989, and are unchanged 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;[4] no domestic deposits qualify.[5]

TABLE 7

U.S. EXPORTS OF MANGANESE ORE, FERROALLOYS, AND METAL, BY COUNTRY

Country	1988		1989	
	Gross weight (short tons)	Value (thousands)	Gross weight (short tons)	Value (thousands)
	ORE AND CONCENTRATES			
	5% or more manganese		20% or more manganese	
Canada	15,608	$1,349	16,624	$1,413
Mexico[1]	50,618	4,017	35,952	2,957
Other	1,765	129	4,615	643
Total[2]	67,991	5,496	57,191	5,014
	FERROMANGANESE, ALL GRADES			
Belgium-Luxembourg	428	368	510	490
Canada	2,182	1,854	3,108	2,650
Chile	18	27	1,451	688
Germany, Federal Republic of	295	250	329	292
Mexico	99	89	1,593	1,240
Other	[3]419	[3]361	2,025	1,951
Total[2]	3,442	2,950	9,014	7,310
	SILICOMANGANESE			
Canada	4,178	2,829	1,690	990
Mexico	101	111	3,466	2,578
Trinidad and Tobago	2,755	1,543	246	159
Other	[3]433	[3]493	457	342
Total[2]	7,467	4,975	5,858	4,068
	METAL, INCLUDING ALLOYS AND WASTE AND SCRAP			
Belgium-Luxembourg	836	1,264	1,135	1,801
Canada	1,741	3,107	1,097	2,422
Japan	1,822	2,933	756	1,194
Netherlands	2,419	4,096	1,378	2,609
Other	3,041	4,841	1,299	2,605
Total[2]	9,859	16,242	5,667	10,632

[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 the 1988 Minerals Yearbook.

Source: Bureau of the Census; adjusted by the Bureau of Mines.

World reserves of manganese, on the same basis as capacity, are given in table 10 with no distinction between ore type or application. This table excludes perhaps 1% to 2% of total known reserves in nonlisted countries having only a small production.

Australia

Output from the manganese ore operations of Groote Eylandt Mining Co. Pty. Ltd. (GEMCO), a subsidiary of Broken Hill Pty. Co. Ltd. (BHP), advanced to a new record. GEMCO's exports and domestic shipments advanced slightly, to 1,754,000 tons and 440,000 tons, respectively, to give a shipments total of 2,194,000 tons.[6]

Brazil

Shipments of manganese ores from the Serra do Navio, Amapá Territory, operations of Indústria e Comércia de Minérios S.A. (ICOMI), plus 8,000 tons of sinter, totaled only 733,000 tons. Shipments, in tons, via Porto de Santana on the Amazon River, were 441,000 to European Community plus Comecon countries, 77,000 to South America, 43,000 to North America, and 172,000 to Brazilian consumers.[7] The plant ICOMI previously operated in the port area for pelletizing manganese ore fines was converted into a unit for sintering such fines. Once the sinter plant was fully operational, annual output of about 50,000 tons of a high-grade product was projected.

Total manganese ore shipments by Cia. Vale do Rio Doce (CVRD) from its Azul Mine in the Carajás region rose by about one-fifth to 594,000 tons. Exports were up about one-third to 393,000 tons while shipments to Brazilian consumers advanced just slightly to 201,000 tons.[8]

New record highs were set for production of manganese ferroalloys overall and for medium- and low-carbon ferromanganese and silicomanganese categories; the corresponding totals were 429,000 tons, 29,000 tons, and 230,000 tons.

At midyear, Cia. Paulista de Ferro-Ligas (Paulista) brought on-stream a plant at Conselheiro Lafaiete, Minas Gerais State, with annual capacities of 2,750 tons each for electrolytic manganese metal and EMD. The plant is close to where Paulista produces carbonate-type ore.

Canada

Wabush Mines developed the capability to produce, from its mine in Labrador, Newfoundland Province, fluxed or acid iron ore pellets having a manganese content of either 1% or 2%.[9]

China

China continued to import significant quantities of manganese ore, again from Australia and Gabon, and, according to the trade press, also the Republic of South Africa. A portion of these imports was barter and other types of arrangements in which Chinese ferroalloy plants smelted imported ore into products subsequently exported, mainly silicomanganese.

Gabon

Routing of shipments by Compagnie Minière de l'Ogooué S.A. (COMILOG) in 1989 was about evenly divided between railings to the new port at Owendo within Gabon and the established aerial tramway-railway system terminating at the port of Pointe-Noire in the Congo. USX Corp. of the United States reduced its holding in COMILOG to 15% in the fall of 1989, down from 36% at each yearend since 1983.

Ghana

Ore exports from the Nsuta Mine of Ghana National Manganese Corp. totaled 314,000 tons. Shipments were

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1988			1989		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
	ORE AND CONCENTRATES					
	35% or more manganese			20% or more manganese		
Australia	[1]75,717	[1]39,324	[1]$3,440	115,844	60,436	$9,492
Brazil	57,528	27,004	2,700	216,526	[1]93,283	10,481
Canada[2]	—	—	—	2,173	1,086	49
Gabon[3]	[1]290,548	[1]146,654	16,972	218,039	[1]109,637	19,196
Ghana	—	—	—	5,692	2,562	148
Mexico	87,730	35,490	5,920	[1]25,366	[1]9,828	[1]1,425
Morocco	172	[4]94	42	39	[4]20	9
South Africa, Republic of	—	—	—	54,821	21,618	2,988
United Kingdom[2]	—	—	—	24	16	5
Total[5]	511,695	248,566	29,074	638,524	298,485	43,794
	Of which, more than 35% but less than 47% manganese			Of which, more than 20% but less than 47% manganese		
Brazil	22,652	10,263	879	184,121	77,230	7,700
Ghana	—	—	—	5,692	2,562	148
Mexico	79,778	31,742	4,757	[1]24,411	[1]9,369	[1]1,279
South Africa, Republic of	—	—	—	52,657	20,562	2,776
Total[5]	102,430	42,005	5,636	266,881	109,724	11,903
	Of which, 47% or more manganese					
Australia	[1]75,717	[1]39,324	[1]3,440	115,844	60,436	9,492
Brazil	34,876	16,741	1,821	32,405	[1]16,053	2,781
Canada[2]	—	—	—	2,173	1,086	49
Gabon[3]	[1]290,548	[1]146,654	16,972	218,039	[1]109,637	19,196
Mexico	7,952	3,748	1,163	955	[1]459	146
Morocco	172	[4]94	42	39	[4]20	9
South Africa, Republic of	—	—	—	2,164	1,056	212
United Kingdom[2]	—	—	—	24	16	5
Total[5]	409,265	206,561	23,438	371,643	188,761	31,891
	FERROMANGANESE					
	All grades					
Australia	14,897	10,777	3,011	28,987	21,536	8,407
Brazil	26,333	20,119	9,634	15,786	11,980	7,558
Canada	32,221	24,752	11,024	5,139	3,887	1,878
China	4,778	3,658	1,916	8,893	6,787	3,934
France	143,808	113,874	56,361	146,727	115,217	72,988
Germany, Federal Republic of	12,620	10,122	9,646	16,149	13,124	13,643
Mexico	37,012	29,361	19,685	37,775	30,218	28,018
Norway	[1]39,718	[1]32,388	[1]24,238	19,636	16,239	15,730
South Africa, Republic of	195,729	151,867	63,171	181,402	139,267	83,496
Other	24,164	18,938	13,534	15,570	12,228	10,887
Total[5]	531,281	415,858	212,221	476,063	370,483	246,540
	Of which, 1% or less carbon					
France	14,631	13,196	15,580	8,805	7,761	12,552
Italy	2,256	2,014	2,481	2,015	1,778	2,644
Norway	[1]3,488	[1]3,018	[1]4,060	5,153	4,402	5,645
Other	560	501	583	1,202	1,063	1,548
Total[5]	20,935	18,729	22,704	17,175	15,006	22,388

See footnotes at end of table.

TABLE 8—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1988			1989		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
	FERROMANGANESE—Continued					
	More than 1% to 4% or less carbon			More than 1% to 2% or less carbon		
Belgium-Luxembourg	3,620	2,973	$2,741	—	—	—
France	4,707	3,863	2,230	1,378	1,144	$1,306
Germany, Federal Republic of	12,104	9,856	9,481	16,133	13,112	13,631
Japan	3,362	2,602	1,967	2,205	1,682	1,729
Mexico	27,421	21,668	14,453	34,777	27,987	26,829
Norway	[1]28,996	[1]23,771	[1]17,830	11,386	9,384	8,631
South Africa, Republic of	2,599	2,090	1,802	1,093	867	955
Other	4,104	3,300	2,166	331	265	226
Total[5]	86,913	70,123	52,670	67,302	54,441	53,307
	More than 2% to 4% or less carbon					
Mexico	XX	XX	XX	73	58	29
Total	XX	XX	XX	73	58	29
	More than 4% carbon					
Australia	14,897	10,777	3,011	28,987	21,536	8,407
Brazil	25,392	19,401	9,040	15,786	11,980	7,558
Canada	31,756	24,383	10,752	5,139	3,887	1,878
China	4,778	3,658	1,916	8,562	6,522	3,708
France	124,470	96,815	38,551	136,544	106,312	59,130
South Africa, Republic of	193,094	149,744	61,341	180,309	138,400	82,541
Other	29,046	22,228	12,235	16,186	12,343	7,592
Total[5]	423,433	327,006	136,846	391,513	300,978	170,816
	SILICOMANGANESE					
Australia	33,158	21,549	10,033	41,281	26,962	16,057
Brazil	22,102	14,551	8,776	24,657	16,147	15,596
China	—	—	—	7,190	4,814	4,832
Mexico	34,459	22,590	13,806	42,854	28,207	24,053
Norway	,4,108	2,595	2,863	5,780	3,635	4,956
South Africa, Republic of	101,705	67,717	40,147	81,929	52,940	50,948
Yugoslavia	32,606	21,247	13,415	38,715	25,213	25,281
Other	4,076	2,635	2,888	12,984	8,566	9,517
Total[5]	232,214	152,884	91,928	255,391	166,484	151,241
	METAL					
Unwrought:						
China	—	XX	—	99	XX	142
South Africa, Republic of	11,730	XX	14,946	12,075	XX	16,354
Total[5]	11,730	XX	14,946	12,175	XX	16,497
Other:						
South Africa, Republic of	XX	XX	XX	3,467	XX	4,388
Other	XX	XX	XX	468	XX	1,375
Total[5]	XX	XX	XX	3,936	XX	5,763
Waste and scrap:						
Canada	82	XX	4	36	XX	23

See footnotes at end of table.

TABLE 8—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1988			1989		
	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)	Gross weight (short tons)	Manganese content (short tons)	Value (thousands)
	MANGANESE DIOXIDE					
Belgium-Luxembourg	1,293	XX	$1,613	1,284	XX	$1,637
Brazil	1,393	XX	1,500	1,914	XX	2,045
Greece	139	XX	168	103	XX	146
Ireland	—	XX	—	377	XX	465
Japan	18,895	XX	19,559	171	XX	253
South Africa, Republic of	597	XX	486	2,651	XX	2,293
Other	250	XX	405	201	XX	373
Total[5]	22,567	XX	23,731	6,701	XX	7,212
	POTASSIUM PERMANGANATE					
China	551	XX	568	1,038	XX	1,117
German Democratic Republic	220	XX	249	335	XX	434
Spain	677	XX	1,157	690	XX	1,274
Other	139	XX	491	136	XX	411
Total[5]	1,587	XX	2,465	2,198	XX	3,236

XX Not applicable.
[1] Includes 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 50,000 tons in 1988 and 36,000 tons in 1989.
[4] Includes 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.

Source: Bureau of the Census, adjusted by the Bureau of Mines.

made through the Port of Takoradi to Finland, Ireland, Italy, Norway, Portugal, and Spain in Western Europe; to Romania in Eastern Europe; to Japan and Singapore in the Far East; and to the United States.[10]

Japan

Production increased to 434,000 tons for ferromanganese overall and 135,000 tons for silicomanganese.

In foreign trade in manganese ferroalloys, imports of silicomanganese easily set a new record in rising to 302,000 tons. China was the source of over one-half of the total. Exports of silicomanganese advanced 2.5-fold to 2,750 tons. For ferromanganese, imports decreased 20% to 24,000 tons while exports increased 17% to 16,600 tons.

For EMD, production fell almost one-fifth to 61,300 tons, the least since 1985. Exports declined nearly 30%, from 49,800 tons in 1988 to 36,000 tons, the lowest level since 1982.

Production of electrolytic manganese metal advanced 14% to 4,960 tons. Imports of unwrought manga-

TABLE 9

U.S. IMPORT DUTIES ON MANGANESE MATERIALS[1]

Item	HTS No.	Rate of duty effective Jan. 1, 1989	
		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] 3.7% 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] 12.6% ad valorem for products of Canada.

nese metal, including scrap, increased to 11,800 tons, most of which was from the Republic of South Africa. Exports were 1,080 tons, compared with 150 tons for 1988.

Mexico

Toward midyear, Nacional Financiera, a development bank of the Mexican Government, foreclosed on its controlling interest and took over management and operation of Cía. Minera Autlán S.A. de C.V. (Autlán). Production decreased at Autlán's operations in the Molango District of Hidalgo State. Respective 1989 and 1988 outputs were, in tons, 700,000 and 745,000 for carbonate ore, 388,000 and 434,000 for oxide nodules produced by calcining carbonate ore, and 19,700 and 29,300 for battery ore from the Nonoalco Mine.

Norway

The Government approved requests of Elkem A/S and Tinfos Jernverk A/S, the country's two manganese ferroalloy producers, and extended from July 20, 1989, until July 20, 1991, their exemption from sanctions against importing manganese ore from the Republic of South Africa.

South Africa, Republic of

Ore production increased 3%, attaining the highest level since 1986. Production in 1989 of the various categories of ore was as follows:

	Quantity (thousand short tons, gross weight)[1]
METALLURGICAL ORE	
30% to 40% Mn	1,205
Over 40% to 45% Mn	720
Over 45% to 48% Mn	726
Over 48% Mn	1,260
Total	3,910
CHEMICAL ORE	
35% MnO_2 and less	—
Over 35% to 65% MnO_2	82
Over 65% to 75% MnO_2	2
Total	83

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

Manganese ore shipments by The Associated Manganese Mines of South Africa Ltd. (AMMOSAL) rose 17% to 1,965,000 tons, the greatest volume of shipments since 1979. USX of the United States sold its former equity interests of 21% in AMMOSAL and 45% in Feralloys Ltd., the ferromanganese-producing subsidiary of AMMOSAL.

Samancor Ltd. completed renovation of a 25-megavolt-ampere furnace for manganese ferroalloys at its Metalloys Works at Meyerton, Transvaal Province. Close to yearend, Samancor put into operation at its Mamatwan Mine a heavy-medium ore-beneficiating plant for producing concentrate containing about 43% manganese. This concentrate became feed for the mine's sinter plant, with which high-grade sinter containing a minimum of 48% manganese could now be obtained.

TABLE 10

WORLD ANNUAL MANGANESE MINE PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand short tons of manganese content)

	Rated capacity
North America:	
Mexico	250
United States	—
Total	250
South America:	
Brazil	1,400
Chile	20
Total	1,420
Europe:	
Bulgaria	15
Hungary	30
U.S.S.R.	3,500
Other	40
Total	3,585
Africa:	
Gabon	1,300
Ghana	150
Morocco	30
South Africa, Republic of	2,300
Total	3,780
Asia:	
China	550
India	600
Other	15
Total	1,165
Oceania:	
Australia	1,300
World total (rounded)	11,500

Also in the second half of 1989, Manganese Metal Co. (Pty.) Ltd. (MMC) began producing manganese oxide (Mn_3O_4) for ferrite manufacture. Annual capacity for oxide of MMC's new plant at Nelspruit, Transvaal Province, was 2,200 tons.

U.S.S.R.

Lack of the customary published reports implied production declines for both major ore-producing areas, the Nikopol' Basin in the Ukraine and the Chiatura Basin in Georgia.

Ore exports in 1988 were nearly 40% greater than those in 1987, and shipments to Poland increased over 70%. Even so, the total of 1,082,000 tons for 1988 was the lowest of any year since 1964. Principal destinations for 1988 exports, accounting for 90% of the total, were, in tons: Poland, 649,000; Czechoslovakia, 197,000; German Democratic Republic, 93,000; and Bulgaria, 40,000.

CURRENT RESEARCH

Recent trends have affected the manner of manganese usage in steelmaking.

TABLE 11

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

TABLE 12

MANGANESE ORE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons unless otherwise specified)

Country[2]	Range percent Mn[e 3]	Gross weight					Metal content				
		1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Australia[4]	37–53	2,208	1,818	2,043	2,189	[5]2,341	1,056	867	972	[e]1,041	[5]1,111
Brazil[6 7]	30–50	2,781	2,973	2,279	2,144	1,800	997	1,277	842	794	670
Bulgaria	29	42	41	42	[e]44	44	12	12	12	[e]13	12
China[6 8]	20–30	2,900	3,000	[e]3,000	[e]3,000	3,000	580	600	600	600	600
Gabon[6 9]	50–53	2,579	2,767	2,649	2,485	2,900	1,191	1,277	1,223	1,147	1,340
Ghana[6]	30–50	[r]351	[r]335	303	286	350	130	122	108	106	130
Hungary[6]	30–33	69	69	86	89	83	21	21	28	29	26
India[6 9 10]	10–54	1,367	1,337	1,435	1,459	1,500	509	498	534	544	560
Iran[6]	25–35	61	61	61	66	66	18	18	18	19	19
Japan	26	23	7	—	—	—	6	2	—	—	—
Mexico[11]	27–50	[e]437	[e]506	[e]425	489	473	166	192	161	186	180
Morocco[6]	50–53	48	44	47	33	33	26	24	25	18	18
Romania[6]	30	75	74	[e]72	[e]72	66	22	22	21	21	20
South Africa, Republic of[6 9]	30–48+	3,969	4,100	3,188	3,807	[5]3,994	1,587	1,663	1,337	1,571	1,675
Thailand[6]	46–50	5	5	10	9	9	2	3	5	4	4
Turkey[6]	27–46	12	8	[e]8	[e]8	8	4	3	3	3	3
U.S.S.R.	29–30	10,900	10,300	10,400	10,000	9,700	3,200	3,100	[e]3,100	[e]3,000	2,900
Yugoslavia	25–45	[e]28	46	46	44	45	[e]10	16	16	[e]15	15
Other[e 12]	XX	[r]92	55	43	76	71	[r]37	[r]20	15	[r]27	26
Total[13]	XX	[r]27,948	[r]27,545	26,134	26,300	26,483	[r]9,576	[r]9,736	9,019	9,137	9,309

[e] Estimated. [p] Preliminary. [r] Revised. XX Not applicable.

[1] Table includes data available through May 16, 1990. 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), 1985—8, 1986—11, 1987—11, 1988—11, and 1989—10 (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] Much of India's production grades below 35% Mn; average content was reported as 38% Mn in 1985.

[11] Estimated product total, mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications.

[12] Category represents the combined totals of Chile, Greece, Indonesia, Italy (from wastes), the Republic of Korea, Pakistan, the Philippines, and, beginning with 1988, Zambia.

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

Differing circumstances have caused hot metal manganese contents as of 1989 to be relatively low in Japan, 0.2% to 0.4%; intermediate in Western Europe, 0.20% to 0.65%; and relatively high in the United States, 0.50% to 0.75%. At the Hoogovens Ijmuiden BV plant in the Netherlands, a drop in hot metal manganese content from 0.70% to 0.50%, or below, was made to facilitate production of low-carbon, low-manganese steels, with some penalty of a lower converter lining life. Manganese ore addition to the blast furnace feed was still required to achieve the 0.5% manganese content target. Recycling of converter slag, which would return some manganese to the blast furnace, was stopped to help control phosphorus to a low level.[11]

A thermodynamic model of oxygen refining of high-carbon ferromanganese, developed on the basis of activities in the iron-manganese-carbon system, was used to predict limiting carbon and silicon contents during refining.[12]

In Japan, Mizushima Ferro Alloy Co. Ltd. developed technology for oxygen refining high-carbon ferromanganese into medium- and low-carbon ferromanganese to replace silicothermic methods, thereby reducing dependence on electrical energy. Key features of the new process included diluting the oxygen being top-blown with nitrogen or argon and stirring the bath by rotating the reaction vessel.[13]

Research clarified why ductility problems in hot working of steel, arising from sulfur impurity, are eliminated by an adequate manganese content. The affinity of manganese for sulfur greatly reduces a solid-state segregation of sulfur to the grain boundaries that would otherwise occur.[14]

OUTLOOK

The trend of manganese demand, domestically and globally, will continue to closely follow that of steel production. Nonmetallurgical components of manganese demand, especially batteries, may experience higher growth rates than for steel production, but will have only a minor effect on overall manganese demand.

U.S. apparent consumption of manganese was about 750,000 tons of contained manganese in 1988, as given in table 12. On the basis of 1982–88 data, the time trend value for 1988 is 733,000 tons; the projection for 1995 is 831,000 tons. The course of year-to-year steel production and, therefore, that of manganese demand between the present and 1995 is uncertain, particularly because of dependence on Government policy, as discussed in the "Iron and Steel" chapter of this yearbook. U.S. apparent consumption of manganese in 1990–95 seems likely to range between 700,000 and 850,000 tons annually, assuming no further sizable decreases in manganese unit consumption in steelmaking. The majority of U.S. demand will be met by imports.

BACKGROUND

Definitions, Grades, and Specifications

Ore.—The Bureau of Mines has compiled statistics on manganese-bearing ores, concentrates, nodules, and sinter, all referred to simply as "ore," by manganese content as follows: **manganese ore,** 35% or more manganese; **manganiferous ore,** less than 35% but not less than 5% manganese; and within the latter, **ferruginous manganese ore,** 10% to 35% manganese; and **manganiferous iron ore,** 5% to 10% manganese.

Manganese ore may be considered as metallurgical, chemical, or battery grade. Metallurgical-grade material has an approximate manganese content range of 38% to 55% and may differ from chemical-grade ore only in physical form. Chemical- and battery-grade ores are often categorized by manganese dioxide (MnO_2) content, which typically is in the range of 70% to 85% (44% to 54% Mn). The U.S. Government maintains specifications for metallurgical, chemical, and battery grades of ore for stockpile purposes; industry has no corresponding standards.

Ferroalloys and Metal.—Ferromanganese is a manganese-iron-carbon alloy classified according to decreasing carbon content into standard or high-carbon

TABLE 13

MANGANESE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand short tons, manganese content)

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines[2]	38	31	23	24	4	4	11	2	1	2	1
Shipments of Government stockpile excesses	279	264	159	128	28	35	10	91	8	105	-2
Imports, ore	278	244	330	301	111	178	180	204	237	181	262
Imports, alloy and metal	604	708	530	615	430	364	426	405	452	422	581
Industry stocks, Jan. 1	1,092	811	749	710	702	576	463	420	380	315	279
Total U.S. supply	2,291	2,058	1,791	1,778	1,275	1,157	1,090	1,122	1,078	1,025	1,121
Distribution of U.S. supply:											
Industry stocks, Dec. 31	811	749	710	702	576	462	420	380	315	279	316
Exports, ore	100	29	26	32	14	10	30	31	23	38	35
Exports, alloy and metal	17	30	26	17	13	17	13	13	10	9	18
Industrial demand	1,363	1,250	1,029	1,027	672	668	627	698	730	699	752
U.S. DEMAND PATTERN											
Appliances and equipment	58	59	49	51	30	33	36	32	27	31	19
Batteries	18	17	17	16	21	25	34	39	43	43	48
Cans and containers	60	61	49	46	31	28	38	35	31	35	31
Chemicals[3]	61	59	50	50	29	22	34	22	23	44	46
Construction	279	291	243	252	152	151	170	164	148	165	244
Machinery	216	217	167	171	92	90	97	78	65	77	110
Oil and gas industries	74	70	79	89	40	28	36	34	25	30	21
Transportation	317	296	214	214	115	129	139	124	95	105	102
Other[4]	280	180	161	138	162	162	43	170	273	169	131
Total U.S. primary demand	1,363	1,250	1,029	1,027	672	668	627	698	730	699	752

[1] Where available, data for manganese dioxide included beginning in 1984.
[2] Including manganiferous ore.
[3] Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.
[4] Not specifically based on reported data; includes processing losses. Within this category, the distribution of components is approximately the same as for identified end uses above.

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 material with less iron would be treated as metal.

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 1989, with the cost of manganese in metallurgical ore taken as 1.0, the corresponding approximate costs per manganese unit were 3.0 for high-carbon ferromanganese, 3.5 for silicomanganese, 4.9 for medium-carbon ferromanganese, and 7.4 for manganese metal. Metallic manganese is little used per se, as 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, GEMCO; Brazil, CVRD and ICOMI, plus a number of relatively small mines; China, apparently mostly small- to moderate-size operations in the eastern Provinces; Gabon, COMILOG; Ghana, Ghana National Manganese Corp.; India, over 200 mines, with Manganese Ore India Ltd. the most prominent company; Mexico, Autlán; Republic of South Africa, AMMOSAL and Samancor; and the U.S.S.R., two large complexes, mining the Chiatura Basin in Georgia and the Nikopol' Basin in the Ukraine. Most output is for metallurgical applications. Ore for nonmetallurgical uses generally is supplied by the large-scale producers mentioned plus smaller ones elsewhere.[15]

In recent years, the U.S.S.R. has been supplying over 1 million tons of ore annually to Eastern Europe, although such exports were notably lower in 1987 and appear likely to decline 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 plus CVRD quite recently), 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, Paulista (a number of plants); China, many plants; France, Soc. 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 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 metallothermically in the U.S.S.R. World productive capacity for metal was given as 84,000 tons annually as of 1985,[16] and was approximately the same in 1989.

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.[17] 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.[18] 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.[19] As given in the "World Review" section of this chapter, the reserve base for manganese can be considered more than ten 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.

Technology

Exploration.—Highly selective methods of locating land manganese deposits do not exist, but interpretation of geologic environments can assist prospecting.[20]

Mining.—Most manganese ore is produced by mechanized operations. Standard earth-moving equipment is used in surface mining. Underground mining generally is by room-and-pillar techniques.

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 lumps at some ferroalloy plants, a practice which appears likely to be adopted increasingly by ore producers.

Smelting.—Electrothermy is the predominant method of manufacturing manganese ferroalloys, as by the submerged-arc-furnace process.[21] Blast furnace-type operations are still used in a few foreign countries to make impor-

tant 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.[22] Chemical manganese dioxide can be prepared by precipitating manganese carbonate from a sulfate solution and decomposing the carbonate to oxide.[23]

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

Costs.—As noted in a study of the Minerals Availability Program (MAP) of the Bureau of Mines, transportation is the most significant cost element in the production of manganese concentrates.[24] 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 imposed an annual requirement of reporting releases to the environment of manganese metal and manganese chemical compounds (40 CFR 372). This requirement initially applied to annual manufacturing or processing of 75,000 pounds and annual use otherwise of 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.[25] Thus, manganese can be an industrial poison, but normally is not a hazard.

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[1] Unless otherwise specified, the unit of weight in this report is the short ton of 2,000 pounds.

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MERCURY

By Staff, Branch of Nonferrous Metals

Domestic survey data were prepared by Mr. Tony E. Morris, Nonferrous Data Section. International data tables were prepared by Ms. Virginia A. Woodson, International Data Section.

Mercury for use in domestic manufacturing in 1989 came from domestic mines, sales of surplus metal from Government stocks, imports, waste and scrap, and the drawdown of industry stocks. Industrial consumption was down 24% from the 1988 level. Mine production remained at about the same level. The United States was a net exporter of mercury in 1989. The average annual price of mercury fell 14% in 1989.

PRODUCTION

Mercury was produced as a principal product at one mine in Nevada, the McDermitt Mine, and as a byproduct at nine gold mines in Nevada, California, and Utah. Nearly all of the newly mined mercury came from Nevada. Actual production figures were withheld by the Bureau of Mines to avoid disclosing company proprietary data.

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. Total secondary production was down sharply in 1989.

CONSUMPTION AND USES

Two dozen plants, all but two in the eastern half of the Nation, accounted for 97% of the mercury consumed in 1989. About 90 other plants, laboratories, and other diverse organizations used much smaller quantities of mercury. Of the major quantities consumed, about 34% was used in chloralkali production, catalysis, and in various laboratory uses; 42% went into electrical products and instruments, of which batteries was the most important single category; and the remainder went into exterior paints, dental amalgams, catalysts, pigments, and pharmaceuticals. The substantial drop in overall consumption in 1989 was attributable principally to a further decline—for the sixth consecutive year—in the

TABLE 1

SALIENT MERCURY STATISTICS

		1985	1986	1987	1988	1989
United States:						
Producing mines		6	8	9	10	10
Mine production	metric tons	570	W	W	W	W
Secondary production:						
Industrial	do.	185	219	265	278	137
Government[1]	do.	20	106	117	214	180
Industry stocks, yearend[2]	do.	965	W	W	W	W
Shipments from the National Defense Stockpile[3]	do.	156	16	128	52	170
Imports for consumption	do.	651	696	636	329	131
Exports[4]	do.	NA	NA	NA	NA	221
Consumption	do.	1,718	1,588	1,446	1,593	1,214
Price: New York, average per flask		$310.96	$232.79	$295.50	$335.52	$287.72
Employment, mine and mill, average		35	22	9	12	25
World: Mine production	metric tons	r6,136	r7,247	5,810	p5,890	e5,840

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

[1] Secondary mercury shipped from U.S. Department of Energy stocks.

[2] Stocks at mines, consumers, and dealers.

[3] Primary mercury.

[4] Mercury export data were not available for 1978 through 1988.

TABLE 2

BYPRODUCT MERCURY-PRODUCING MINES IN THE UNITED STATES IN 1989

Mine	County and State	Operator
Alligator Ridge	White Pine, NV	Amselco Minerals Inc.
Borealis Project	Mineral, NV	Echo Bay Minerals Co.
Carlin Mines Complex	Eureka, NV	Newmont Gold Co.
Hog Ranch	Washoe, NV	Western Goldfields Co.
Jerritt Canyon (Enfield Bell)	Elko, NV	Freeport-McMoran Gold Co.
McLaughlin	Napa, CA	Homestake Mining Co.
Mercur	Tooele, UT	Barrick Mercur Gold Mines Inc.
Paradise Peak	Nye, NV	FMC Gold Co.
Pinson and Prebble	Humboldt, NV	Pinson Mining Co.

TABLE 3

SECONDARY MERCURY IN THE UNITED STATES

(Metric tons)

Year	Industrial production	DOE shipments	Total
1985	185	20	205
1986	219	106	325
1987	265	117	382
1988	278	214	492
1989	137	180	317

manufacture of mercury batteries, and to lower use in chloralkali production.

STOCKS

Stocks of refined mercury held by consumers and dealers fell by more than one-third in 1989, and at yearend were equivalent to about 2 month's industrial consumption. Figures on stocks held at mines were withheld to avoid disclosing company proprietary data.

TABLE 4

MERCURY CONSUMED IN THE UNITED STATES, BY USE

(Metric tons)

SIC code	Use	1985	1986	1987	1988	1989
28	Chemical and allied products:					
2812	Chlorine and caustic soda manufacture	235	259	311	445	381
2819	Laboratory uses	14	20	20	26	18
2851	Paint	169	179	198	197	192
—	Other chemical and allied products[1]	61	90	59	86	40
36	Electrical and electronic uses:					
3641	Electric lighting	40	41	45	31	31
3643	Wiring devices and switches	95	103	131	176	141
3692	Batteries	952	750	533	448	250
38	Instruments and related products:					
382	Measuring and control instruments	79	63	59	77	87
3843	Dental equipment and supplies	50	52	56	53	39
—	Other uses[2]	20	31	34	55	35
	Total[3]	1,718	1,588	1,446	1,593	1,214

[1] Pigments, pharmaceuticals, catalysts for plastics, and miscellaneous catalysts, shown as separate items in previous editions of this table, have been included in this category.
[2] 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.
[3] Data may not add to totals shown because of independent rounding.

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. One hundred and eighty metric tons was shipped during the year, leaving yearend stocks at 793 tons. DLA also held several monthly auctions of excess primary mercury from the National Defense Stockpile, and shipped 170 tons during the year, leaving a yearend inventory of 5,459 tons. Of this inventory, all but 362 tons was considered excess to Government needs.

TABLE 5

STOCKS OF MERCURY IN THE UNITED STATES, DECEMBER 31

(Metric tons)

Year	Producer (mine)	Consumer and dealer	Total
1985	669	296	965
1986	W	234	W
1987	W	320	W
1988	W	338	W
1989	W	231	W

W Withheld to avoid disclosing company proprietary data.

PRICES

The New York dealer price for delivered primary mercury, reported in Metals Week as a range, was relatively stable in 1989, as compared with the price in most years. The price at the low end of the range began the year at $280 per flask, rose to a high of $320 from mid-February through most of March, then declined to a low of $260 from mid-September through the first week of October, and ended the year at $290. The price at the high end of the range tracked the movement of the low end price fairly closely, but was $5 to $25 per flask higher. The annual average of the weekly low end price was $287.72, compared with $335.52 in 1988. The low end price of Metals Week's European Dealer price range (c.i.f. Rotterdam) began the year at $275 per flask and trended downwards irregularly during the year, ending the year at $230. The high end price ran $10 to $20 above the low end price.

FOREIGN TRADE

Imports of mercury fell sharply for

TABLE 6

AVERAGE PRICE OF MERCURY AT NEW YORK

(Per flask)

Period	Price
1985	$310.96
1986	232.79
1987	295.50
1988	335.52
1989:	
January	281.75
February	315.79
March	312.39
April	295.00
May	295.00
June	295.00
July	283.00
August	270.00
September	261.40
October	267.62
November	285.71
December	290.00
Average	287.72

Source: Metals Week.

the second consecutive year, to less than one-half the figure for 1988. Nearly all of the imported material was prime mercury from Spain, but none was imported from two important sources of the previous few years, China and Turkey. For the first time since 1977, data on exports of mercury became available, and showed that the United States was a net exporter in 1989. While imports came largely from 1 country, with much smaller quantities coming from 7 other countries, exports went to 24 countries, of which 3 received nearly three-fourths of the total. U.S. trade figures do not distinguish between primary mercury and scrap mercury.

WORLD REVIEW

Mercury was mined in at least 11 countries in 1989, with the U.S.S.R. and Spain together accounting for nearly two-thirds of production. Production capacity exceeded actual production by a considerable margin.

Contamination of the environment by mercury remained a concern. In Brazil, for example, where many of the small gold mines in the Amazon basin recover gold by amalgamation with mercury, a method abandoned some years ago in most other countries, the State environmental agency, IBAMA, issued rules in mid-1989 governing the importation, sales, and use of mercury. It reportedly had been estimated that as much as 1,800 tons of mercury had entered the Amazon basin's environment in the period 1980–87. The new rules permitted less than 4% loss of mercury to the environment.

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.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF MERCURY AND MERCURY-BEARING WASTE AND SCRAP, BY COUNTRY

Country	1987		1988		1989	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Algeria	—	—	31	$253	—	—
Australia	—	—	—	—	2	$13
Canada	5	$59	5	72	—	—
China	406	2,235	131	1,053	—	—
Germany, Federal Republic of	—	—	1	14	1	51
Hong Kong	17	62	—	—	—	—
Japan	34	238	—	—	—	—
Netherlands	—	—	—	—	1	9
Spain	172	1,230	147	1,263	127	1,137
Turkey	—	—	3	30	—	—
United Kingdom	—	—	11	77	—	—
Other	2	36	(1)	36	(1)	37
Total	636	3,860	329	2,798	131	1,247

[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8

U.S. EXPORTS OF MERCURY, BY COUNTRY[1]

Country	1989	
	Metric tons	Value (thousands)
Australia	8	$72
Brazil	10	308
Canada	11	64
Colombia	3	42
Germany, Federal Republic of	37	19
India	9	287
Ireland	4	36
Korea, Republic of	1	22
Mexico	1	7
Netherlands	82	512
Peru	1	14
Singapore	2	22
South Africa, Republic of	44	269
Taiwan	2	90
United Kingdom	2	24
Venezuela	3	39
Other	1	47
Total	221	1,874

[1] Mercury export data were unavailable from 1978 through 1988.

Source: Bureau of the Census.

TABLE 9

MERCURY: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Algeria	794	756	705	[r e]700	700
China[e]	700	700	700	700	700
Czechoslovakia	158	168	164	168	165
Dominican Republic	1	(2)	(2)	(2)	(2)
Finland	125	146	144	130	125
Mexico	394	[r]104	124	345	300
Spain	[r]873	[r]2,757	1,395	[r e]1,380	1,380
Turkey	[r]233	[r]291	211	97	100
U.S.S.R.[e]	2,200	2,250	2,300	2,300	2,300
United States	570	W	W	W	W
Yugoslavia	88	75	67	70	70
Total	[r]6,136	[r]7,247	5,810	5,890	5,840

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."
[1] Table includes data available through Apr. 25, 1990.
[2] Less than 1/2 unit.

TABLE 10

WORLD ANNUAL MERCURY PRODUCTION CAPACITY, DECEMBER 31, 1989

(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.

OTHER SOURCES OF INFORMATION

Bureau of Mines publications:

Mercury. Ch. in Minerals Yearbook, annual.
Mercury. Ch. in Mineral Commodity Summaries, annual.
Mercury. Reported quarterly and annually in Mineral Industry Surveys.

Other sources:

American Metal Market.
Chemical Marketing Reporter.
Engineering and Mining Journal.
London Metal Bulletin.
Metals Week.

MICA

By Lawrence L. Davis

Mr. Davis, a physical scientist with 34 years of industry and 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 assistant.

Public Law 100-418 requires that U.S. Government agencies implement the use of metric units in their business activities by the end of Fiscal Year 1992. Consequently, all numbers in the text and tables are shown in metric units.

In 1989, about 119,000 metric tons of scrap and flake mica was produced in the United States, a decrease of 8% from 1988 production. Ground mica sales were 101,000 tons valued at $22 million, a decrease in tonnage of about 7%.

Nearly all sheet mica supply continued to be imported. Consumption of muscovite block mica decreased 46% to 7.5 tons. Consumption of mica splittings increased slightly to 1,100 tons. The value of sheet mica exports increased 16% to $7.4 million. The value of imports for consumption of sheet mica increased 13% to $8.8 million.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for mica are developed by the Bureau of Mines by means of three separate, voluntary surveys and one mandatory survey. Of the 18 operations to which the crude scrap and flake mica production form was sent, 17 operations, or 94%, responded, representing 95% of the production shown in table 1. Of the 17 operations to which the ground mica form was sent, all responded, representing 100% of the production in table 1. Of the seven canvassed operations to which the mica block and film consumption form was sent, six, or 86%, responded, representing 82% of the consumption shown in table 1. Of the nine canvassed operations to which the mica splittings consumption form was sent, seven operations, or 78%, responded, representing 96% of the splittings consumption shown in table 1. Consumption for the nonrespondents was estimated using prior year production data.

TABLE 1

SALIENT MICA STATISTICS

		1985	1986	1987	1988	1989
United States:						
Production (sold or used by producers):						
Scrap and flake mica	thousand metric tons	125	134	146	130	119
Value	thousands	$6,330	$7,108	$8,201	$6,793	$6,273
Ground mica	thousand metric tons	124	112	113	109	101
Value	thousands	$21,256	$21,872	$22,376	$23,687	$22,443
Consumption:						
Block, muscovite	metric tons	23	23	26	14	7
Value	thousands	$751	$755	$982	$628	$599
Splittings	metric tons	1,071	1,010	960	1,104	1,108
Value	thousands	$1,610	$1,252	$1,417	$1,544	$1,703
Exports	metric tons	8,638	7,685	5,828	7,168	5,327
Imports	do.	10,897	11,761	11,450	14,478	15,834
World: Production	do.	r254,993	r289,836	290,030	p274,585	e265,387

eEstimated. pPreliminary. rRevised.

LEGISLATION AND GOVERNMENT PROGRAMS

The Government inventory of stockpile-grade mica remained about the same at 10,000 tons. The Department of Defense sold 8 tons of phlogopite splittings.

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 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 sig-

TABLE 2

STOCKPILE GOALS AND GOVERNMENT INVENTORIES FOR MICA, DECEMBER 31, 1989

(Metric tons)

Material	Inventory				
	Goal	Stockpile grade	Non-stockpile grade	Available for disposal	1989 sales
Block:					
Muscovite, stained and better	2,812	2,270	94	—	—
Phlogopite	95	8	52	—	—
Film: Muscovite, 1st and 2d qualities	41	533	(1)	468	—
Splittings:					
Muscovite	5,728	6,526	—	340	—
Phlogopite	422	680	—	259	8

[1] Less than 1/2 unit.

TABLE 3

SCRAP AND FLAKE MICA[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Quantity	Value
1985	125	6,330
1986	134	7,108
1987	146	8,201
1988	130	6,793
1989:		
North Carolina	73	4,192
Other States[2]	46	2,081
1989 total	119	6,273

[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.

nificant 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 61% 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.[1] The five largest producers were, in alphabetical order: The Feldspar Corp., Spruce Pine, NC; KMG Minerals Inc., Kings Mountain, NC; Lithium Corp. of America, Gastonia, NC; Pacer Corp., Custer, SD; and Unimin Corp., New Canaan, CT. These five companies produced 69% of the national total.

Ground Mica

Thirteen companies operated 16 grinding plants. Eleven plants produced dry-ground and five produced wet-ground mica. The five largest producers accounted for 72% of the total. They were, in alphabetical order: KMG Minerals, Kings Mountain, NC; Mineral Mining Corp., Kershaw, SC; Pacer, Custer, SD; Unimin, New Canaan, CT; and USG Corp., Chicago, IL.

Low-quality sericite, used primarily in brick manufacturing, is excluded from tabulated data contained in this report. In 1989, four companies, one in North Carolina and three in South Carolina, mined low-quality sericite and reported an average value of $3.75 per ton.

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 in vacuum tubes where fabricated mica spacers position, insulate, and support the tube elements. High-quality block mica is also used to line the gauge glasses of high-pressure steam boilers. Transparency, flexibility, 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. Block mica is also fabricated into washers of various sizes that act as insulators in electronic equipment.

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
1985	112	15,993	12	5,263	124	21,256
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

[1] Domestic and some imported scrap. Low-quality sericite is not included.
[2] Data do not add to total shown because of independent rounding.

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 7.5 tons, a 46% decrease from that of 1988. Consumption of stained and lower-than-stained quality decreased 48%, but remained in greatest demand accounting for 88% of consumption. About one-half of the muscovite consumed was grade No. 5 or smaller. The decrease in consumption was the result of one more company ceasing fabrication operations. Five companies continued to consume muscovite block and film in five plants in four States: two in North Carolina and one each in New Jersey, Ohio, and Virginia.

Splittings represent the largest part of the sheet mica industry in the United States. Muscovite and phlogopite splittings are used to make built-up mica. Consumption of mica splittings increased slightly to 1,100 tons. Muscovite splittings from India accounted for 96% 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 end uses of built-up mica 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 since it will wear at the same rate as the copper segments. Muscovite has a greater resistance to wear, causing uneven ridges which 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 slightly from that of 1988. Segment plates and molding plates were the major end products, accounting respectively for 38% and 32% 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 1989 were: Corona Films Inc., West Townsend, MA; General Electric Co., Coshocton, OH; and US Samica Corp., Rutland, VT. Kirkwood-Acim Corp.'s plant at Hempstead, NY was closed in 1988; the plant was absorbed by a sister company, Midwest Mica and Insulation Co., and relocated to Conway, AR. The plant might reopen in 1991.

TABLE 5

FABRICATION OF MUSCOVITE BLOCK MICA IN THE UNITED STATES, BY QUALITY

(Kilograms)

Quality	1988	1989
Good stained or better	1,176	886
Stained or lower[1]	12,622	6,595
Total	13,798	7,481

[1] Includes punch mica.

Ground Mica

The largest domestic use of ground mica was in gypsum plasterboard 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

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:						
1985	1,055	$1,485	15	$125	1,071	$1,610
1986	966	1,136	13	116	1,010	1,252
1987	930	1,231	30	185	960	1,417
1988	1,069	1,388	30	206	1,104	1,544
1989	1,062	1,448	46	255	1,108	1,703
Stocks on Dec. 31:						
1985	492	NA	19	NA	511	NA
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

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

the tone of colored pigments.

Ground mica is used in the well drilling industry as an additive to drilling muds. The coarsely-ground mica flakes help prevent lost circulation by sealing porous sections of the drill hole.

The rubber industry uses ground mica as an inert filler and as a mold lubricant in the manufacture of molded rubber products such as tires. The plastics industry uses ground mica as an extender and also as a reinforcing agent.

Ground mica is used in the production of rolled roofing and asphalt shingles where it serves as an inert filler and surface coating to prevent sticking of adjacent surfaces. The coating is not absorbed by freshly made roofing because mica has a platy structure and is not affected by the acid in the asphalt or by weathering. Other uses include decorative coatings on wallpaper and on concrete, stucco, and tile surfaces; as an ingredient in some special greases; as a coating for cores and molds in metal casting, and as a flux coating on welding rods.

In 1989, the major end uses were joint cement, 57%; paints, 10%; and well-drilling muds, 7%.

STOCKS

Reported yearend consumer stocks of sheet mica increased slightly to 542 tons; of this, mica splittings represented 93%, and mica block represented 7%.

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 1989 compared with 1988 were as follows: Block increased 76% to $80 per kilogram; film remained at $31 per kilogram; and splittings remained at $1.36 per kilogram. The average value of phlogopite block increased 20% to $22 per kilogram, while the value of phlogopite splittings increased 23% to $5.53 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 $53 per ton. The average value per ton for North Carolina flake mica, predominantly a flotation product, was $57.

TABLE 7

BUILT-UP MICA[1] SOLD OR USED IN THE UNITED STATES, BY PRODUCT

Product	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Flexible (cold)	85	$499	85	$545
Heater plate	21	76	18	74
Molding plate	328	1,898	316	1,011
Segment plate	325	2,241	378	2,216
Tape	37	305	51	277
Other	195	1,810	141	1,607
Total[2]	992	6,829	990	5,730

[1] Consists of alternating layers of binder and irregularly arranged and partly overlapped splittings.
[2] Data may not add to totals shown because of independent rounding.

TABLE 8

GROUND MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY END USE

(Thousand metric tons and thousand dollars)

End use	1988		1989	
	Quantity	Value	Quantity	Value
Joint cement	60	10,936	58	11,198
Paint	17	3,536	10	1,512
Plastics	1	366	3	876
Well-drilling mud	6	741	7	816
Other[1]	24	8,108	23	8,041
Total	[2]109	23,687	101	22,443

[1] Includes mica used for molded electrical insulation, rubber, textile and decorative coatings, welding rods, and miscellaneous.
[2] Data do not add to total shown because of independent rounding.

TABLE 9

AVERAGE REPORTED PRICE FOR DRY- AND WET-GROUND MICA SOLD OR USED BY U.S. PRODUCERS IN 1989

(Dollars per metric ton)

Kind	Price
Wet-ground	680
Dry-ground	153
End uses:	
Joint cement	193
Paint	149
Plastics	316
Well-drilling mud	111
Other[1]	354

[1] Includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coating, welding rods, and miscellaneous.

FOREIGN TRADE

The United States continued to rely on imports, mostly from India, for nearly all of its sheet mica and paper-quality scrap mica. Imports for consumption of unmanufactured block, film, and splittings were about 1600 tons, about the same as in 1988 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

TABLE 10

U.S. EXPORTS OF CRUDE AND RIFTED MICA, MICA POWDER, AND MICA WASTE IN 1989, 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)
Austria	33	$12	17	$18	50	$30	—	—
Belgium	—	—	—	—	202	88	15	$26
Canada	170	52	6	7	652	257	18	10
Colombia	41	13	—	—	202	85	—	—
France	5	2	—	—	108	49	—	—
Germany, Federal Republic of	—	—	—	—	207	57	—	—
Indonesia	—	—	—	—	36	44	—	—
Italy	—	—	—	—	64	21	—	—
Japan	411	128	—	—	134	95	—	—
Korea, Republic of	—	—	2	14	321	222	—	—
Malaysia	—	—	—	—	16	15	—	—
Mexico	278	87	16	73	932	283	34	11
Netherlands Antilles	22	7	1	12	—	—	—	—
Netherlands	—	—	12	17	140	54	—	—
Peru	—	—	5	6	34	13	—	—
Philippines	—	—	—	—	99	49	—	—
Spain	—	—	—	—	19	8	93	169
Taiwan	—	—	—	—	171	78	—	—
United Kingdom	—	—	1	6	83	85	—	—
Venezuela	—	—	—	—	71	26	20	8
Other[1]	62	20	(2)	2	86	74	22	12
Total[3]	1,022	320	60	156	1,230	1,634	202	235

[1] Includes Barbados, Brazil, Chile, the Dominican Republic, Ecuador, French Polynesia, Guatemala, Hong Kong, Ireland, Israel, Jamaica, Pakistan, Portugal, Singapore, the Republic of South Africa, Sweden, and Thailand,
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

decrease in domestic fabrication of mica parts. Worked mica imports increased 50% to 1,100 tons. This increase is probably caused by reduced domestic production of mica paper. About 9,000 tons of ground mica was imported, mostly from Canada, while about 4,000 tons was exported to 32 countries. The combined value of all mica imports increased 13% to $15.0 million, while the combined value of all mica exports increased 14% to $9.6 million.

WORLD REVIEW

World production of mica decreased 3% to 265,000 tons. The United States continued to lead in the production of flake mica. India continued to lead in the production of sheet mica.

Brazil

A mica and graphite mine in Minacu, Goias, is being developed by Cia Araguia de Metais Nobres, and is expected to begin operating by mid-1990. The company recently opened a pilot plant in Sao Paulo to reduce the minerals to micron size.

India

The Mica Trading Corp. of India Ltd. (MITCO) instituted a policy whereby foreign purchasers of scrap mica may buy directly from private Indian suppliers, but only for orders under 1 million rupees ($62,500). For larger orders the balance must be shared with MITCO.

MITCO's 600-ton-per-year-capacity mica paper plant has not reached the full production stage. The target production for the year, April 1989 through March 1990, was 150 tons.[2]

OUTLOOK

Demand for sheet mica has decreased dramatically over the last 30 years. For block and film mica the major cause of decreased demand was technological change, specifically the introduction of semi-conductor 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, con-

TABLE 11

U.S. EXPORTS OF WORKED MICA IN 1989, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	7	$118	(1)	$2
Austria	5	47	—	—
Bahamas	4	21	6	24
Bolivia	—	—	3	10
Brazil	41	901	2	68
Canada	66	1,414	35	898
Colombia	2	10	1	25
Egypt	18	59	—	—
France	1	4	3	55
Germany, Federal Republic of	23	557	2	12
India	1	34	8	77
Italy	15	373	(1)	14
Japan	(1)	5	3	105
Mexico	46	500	26	520
New Zealand	4	17	—	—
Peru	—	—	12	395
Philippines	8	30	—	—
Spain	5	110	—	—
Taiwan	9	30	40	502
United Kingdom	—	—	2	29
Other[2]	13	198	2	61
Total[3]	268	4,430	147	2,797

[1] Less than 1/2 unit.
[2] Includes Argentina, Barbados, Belgium, Bermuda, Chile, China, the Dominican Republic, Ecuador, Guatemala, Honduras, Hong Kong, Ireland, the Republic of Korea, Kuwait, Netherland Antilles, Nigeria, Pakistan, Panama, Saudi Arabia, Sierra Leone, Singapore, the Republic of South Africa, Suriname, Sweden, and Switzerland.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

sumption 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 of 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, reaching an annual consumption level of 1,000 tons by 1995.

Scrap and flake mica enters markets as ground mica, and demand tends to follow construction activity levels. For the major use of ground mica, a filler in wallboard joint compounds, consumption follows the macroeconomic indicator, New Construction Activities. Based on this indicator, annual consumption of mica in joint compounds is expected to increase to 75,000 tons in 1995, an average annual increase of 4.5%. Mica consumption in oil well drilling muds closely follows the Fed-

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND RIFTED MICA IN 1989, 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)
Canada	—	—	—	—	54	$22	—	—
France	2	$34	(1)	$12	—	—	42	$56
India	155	177	1,348	1,264	2,992	685	21	312
Madagascar	1	24	15	69	—	—	15	68
Other[2]	—	—	16	10	1	27	—	—
Total[3]	158	235	1,379	1,355	2,996	714	79	436

[1] Less than 1/2 unit.
[2] Includes Brazil, China, Japan, the Republic of Korea, and the United Kingdom.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF MICA POWDER AND WASTE IN 1989, BY COUNTRY

Country	Powder		Waste	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Canada	8,641	$3,927	—	—
China	—	—	72	$32
India	72	29	1,078	474
Japan	72	931	—	—
Norway	100	68	—	—
Other [1]	18	16	39	37
Total [2]	8,902	4,971	1,189	542

[1] Includes Brazil, Finland, France, the Federal Republic of Germany, and the United Kingdom.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of Census.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF WORKED MICA IN 1989, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	626	$4,422	4	$71
Brazil	98	265	37	142
China	42	106	(1)	1
France	24	118	18	100
India	5	137	209	750
Other [1]	29	234	35	364
Total [2]	825	5,282	304	1,429

[1] Includes Austria, Canada, the Federal Republic of Germany, Italy, Japan, the Republic of Korea, Macao, Madagascar, Spain, Switzerland, Taiwan, and the United Kingdom.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of Census.

eral Reserve Board's Index of Production: Oil and Gas Drilling. Based on this index, annual consumption in well-drilling muds is expected to decrease to about 2,000 tons in 1995, an average annual decrease of about 20%. Mica consumption in other uses, such as paints, plastics, rubber, and roofing, etc., does not correlate well with any available indicators. Annual consumption has been relatively constant over the last decade and is expected to increase slightly by 1995.

BACKGROUND

Definitions, Grades, and Specifications

Mica is a group name for a number of complex, hydrous potassium silicate minerals with differing chemical compositions and physical properties. Crystals of mica have excellent basal cleavage and split easily into tough, flexible sheets. The important mica minerals are muscovite and phlogopite.

Commercial qualities of sheet mica are relatively free of defects and tough enough to be punched or stamped into specific shapes. Sheet mica is classified as block, film, or splittings. Block mica is not less than 0.018 centimeters thick and has a minimum usable area of 2.54 square centimeters. Film mica is split to specified thicknesses ranging from 0.0030 to 0.010 centimeters. Splittings

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:								
1985	6,558	$1,962	1,323	$408	37	$159	NA	$5,102
1986	5,300	1,758	1,454	472	44	196	NA	4,502
1987	4,235	1,275	824	259	77	145	NA	4,748
1988	5,202	1,623	1,088	367	63	228	NA	6,148
1989	3,628	1,634	1,224	555	60	156	415	7,227
Imports for consumption:								
1985	5,486	2,202	3,610	718	763	1,080	444	3,154
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

NA Not available.

Source: Bureau of Census.

TABLE 16

MICA: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina:					
Sheet	347	234	340	330	330
Waste, scrap, etc.	374	[r]317	451	630	500
Brazil	2,881	[r]2,060	2,400	2,520	2,500
Canada[e]	11,500	12,000	13,500	12,000	12,000
France	10,084	10,834	[e]11,000	[e]11,000	11,000
India:[e]					
Exports:					
Block	1,200	1,200	1,000	1,000	1,000
Film and disk	250	250	200	200	200
Splittings	4,000	4,000	3,000	3,000	3,000
Scrap	11,000	11,000	10,000	10,000	12,000
Powder	4,700	4,700	3,800	3,800	4,000
Manufactured	1,000	1,000	2,000	2,000	2,000
Domestic consumption, all forms	3,500	3,500	4,000	4,000	4,000
Total	25,650	25,650	24,000	24,000	26,200
Iran[e 3]	[4]820	820	820	820	800
Korea, Republic of (all grades)	20,044	41,997	31,938	[e]30,000	30,000
Madagascar (phlogopite)	589	1,594	402	617	600
Mexico (all grades)	1,446	1,748	3,419	2,584	2,500
Morocco[e]	[4]1,440	1,500	1,500	1,500	1,500
Mozambique[e]	300	300	([5])	([5])	—
Namibia	—	—	—	—	5
Peru[e]	550	550	550	550	500
South Africa, Republic of:					
Sheet	81	—	—	—	—
Scrap	2,072	2,509	970	1,669	1,700
Spain	727	325	[e]250	[e]300	300
Sri Lanka (scrap)[e]	200	200	200	200	200
Sudan (all grades)[e]	10	10	10	10	10
Taiwan	[e]114	774	787	4,387	4,000
Tanzania (sheet)	([5])	([5])	([5])	([5])	([5])
U.S.S.R. (all grades)[e]	50,000	50,000	50,000	50,000	50,000
United States (scrap and flake)[6]	124,800	134,400	145,650	129,900	[4]119,142
Yugoslavia	[r]382	674	1,043	768	800
Zimbabwe	582	1,340	800	[e]800	800
Total	[r]254,993	[r]289,836	290,030	274,585	265,387

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 25, 1990.

[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 Mar. 21 of that stated.

[4] Reported figure.

[5] Less than 1/2 unit.

[6] Excludes U.S. production of low-quality sericite and sheet mica, if any.

are sheets with a maximum thickness of 0.0030 centimeters and a minimum usable area of 1.9 square centimeters. Punch mica, which includes circle and washer mica, is low-quality, hand-trimmed mica up to about 5 centimeters in diameter. The American Society for Testing and Materials (ASTM) designates 13 quality groups for sheet mica, based on quantity of visible inclusions and structural imperfections, ranging from black- and red-stained to perfectly clear. ASTM also designates 12 grades based on the maximum usable rectangle. The sizes range from grade 6 (with 2.54 usable square centimeters) to grade OOEE special (with 254 usable square centimeters).

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 in order to be able to cut the mica into any pattern desired.

Built-up mica, or micanite, consists of partly overlapped and irregularly shaped and arranged splittings cemented together with either an organic or inorganic binder. Large sheets of built-up mica are made by alternating layers of splittings and binder. Sheets of any thickness are made by pressing the layers at high temperatures. Built-up mica is sold in large, uncut sheets or is cut or molded to any size and shape specified by the customer. It is often bonded to another material such as fiberglass cloth to form a composite sheet.

Reconstituted mica or mica paper is a paperlike material made by depositing fine flakes of scrap mica as a continuous mat, which is then dried. The mica paper is sometimes impregnated with an organic binder.[3]

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.[4]

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 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 a 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 Colorado, Wyoming, Idaho, Montana, and California.

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 schist 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.

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[1] Production of high-quality sericite is included in the totals; however, figures for low-quality sericite, used principally for brick manufacturing, are not included.

[2] U.S. Consul, Calcutta, India. State Dep. Telegram 1404, May 15, 1989, p. 1.

[3] American Society for Testing and Materials. Standard Specification for Natural Muscovite Block Mica and Thins Based on Visual Quality. D351-71 (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. Philadephia, PA, 1984, pp. 136-143.

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MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 42 years industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Cheryl M. Jackson, mineral data assistant; and the world production tables were prepared by Harold D. Willis, international data assistant.

Domestic and foreign molybdenum markets expanded in 1989, but mine production among market economy countries exceeded demand. Domestic producer and consumer stocks increased. U.S. mine output of molybdenum increased to 54% of world production. Reported end use consumption of molybdenum in raw materials increased. The reported U.S. consumption by end use remained about the same as in the previous year. Exports of all forms of molybdenum from the United States increased. Domestic producer stocks of molybdenum products increased to about 11 months of annual consumption.

DOMESTIC DATA COVERAGE

Domestic production data for molybdenum are developed by the 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. Out of 15 operations to which surveys were sent, all responded, representing 100% of the total production shown in table 1.

PRODUCTION

Domestic mine production of molybdenum concentrate increased to a total of 139 million pounds of contained molybdenum, compared with 94 million pounds in 1988. The country's two largest suppliers, AMAX Inc. and Cyprus Minerals Co., produced sufficient material during 1989 to keep the molybdenum market stable.

TABLE 1

SALIENT MOLYBDENUM STATISTICS

(Thousand pounds of contained molybdenum and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Concentrate:					
Production	108,409	93,976	75,117	94,911	139,123
Shipments	111,936	95,006	69,868	99,738	136,097
Value	$347,812	$240,484	$179,286	$266,899	$421,427
Reported consumption	W	53,061	37,442	78,684	92,324
Imports for consumption	112	1,120	1,264	169	—
Stocks, Dec. 31: Mine and plant	9,322	8,715	15,082	r10,433	12,931
Primary products:					
Production	87,436	41,490	34,659	56,540	61,696
Shipments	73,861	57,855	40,668	45,273	40,293
Stocks, Dec. 31:	21,014	20,699	22,168	15,688	14,716
Reported consumption, by end use	33,451	31,898	32,629	38,408	38,064
World: Mine production	r216,959	204,588	196,522	p208,209	e256,658

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 2

PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM PRODUCTS IN THE UNITED STATES

(Thousand pounds of contained molybdenum)

	1988	1989	1988	1989
	Molybdic oxides[1]		Metal powder	
Received from other producers	7,258	W	W	W
Gross production during year	W	W	6,214	4,486
Used to make other products listed here	21,214	W	1,836	W
Net production	W	W	4,378	W
Shipments	W	W	3,731	2,028
Producer stocks, Dec. 31	10,617	W	300	274
	Other[2]		Total	
Received from other producers	r3,327	5,577	10,585	5,577
Gross production during year	50,326	57,210	56,540	61,696
Used to make other products listed here	r3,709	25,220	26,758	25,220
Net production	25,404	36,475	29,782	36,475
Shipments	41,542	38,265	45,273	40,293
Producer stocks, Dec. 31	4,771	14,442	15,688	14,716

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, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl, and data indicated by symbol W.

CONSUMPTION AND USES

Consumption of molybdenum concentrate increased 13 million pounds in 1989. 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 increased over that of 1988. Oxide is the chief form of molybdenum utilized by industry, particularly steel, cast iron, and superalloy producers. However, some of the material is also converted to other molybdenum products, such

TABLE 3

U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Thousand pounds of contained molybdenum)

End use	Molybdic oxides	Ferro-molybdenum[1]	Ammonium and sodium molybdate	Other molybdenum materials[2]	Total[3]
1988					
Steel:					
Carbon	1,199	217	—	30	1,446
Stainless and heat resisting	7,054	442	—	162	7,657
Full alloy	6,743	2,220	—	86	9,050
High-strength, low-alloy	1,089	898	—	2	1,989
Tool	1,810	W	—	33	1,843
Cast irons	178	1,372	—	20	1,570
Superalloys	964	102	—	1,671	2,737
Alloys (excludes steels and superalloys):					
Welding and alloy hard-facing rods and materials	—	130	—	15	144
Other alloys[4]	285	103	—	181	568
Mill products made from metal powder	—	—	—	5,259	5,259
Chemicals and ceramics:					
Pigments	—	—	240	—	240
Catalysts	1,579	—	W	406	1,985
Other	8	—	1	908	917
Miscellaneous and unspecified	696	752	1,492	64	3,004
Total[3]	21,604	6,235	1,733	8,836	38,408
1989					
Steel:					
Carbon	1,016	205	—	54	1,275
Stainless and heat resisting	6,786	490	—	163	7,439
Full alloy	6,291	2,116	—	50	8,457
High-strength, low-alloy	1,030	741	—	—	1,771
Tool	1,649	W	—	9	1,658
Cast irons	W	1,703	—	20	1,723
Superalloys	1,087	123	—	2,233	3,442
Alloys (excludes steels and superalloys):					
Welding and alloy hard-facing rods and materials	—	149	—	11	160
Other alloys[4]	315	112	—	190	617
Mill products made from metal powder	—	—	—	4,228	4,228
Chemicals and ceramics:					
Pigments	W	—	W	—	W
Catalysts	2,028	—	W	395	2,424
Other	8	2	2	1,082	1,092
Miscellaneous and unspecified	581	563	2,559	72	3,775
Total[3]	20,791	6,204	2,560	8,509	38,064

W Withheld to avoid disclosing company proprietary data.

[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.

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 64 million pounds of molybdenum.

STOCKS

Total industry stocks, which include those of producers and consumers, increased to 33.5 million pounds of contained molybdenum. Inventories of molybdenum in concentrate at producer locations increased about 2.5 million pounds. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 1 million pounds. Compared with apparent consumption, yearend producer stocks of these materials represented about a 10-month supply. Domestic consumer inventories of about 6 million pounds, the same amount as at yearend 1988, representing approximately a 2-month supply as measured by average monthly reported consumption.

PRICES

The "Metals Week Dealer" (MWD) price of molybdic oxide (per pound of contained molybdenum) decreased from $3.50 in January to $2.55 at the end of December 1989. The average MWD price of oxide was $3.39, or 8 cents less than the average MWD price in 1988.

The posted producer price for molybdic oxide was $3.65 on January 1, 1989. Cyprus Minerals Co. increased its posted price to $3.97 in February and returned to a posted price of $3.65 on July 1. Both AMAX Inc. and Cyprus Minerals Co. reduced their posted prices to $3.35 in October, where the price remained to the end of 1989.

FOREIGN TRADE

Exports

Exports of molybdenum in concentrate and of oxide increased compared with those of 1988. Molybdenum concentrate exports were about 43% of domestic mine production. Approximately 98% of reported shipments of concentrate and oxides were to Belgium-Luxembourg, Canada, the Federal Republic of Germany, Japan, Mexico, the Netherlands, and the United Kingdom. The calculated molybdenum content of all exports was about 118 million pounds in 1989. Total value of exports increased from $205 million in 1988 to $327 million in 1989.

Imports

Approximately 5 million pounds of molybdenum in various forms were imported into the United States, 4.5 million pounds less than in 1988. Total value of all forms of molybdenum imported decreased from $37 million in 1988 to $30 million in 1989. In terms of both value and quantity, the major form imported was ferromolybdenum, principally from Chile and China.

TABLE 4

INDUSTRY STOCKS OF MOLYBDENUM MATERIALS, DECEMBER 31

(Thousand pounds of contained molybdenum)

	1985	1986	1987	1988	1989
Concentrate: Mine and plant	9,322	8,715	15,082	r10,433	12,931
Producers:					
Molybdic oxides[1]	16,281	16,459	W	10,617	W
Metal powder	W	W	457	300	274
Other[2]	4,733	4,240	21,711	4,771	14,442
Total[3]	21,014	20,699	22,168	15,688	14,716
Consumers:					
Molybdic oxides[1]	2,020	2,168	3,653	3,486	3,600
Ferromolybdenum[4]	597	618	554	573	514
Ammonium and sodium molybdate	47	129	76	55	41
Other[5]	1,778	1,654	1,643	1,658	1,664
Total[3]	4,441	4,569	5,925	5,772	5,818
Grand total[3]	34,777	33,983	43,175	31,893	33,465

r Revised. W Withheld to avoid disclosing company proprietary data.

[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 5

DOMESTIC PRICE LISTINGS FOR MOLYBDENUM

(Per pound of contained metal)

	1988	1989
Merchant quotes:[1]		
Concentrate (byproducts)	$2.68	$3.17
Ferromolybdenum-export	4.27	4.31
Oxide	3.47	3.39
Producer quotes:		
Oxide	$3.25- 3.65	$3.35- 3.97

[1] Average.

Source: Metals Week.

WORLD REVIEW

World mine production of molybdenum was 257 million pounds, an increase of 49 million pounds from that in 1988. Canada, Chile, the U.S.S.R., and the United States accounted for more than 90% of the molybdenum produced worldwide.

Capacity

The data in table 10 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 molybdenum is based on published reports, production statistics, and estimates.

Reserves

The definitions of reserves and re serve 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 the "Mineral Facts and Problems, 1985 Edition" and "Mineral Commodity Summaries, 1990."

Estimated world reserves and reserve base of molybdenum appear in table 12. 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.

The United States, with a reserve base of molybdenum estimated at 11.8 billion pounds, has 47% of the world molybdenum reserve base. About 90% of U.S. reserves occurs in large porphyry or disseminated deposits mined, or anticipated to be mined, primarily for molybdenum. These deposits are located in Alaska, Colorado, Idaho, Nevada, New Mexico, and Utah. Other molybdenum sources contribute insignificantly to U.S. reserves.

Canadian reserves of primary molybdenum are located in British Columbia, including nearly 30% of the total in the Endako primary deposit. Other Canadian reserves are associated with molybdenum and copper-molybdenum porphyry deposits in British Columbia, and in relatively minor sources in Quebec and New Brunswick.

Molybdenum reserves in Central and South America are mainly in large copper porphyry deposits. Of several such deposits in Chile, the Chuquicamata and El Teniente deposits are among the world's largest and account for 85% of total molybdenum reserves in Chile. Mexico and Peru have substantial reserves. The La Caridad deposit in Mexico is a large producer. Numerous other copper porphyries that may contain recoverable quantities of molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in the U.S.S.R. and China 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.

TABLE 6

U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES (INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

(Thousand pounds of contained molybdenum and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Argentina	—	—	370	1,247
Australia	—	—	305	998
Austria	26	71	—	—
Belgium-Luxembourg	8,560	25,557	17,167	42,944
Brazil	192	733	437	9,814
Canada	82	355	3,579	11,033
Chile	136	52	1,307	2,679
France	—	—	80	233
Germany, Federal Republic of	5,803	13,961	5,778	13,910
India	—	—	402	1,756
Japan	7,179	18,730	8,589	25,380
Mexico	45	51	1,295	6,774
Netherlands	16,984	51,703	46,129	110,939
Sweden	2,510	6,522	248	370
United Kingdom	9,034	26,763	26,488	53,744
Other	1,256	3,742	772	1,550
Total[1]	51,807	148,237	112,946	283,371

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

Source: Bureau of the Census.

OUTLOOK

Capital expenditures are expected to decrease to a more normal growth rate over the next few years. Alloy and stainless steel demand is forecast to decline in 1990. Short-term molybdenum demand is expected to remain a little below the peak of 1989. Molybdenum demand appears to have ascended to a new level of usage. 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 capacities.

BACKGROUND

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 num-

TABLE 7

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Thousand pounds, gross weight, and thousand dollars)

Product and country	1989 HTSUS No.	1988		1989	
		Quantity	Value	Quantity	Value
Molybdates—All:	2841.70.0000				
Argentina		(1)	2	5	67
Australia		55	159	4	14
Belgium-Luxembourg		244	867	578	1,255
Brazil		1	4	—	—
Canada		235	856	138	690
Chile		1,300	3,325	—	—
Germany, Federal Republic of		(1)	2	1	19
Japan		5,261	12,722	2,042	12,977
Korea		9	30	60	116
Mexico		4	18	16	130
Netherlands		755	2,524	187	1,288
Taiwan		5	16	—	—
United Kingdom		123	341	4	17
Venezuela		342	834	(1)	2
Other		16	128	32	372
Total[2]		8,350	21,828	3,067	16,947
Ferromolybdenum:[3]	7202.70.0000				
Belgium		—	—	40	159
Canada		31	122	65	254
Japan		49	146	12	49
Malaysia		—	—	6	20
Mexico		24	80	3	13
Singapore		—	—	22	56
Venezuela		—	—	10	38
Other		9	35	7	26
Total[2]		113	382	165	615
Molybdenum, unwrought:	8102.91.0000				
Belgium		68	472	—	—
Canada		21	140	15	119
France		5	49	4	57
Germany, Federal Republic of		36	283	13	60
India		2	13	3	14
Japan		503	3,101	297	1,709
Mexico		8	93	16	63
Netherlands		140	762	186	1,029
United Kingdom		21	158	2	25
Other		190	1,616	22	140
Total[2]		995	6,686	558	3,216
Wire:	8102.93.0000				
Argentina		5	95	1	29
Belgium-Luxembourg		18	162	31	444
Brazil		64	1,091	78	1,034
Canada		31	543	22	309
France		65	1,126	45	615
Germany, Federal Republic of		219	2,857	210	2,562
India		5	115	13	269
Italy		87	1,266	33	625
Japan		101	1,911	132	1,888

See footnotes at end of table.

bers 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 tungsten, rhenium, osmium, and tantalum 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 oxidizes readily above 500° C.

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. Typically, "technoxide" has a molybdic-oxide 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 next section, "Products for Trade and Industry."

The American Society for Testing and Materials (ATSM) 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 with additional grinding and flotation steps to produce lubricant-grade 99% molybdenum disulfide.

Molybdenite concentrate is con-

TABLE 7—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Thousand pounds, gross weight, and thousand dollars)

Product and country	1989 HTSUS No.	1988		1989	
		Quantity	Value	Quantity	Value
Wire—Continued					
Korea		—	—	23	617
Mexico		9	271	10	226
Netherlands		1	14	(1)	15
Singapore		1	73	(1)	16
South Africa, Republic of		5	90	3	43
Spain		18	298	14	169
Sweden		26	429	31	453
Taiwan		—	—	55	278
United Kingdom		81	714	41	1,033
Other		105	1,929	9	243
Total[2]		839	12,984	751	10,868
Powder:	8102.10.0000				
Austria		—	—	44	158
Belgium-Luxembourg		529	1,934	2	12
Brazil		—	—	909	416
Canada		79	185	18	151
China		—	—	13	84
France		25	167	105	594
Germany, Federal Republic of		22	291	11	162
India		—	—	24	166
Italy		1	30	12	98
Japan		238	807	11	175
Mexico		2	8	11	73
Netherlands		24	157	29	206
Sweden		—	—	22	143
Taiwan		123	1,003	96	701
United Kingdom		223	797	70	552
Other		75	510	22	155
Total[2]		1,340	5,889	1,399	3,846
Molybdenum, wrought:	8102.92.0000				
Australia		2	34	4	64
Austria		28	292	236	258
Brazil		12	209	1	17
Canada		52	1,104	30	694
France		10	435	22	664
Germany, Federal Republic of		38	805	56	1,113
Japan		89	1,002	108	2,502
Korea		91	1469	159	483
Mexico		4	67	6	78
Netherlands		60	2,355	19	491
Singapore		—	—	(1)	4
South Africa, Republic of		1	79	5	175
Sweden		3	59	2	33
United Kingdom		50	1,120	57	1,164
Other		10	334	38	479
Total[2]		451	9,362	743	8,219

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.
[3]Ferromolybdenum contains about 60% to 65% molybdenum.

Source: Bureau of the Census.

verted to technical-grade 90% molybdic oxide having a maximum sulfur content of 0.1%. This oxide is 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. Technical-grade oxide or ferromolybdenum is used to add molybdenum to steels, cast irons, and nonferrous alloys.

Ferromolybdenum is typically produced by reduction of a mix of technical-grade oxide and iron oxide in a conventional metallothermic process, using silicon and/or aluminum as the reductant. The molybdenum content ranges from 58% to 64%.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made similarly 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.

Geology

Mineralogy.—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. Other molybdenum minerals include chillagite, ilsemannite, koechlinite, lindgrenite, eosite, and jordisite.

Types of Deposits.—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 and are economically important only when molybdenum is associated with other high-valued minerals.

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 in metallogenic provinces encompassing 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.

Mining.—Molybdenum ore is mined by underground and open pit methods, the choice of method being determined by the size, configuration, grade, and depth of the ore body.

Recycling.—Some secondary molybdenum metal 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, CO deposit. Rhenium is extracted from flue gases and dust produced during roasting of molybdenite concentrate 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 of Cyprus Minerals, copper and molybdenum are considered coproduct values.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

(Thousand pounds and thousand dollars)

Item	1989 HTSUS No.	1988			1989		
		Gross weight	Contained molybdenum	Value	Gross weight	Contained molybdenum	Value
Molybdenum ore and concentrates, roasted	2613.10.0000	1,591	965	2,863	1,366	524	1,791
Molybdenum ore and concentrates, other	2613.90.0000	310	169	349	—	—	—
Molybdenum oxides and hydroxides	2825.70.0000	2,192	1,575	7,137	929	NA	3,298
Molydates of ammonium	2841.70.0000	1,346	804	3,262	693	398	2,106
Molybdates—all others	2841.70.5000	82	56	140	128	60	375
Molybdenum orange	3206.20.0000	2,494	NA	3,128	2,307	NA	2,858
Mixtures of inorganic compounds	3823.90.3400	1,247	906	1,348	33	28	202
Ferromolybdenum	7202.70.0000	3,704	2,369	8,504	3,108	1,702	9,062
Molybdenum powders	8102.10.0000	(1)	(1)	(1)	477	436	2,077
Molybdenum, unwrought	8102.91.1000	296	NA	3,752	133	102	2,391
Molybdenum, waste and scrap	8102.91.5000	678	NA	3,276	386	371	1,701
Molybdenum, wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	119	NA	3,457	111	NA	3,311
Molybdenum wire	8102.93.0000	(2)	(2)	(2)	17	NA	553
Molybdenum other		—	—	—	6	NA	637
Total[3]		14,059	6,844	37,216	9,694	3,621	30,361

NA Not available.

[1] Data included with Molybdenum, unwrought.

[2] Data included with Molybdenum, wrought.

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

Source: Bureau of the Census.

Operating Factors

The mining and milling of both primary molybdenum ore and copper ore containing molybdenum are high-tonnage operations. The largest domestic molybdenum mine has an ore-processing capacity of about 48,000 tons per day; processing capacity at the largest copper-molybdenum surface mine exceeds 100,000 tons per day of ore. Ore grade is low; therefore, open pit and underground block caving methods are required to extract ore profitably.

Costs involved in producing molybdenite concentrate vary according to mining methods used (underground or surface), physical characteristics of the ore body, and difficulty in ore beneficiation. In mining, the principal nonlabor operating expenses involve consumption of explosives, utilization of fuel, and electricity for operating equipment. Costs of ore beneficiation are dependent on use of grinding materials, flotation reagents, electricity to operate milling and concentrating equipment, and general plant maintenance. Operating variables are monitored, and adjustments are made when necessary to maximize efficiency and economy of operation.

The mining of primary molybdenum ore and disposal of ore tailings disturb land areas. Land reclamation will become increasingly necessary as mines become inactive. Copper mining that yields byproduct molybdenum entails the disturbance of significantly larger land areas. Development of new mine-mill complexes presents 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 a significant impact on established occupational patterns. Interaction between mining firms and local and state agencies has increased to ensure that mine development proceeds in as orderly and environmentally sound a manner as possible.

The conversion of molybdenite concentrate to technical-grade molybdic oxide involves roasting. Producing firms have modified roasting facilities or in-

TABLE 9

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-kg	13.2¢/kg + 1.9%	$1.13/kg + 15%
Import/export	2613.90.0000	Molybdenum ore and concentrates, other	do.	19.8¢/kg	77.2¢/kg
Molybdenum chemicals:					
Import/export	2825.70.0000	Molybdenum oxides and hydroxides	Gross-kg	3.2%	20.5%
Import	2841.70.0000	Molybdates of ammonium	Content-kg	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-kg	3.7%	25%
Export	3206.20.0000	Pigments based on chromium (moly orange, etc.)	do.	—	—
Miscellaneous chemical products:					
Import	3823.90.3400	Mix of two or more inorganic compounds of molybdenum	Gross-kg	2.8%	18%
Export	3823.30.0000	Nonagglomerated metal binders, moly, etc.	do.	—	—
Ferroalloys:					
Import	7202.70.0000	Ferromolybdenum	Content-kg	4.5%	31.5%
Molybdenum metals:					
Import	8102.10.0000	Powders	Content-kg	13.9¢/kg + 1.9%	$1.10/kg + 15%
Export	8102.10.0000	do.	Gross-kg	—	—
Import	8102.91.1000	Unwrought	Content-kg	13.9¢/kg + 1.9%	$1.10/kg + 15%
Export	8102.91.0000	Unwrought, waste and scrap	Gross-kg	—	—
Import	8102.91.5000	Waste and scrap	Content-kg	Free	Free
Import/export	8102.92.0000	Wrought	Gross-kg	6.6%	60%
Do.	8102.93.0000	Wire	do.	6.6%	60%
Do.	8102.99.0000	Other	do.	5.5%	45%

TABLE 10

MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand pounds of contained molybdenum)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Bulgaria[e]	420	420	440	440	420
Canada (shipments)	17,311	24,804	32,564	29,840	[3]30,102
Chile	40,541	36,555	37,349	34,231	36,500
China[e]	4,400	4,400	4,400	4,400	4,400
Iran[e]	1,100	1,100	1,100	1,100	1,100
Japan	[e]215	—	—	—	[3]—
Korea, Republic of	734	697	717	317	330
Mexico	8,292	7,386	9,700	9,824	9,900
Mongolia[e]	2,200	2,425	2,425	2,425	2,650
Niger[e]	44	44	[r]18	33	33
Peru	8,393	7,681	7,392	5,388	6,800
U.S.S.R.[e]	24,900	25,100	25,300	25,300	25,300
United States	108,409	93,976	75,117	94,911	[3]139,123
Total	216,959	204,588	196,522	208,209	256,658

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 14, 1990.

[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.

Source: Bureau of Mines, Division of International Data.

TABLE 11

WORLD MOLYBDENUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Million pounds of contained molybdenum)

Country	Rated capacity[1]
Bulgaria	2
Canada	35
Chile	45
China	10
Iran	4
Korea, Republic of	2
Mexico	15
Mongolia	5
Niger	(2)
Peru	10
U.S.S.R.	35
United States	165
Total	328

[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

(Million pounds of contained molybdenum)

	Reserves	Reserve base
North America:		
Canada	1,000	2,000
Mexico	200	500
United States	6,000	11,800
Other	—	200
South America:		
Chile	2,500	5,400
Peru	300	500
Other	—	200
Europe:		
Bulgaria	5	20
U.S.S.R.	1,000	1,500
Other	—	600
Asia:		
China	1,100	2,700
Iran	100	300
Other	—	300
Total	12,205	26,020

stalled sulfuric acid recovery equipment to reduce emissions and thereby comply with more stringent pollution restrictions. Because the molybdenum-processing industry is relatively small, raw materials and energy needs generally are not critical concerns, although increasing energy costs will add to overall production costs.

Compared to other industrial metals, molybdenum exhibits low or negligible toxicity. No significant toxic effects in human beings have been identified in the mining and processing of molybdenum materials. As an environmental trace element, molybdenum is an essential micronutrient and has been shown to be related to copper metabolism in certain animal species. Deficiencies or excesses of molybdenum can affect the normal growth and development of numerous plant and animal species.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Engineering and Mining Journal.
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Mining Engineering.
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Skillings' Mining Review.
The Northern Miner (Canada).

NICKEL

By William S. Kirk

Mr. Kirk, a physical scientist with 24 years of Government experience, has been the commodity specialist for nickel since 1987. Domestic survey data were prepared by Barbara J. McNair, Ferrous Data Section. International data tables were prepared by William Zajac and Audrey Wilkes, International Data Section.

Western World consumption rose while domestic demand fell. Prices fell, as demand fell in the second half of the year. The Riddle, OR, ferronickel facility was recommissioned. Falconbridge Ltd., a large Canadian producer, was sold.

LEGISLATION AND GOVERNMENT PROGRAMS

The Agency for Toxic Substances and Disease Registry issued a Toxicological Profile for Nickel, which identified health effects and levels of human exposure to nickel and nickel compounds that may be toxicologically significant.

STRATEGIC CONSIDERATIONS

Nickel is an essential ingredient in austenitic stainless steels 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_4), a major component of acid rain. Inco

TABLE 1

SALIENT NICKEL STATISTICS

(Short tons of contained nickel unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Mine production:					
Nickel ore (gross weight)	868,100	603,400	—	—	—
Shipments	6,127	1,175	—	—	—
Plant production:					
Smelter, from domestic ores	[1] 5,214	[1] 1,651	—	—	382
Refinery, from imported matte	31,168	—	—	—	—
Secondary recovery from purchased scrap: [e]					
From ferrous scrap	36,690	35,320	[r] 27,247	[r] 41,537	35,597
From nonferrous scrap	16,955	8,406	8,392	3,700	8,258
Exports:					
Primary (nickel content)	21,745	2,812	2,413	[r] 2,721	2,302
Secondary (nickel content)	13,500	12,405	12,920	18,251	21,871
Imports for consumption:					
Primary (nickel content)	157,690	129,094	[r] 154,095	[r] 154,366	139,039
Consumption:					
Reported:					
Primary	119,907	107,062	130,504	125,520	116,998
Secondary (purchased scrap) [e]	[r] 53,645	[r] 43,726	[r] 35,639	[r] 45,237	43,855
Apparent:					
Primary	[r] 162,887	137,582	[r] 161,237	[r] 149,165	140,333
Secondary (purchased scrap) [e]	[r] 40,363	[r] 32,952	[r] 23,013	[2] [r] 26,271	[2] 21,769
Stocks, yearend:					
Government	37,222	37,215	37,215	37,214	37,214
Producer	17,400	10,300	6,824	7,672	6,819
Consumer:					
Primary	19,106	16,557	[r] 10,478	[r] 12,110	9,749
Secondary	6,302	4,669	4,375	5,090	5,305
Employment, yearend:					
Mine	130	—	—	—	—
Smelter	170	—	—	—	245
Refinery	—	—	—	—	—
Price (cathode): [3]					
New York dealer, per pound	$2.26	$1.86	$2.28	$6.25	$6.05
World: Mine production	[r] 895,747	[r] 869,293	909,959	961,342	1,027,321

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data.
[1] Includes byproduct nickel.
[2] Secondary exports were included in apparent consumption for the first time in 1988.
[3] Weighted average calculated by Metals Week.

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.

PRODUCTION

The Riddle, OR, ferronickel smelter in Douglas County reopened, becoming the sole domestic source of nickel. The facility, formerly owned by M. A. Hanna Co., closed in 1985 because of the then prevailing low nickel prices. In April 1989, the smelter property was purchased by the Glenbrook Nickel Co., Spokane, WA, which was owned by Cominco American Resources Inc. (CARI), Spokane. CARI was 100% owned by Cominco Resources International Ltd. (CRIL), Vancouver, British Columbia, Canada. CRIL was about 60% owned by Cominco Ltd., Vancouver, BC. The land at the mine was owned by a separate group of individuals and Glenbrook was trying to lease the property from these groups, although no decision had been made at yearend on whether to reopen the mine. After extensive rehabilitation, the smelter was restarted in August, using ore from a reject pile accumulated by Hannah over a 30-year period. The reject pile was at the smelter, rather than the mine, and was considered adequate for about 2 years of smelter feed. Glenbrook produced 382 tons of nickel contained in ferronickel in 1989.

CONSUMPTION

Western World consumption reached record levels for the third consecutive year, although it fell sharply in the second half of the year. U.S. consumption followed a similar pattern; domestic stainless steel production was 24% lower in the second half than in the first, according to data from the American Iron and Steel Institute. Demand by the stainless steel sector slackened

TABLE 2

NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY[e]

(Short tons of contained nickel)

	1987	1988	1989
KIND OF SCRAP			
Aluminum-base	188	233	231
Copper-base	2,097	722	3,605
Ferrous-base	r27,247	r41,537	35,597
Nickel-base	6,107	2,745	4,422
Total	r35,639	r45,237	43,855
FORM OF RECOVERY			
Aluminum-base alloys	229	561	231
Chemical compounds	—	—	—
Copper-base alloys	6,594	1,768	5,396
Ferrous alloys	r27,279	r41,592	35,656
Nickel-base alloys	1,537	1,316	2,572
Total	r35,639	r45,237	43,855

[e]Estimated. [r]Revised.

FIGURE 1

U.S. NICKEL CONSUMPTION IN 1989, BY FORM AND USE

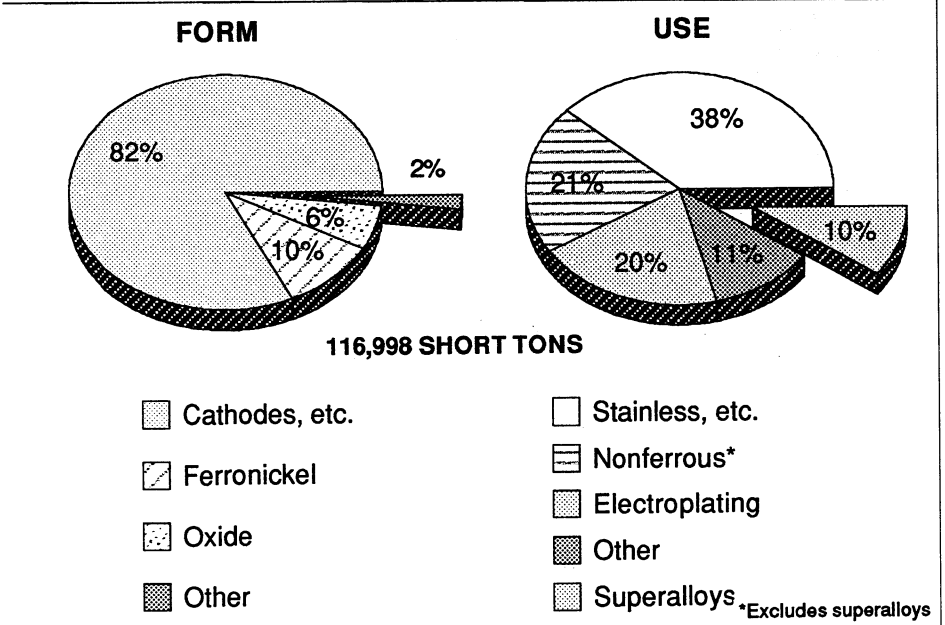


TABLE 3

REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM

(Short tons of contained nickel)

Form	1985	1986	1987	1988	1989
Primary:					
Ferronickel	17,993	13,256	17,418	12,936	11,203
Metal	90,379	82,884	98,673	99,398	96,396
Oxide and oxide sinter	6,297	7,357	9,926	7,790	6,485
Salts[1]	2,770	2,416	2,435	2,657	420
Other	2,468	1,149	2,052	2,739	2,494
Total primary	119,907	107,062	130,504	125,520	116,998
Secondary (scrap)[2]	42,295	31,824	r35,639	r45,237	43,855
Grand total	162,202	138,886	r166,143	r170,757	160,853

r Revised.
[1] Metallic nickel salts consumed by plating industry are estimated.
[2] Based on gross weight of purchased scrap consumed and estimated average nickel content.

first in the United States, then in Europe, and finally in Japan.

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 11% during the year. At yearend, these stocks represented 14 days of domestic apparent consumption. The decrease in stocks took place in the first half of the year. As consumption dropped in the second half, producers began to rebuild inventories.

PRICES

The London Metal Exchange (LME) cash price for nickel fell by 55% through the year. Prices began the year on the rise, reached their peak for the year in March, and, except for a brief rise in late June, declined steadily thereafter. Changes in price levels in 1989, as in recent years, were almost entirely driven by stainless steel demand, the largest end use for nickel (48% of domestic reported consumption in 1989).

The primary reasons for the rise in the first quarter were low stock levels and concerns about actual and potential significant production losses (see World Review). At the end of the first quarter, the service centers began to realize the long boom in stainless steel consumption could be coming to an end. Service centers, which buy stainless steel from the mills for resale to stainless users, handle more than 50% of the stainless steel sold in the United States and are a major factor in Europe as well. The service centers began to sell off their inventories and reduce their purchases from the mills. The drop in orders meant that the stainless steel mills needed less nickel. This coincided with increased availability of stainless steel scrap, a major constituent of stainless steel production. The increased availability occurred because scrap exports were down as a result of decreased foreign demand from Europe and Japan, the major recipients of

TABLE 4

U.S. CONSUMPTION OF NICKEL, BY USE

(Short tons of contained nickel)

Use	Commercially pure nickel	Ferronickel	Nickel oxide	Nickel salts	Other primary forms	Total primary	Secondary[e p] (scrap)	1989 grand total	1988 grand total
Cast irons	625	W	13	W	192	830	1,725	2,555	2,600
Chemicals and chemical uses	1,273	—	W	10	W	1,283	—	1,283	2,002
Electric, magnet, expansion alloys	134	—	—	—	W	134	59	193	273
Electroplating (sales to platers)[1]	23,814	—	—	W	—	23,814	—	23,814	21,517
Nickel-copper and copper-nickel alloys	5,497	W	W	W	51	5,548	5,396	10,944	7,595
Other nickel and nickel alloys	18,263	W	W	W	W	18,263	2,413	20,676	20,994
Steel:									
Stainless and heat-resistant	26,222	10,488	5,784	W	1,564	44,058	33,568	75,910	88,301
Alloys (excludes stainless)	6,181	232	W	W	W	6,413	304	6,717	8,080
Superalloys	11,918	W	W	W	W	11,918	159	12,077	14,922
Other[2]	2,469	483	688	410	687	4,737	231	4,968	2,951
Total reported by companies canvassed	96,396	11,203	6,485	420	2,494	116,998	43,855	160,853	169,235
Total all companies, apparent	XX	XX	XX	XX	XX	[3]140,333	21,769	162,102	r175,436

[e] Estimated. [p] Preliminary. r Revised. 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.
[3] U.S. production plus imports minus exports minus stock increases.

TABLE 5

NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM

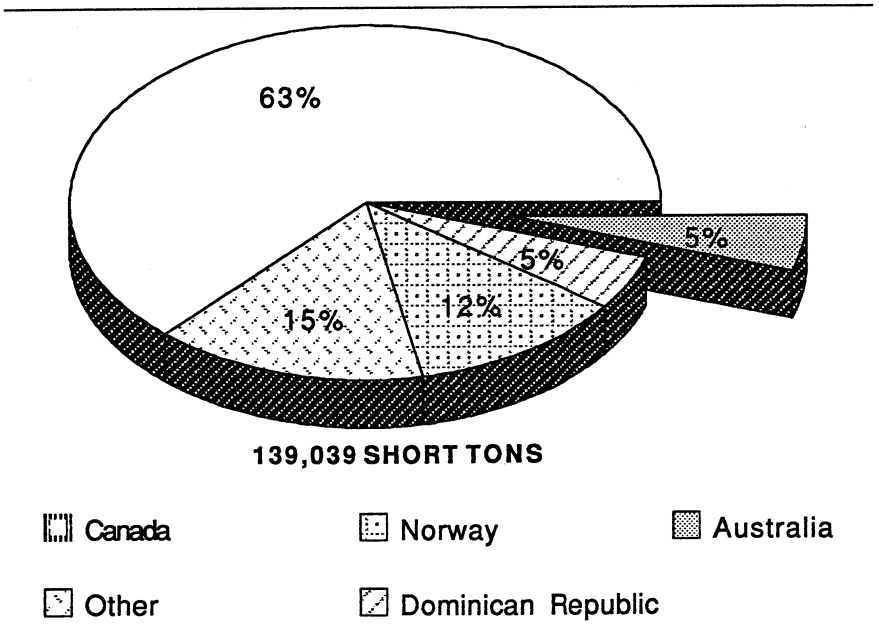
(Short tons of contained nickel)

Form	1985	1986	1987	1988	1989
Primary:					
Ferronickel	1,930	1,028	776	r1,520	2,077
Metal	13,754	11,829	r8,303	r8,140	5,742
Oxide and oxide sinter	3,059	3,281	995	1,980	1,371
Salts	184	175	196	r202	93
Other	179	244	208	268	466
Total primary	19,106	16,557	10,478	12,110	9,749
Secondary (scrap)	6,302	4,669	4,375	5,090	5,305
Grand total	25,408	21,226	14,853	17,200	15,054

r Revised.

FIGURE 2

MAJOR SOURCES OF U.S. PRIMARY NICKEL IMPORTS IN 1989



stainless steel scrap exports. The LME price declined steadily until the third quarter when lower than expected shipments of Soviet nickel caused a brief rally. Stainless steel demand and nickel prices then experienced a steady decline throughout the remainder of the third quarter and through the fourth quarter.

FOREIGN TRADE

The net import reliance was 65% because 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. As a result, U.S. stainless steel scrap exports in 1989 increased considerably. Assuming a nickel content of 7.5%, 21,863 tons of nickel contained in stainless steel scrap were exported in 1989 compared to 18,251 tons in 1988 and an average of about 14,000 tons per year for the 5 years preceding 1989.

WORLD REVIEW

Industry Structure

Nickel was produced in at least 26 countries in 1989. 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, whereas refined metal is most often produced from sulfide ores. From 1985 through 1989, those countries producing from laterite ore accounted for about 35% of world mine production, with the balance coming from sulfide ores. Inco Ltd., of Canada, is the largest single producing company. From 1985 through 1989, the

TABLE 6

U.S. EXPORTS OF NICKEL AND NICKEL ALLOY PRODUCTS, BY CLASS

(Short tons of contained nickel)

Class	1986		1987		1988		1989	
	Quantity (short tons)	Value (thou-ands)	Quantity (short tons)	Value (thou-ands)	Quantity (short tons)	Value (thou-ands)	Quantity (short tons)	Value (thou-ands)
Primary:								
Cathodes, pellets, and briquets (unwrought)	1,936	$12,542	1,547	$10,581	1,940	$19,344	975	$10,861
Electroplating anodes	108	961	213	1,864	206	1,618	NA	NA
Ferronickel	184	NA	71	NA	—	—	666	949
Powder and flakes	584	5,913	582	6,720	575	8,184	661	12,111
Total	2,812	XX	2,413	XX	2,721	XX	2,302	XX
Secondary:								
Stainless steel scrap	165,402	90,066	172,273	94,025	243,344	239,807	291,609	320,683
Nickel content, secondary [1]	12,405	XX	12,920	XX	18,251	XX	21,871	XX
Wrought:								
Bars, rods, profiles, and wire	NA	NA	NA	NA	NA	NA	282	4,399
Sheets, strips and foil	NA	NA	NA	NA	NA	NA	243	4,107
Tubes and pipes	NA	NA	NA	NA	NA	NA	67	3,445
Total	NA	NA	NA	NA	NA	NA	592	11,951
Grand total	NA	NA	NA	NA	NA	NA	24,765	XX
Nickel-compound catalysts, gross weight	2,243	10,631	3,984	16,940	4,812	21,745	6,736	34,875
Nickel waste and scrap, gross weight	10,500	15,012	11,541	17,273	12,782	36,079	14,938	45,739
Total	12,743	25,643	15,525	34,213	17,594	57,824	21,674	80,614

NA Not available. XX Not applicable.

[1] Nickel content of stainless steel scrap is considered to be 7.5%.

Source: Bureau of the Census

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Nickel content unless otherwise specified)

Class	1987		1988		1989	
	Quantity (short tons)	Value (thou-ands)	Quantity (short tons)	Value (thou-ands)	Quantity (short tons)	Value (thou-ands)
Primary:						
Smelter products:						
Ferronickel	r20,910	$57,481	r16,066	$116,990	12,650	$117,630
Salts and other (including slurry)	r5,382	24,754	r11,798	51,512	8,820	16,275
Refined nickel:						
Cathodes, pellets, briquets, and shot (unwrought)	113,249	455,126	112,576	1,024,106	100,448	114,861
Flakes	937	3,622	730	6,274	62	5,702
Oxide and oxide sinter	r2,577	4,277	r2,942	26,009	5,550	3,052
Powder	11,040	56,784	10,254	94,469	11,510	121,416
Total	r154,095	602,044	r154,366	1,319,360	[1]139,039	378,936
Wrought:						
Bars, rods, profiles and wire	NA	NA	NA	NA	425	7,739
Sheets, strip and foil	NA	NA	NA	NA	361	5,973
Tubes and pipes	NA	NA	NA	NA	125	2,799
Total	NA	NA	NA	NA	911	16,511
Nickel waste and scrap, gross weight	7,567	25,133	r4,612	38,039	5,678	78,089

r Revised. NA Not available.

[1] Data do not add to total shown because of independent rounding.

Sources: Bureau of the Census and Journal of Commerce.

TABLE 8

U.S. NICKEL IMPORTS FOR CONSUMPTION OF NEW NICKEL PRODUCTS IN 1989, BY COUNTRY

(Short tons of contained nickel)

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Oxide and oxide sinter	Ferronickel	Salts[e] and other	Total	
						1989	1988
Australia	3,341	1,758	2,209	—	17	7,325	9,259
Botswana	—	—	—	—	—	—	99
Canada	70,819	8,888	3,341	94	3,965	87,108	90,242
Colombia	—	—	—	1,727	—	1,727	2,490
Dominican Republic	1,865	—	—	5,691	1	7,558	9,048
Finland	731	—	—	—	—	731	2,487
France	1,807	—	—	—	755	2,562	3,476
Germany, Federal Republic of	125	83	—	8	938	1,153	1,311
Japan	1	1	—	—	118	120	728
New Caledonia	—	—	—	4,757	7	4,764	3,595
Norway	16,606	—	—	—	38	16,643	21,910
South Africa, Republic of	1,039	654	—	18	7	1,718	2,179
United Kingdom	119	85	—	—	431	634	1,073
Zimbabwe	3,634	39	—	—	201	3,873	3,644
Other	361	65	—	354	2,344	3,123	2,826
Total[2]	100,448	11,572	5,550	12,650	8,820	139,039	154,366

[e] Estimated.

[1] Data may not add to totals shown because of individual rounding of converted units.

Sources: Bureau of the Census and Journal of Commerce.

five largest producing countries and their share of world mine production were: the U.S.S.R. (24%), Canada (22%), Australia (9%), New Caledonia (9%), 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 at present is the Glenbrook Nickel Co., which operates the ferronickel smelter at Riddle, OR. Some nickel is also produced in the United States as a byproduct of copper refining and recycling.

Capacity

The data in table 9 are rated capacity for mines, smelters and refineries 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 operation rate, based on the physical equipment of the plant, and given acceptable operating procedures involving labor, energy, materials, and maintenance.

The major corporate event of the year was the sale of Falconbridge Ltd., of Canada. As a result of unprecedentedly high nickel demand in recent years, there was a spate of exploration and development activity, most of which took place in Australia.

Australia

Australian Consolidated Minerals Ltd. (ACM) and Outokumpu were planning to form a 50–50 joint venture to exploit ACM's wholly owned Mt. Keith deposit in Western Australia. Preliminary feasibility studies indicated an initial reserve of 110 million tons of ore grading 0.63% nickel. One purpose of the joint venture was to provide Outokumpu with an additional source of feed for its nickel facilities in Finland by shipping concentrates to the company's facility in Kokkola, Finland. There, the concentrate was to be roasted in existing facilities, and an electric furnace was to be built to produce ferronickel. The companies indicated that, although the project was planned to have a capacity of 22,000 short tons per year, the deposit had the capacity to supply a much larger operation. The joint venture was to hold discussions with other users of nickel concentrate to identify potential purchasers. The project was subject to approval on completion of a final feasibility study in 1990.

Outokumpu was also reported to be planning to begin a $27 million nickel project in Forrestania in Western Australia. The company bought a 55% interest in the project from Metals Exploration Ltd. Forrestania was comprised of two properties, Digger Rocks and Cosmic Bay. Outokumpu planned to complete the development of the open pit Digger Rocks and underground Cosmic Bay properties and build a 440,000-short-ton-per-year concentrator by early 1991. Digger Rocks reportedly had reserves of 1.3 million tons of ore grading 1.76% nickel, and Cosmic Bay had 2.5 million tons grading 2.82% nickel. The project was expected to have a lifetime of 7 years based on forecast production. The concentrate from the facility was to be sent to Outokumpu's smelter and refinery in Finland. Outokumpu was also reported to be considering developing the richer Flying Fox and New Morning nickel deposits in the region. The Forrestania purchase was part of Outokumpu's efforts to obtain a long-term

TABLE 9

WORLD NICKEL ANNUAL MINE AND PLANT PRODUCTION CAPACITY AS OF DECEMBER 31, 1989

(Thousand short tons contained nickel)

Country	Mine capacity	Refinery and smelter[1] capacity
North America:		
Canada	220	170
United States	—	55
Total	220	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.	210	270
United Kingdom	—	50
Other[2]	30	17
Total	288	465
Africa:		
Botswana	22	—
South Africa, Republic of	50	32
Zimbabwe	20	20
Total	92	52
Asia:		
China	40	30
Indonesia	65	6
Japan	—	124
Korea	—	13
Philippines[3]	45	35
Taiwan	—	9
Total	150	217
Oceania:		
Australia	83	59
New Caledonia	100	50
Total	183	109
World total	1,078	1,182

[1] Because matte is an intermediate product that must be refined before the nickel it contains can be used in making alloys or other products, smelter capacity for matte is not listed to avoid double counting.
[2] Includes Austria, Czechoslovakia, the Federal Republic of Germany, the German Democratic Republic, Poland, and Yugoslavia.
[3] Standby or partially standby capacity.

supply of feed, because its own reserves have been diminished.

Queensland Nickel Pty. Ltd. was considering a plan that would permit the company to increase the production rate of its nickel refinery near Townsville, Australia, by 50%. This was to be accomplished by increasing the production capacity by 20% and processing higher grade ore. Reserves at the refinery's source of feed, the Greenvale Mine, were expected to be depleted in 1992. Queensland Nickel signed an agreement with P.T. Aneka Tambang to supply nickel ore to the plant. The Indonesian Government-owned mining concern was to supply as much as 1.1 million short tons of ore per year for 8 years. This was enough feedstock to satisfy about one-third of the Yabulu plant's requirements at the time, and was expected to decrease to about one-quarter as the plant's capacity was increased. Queensland also signed a long-term contract with New Caledonian firms. The two agreements were expected to fulfill the refinery's feedstock needs for several years.

Resolute Resources of Australia was planning to develop a nickel deposit with reserves estimated at 119 million short tons near Kalgoorlie in Western Australia. Plans called for the production of 14,000 tons of nickel per year over about 15 years.

An Italian state-owned company, AGIP SpA., announced that its subsidiary, Agip Australia Pty. Ltd., had formed a joint venture with an Australian company, Whim Creek Consolidated, to develop a nickel-copper mine in Australia. The property, known as Radio Hill, contained proven reserves of more than 1 million tons of ore grading 2.22% nickel and 1.68% copper. A feasibility study was being conducted by Agip at the site, located near Karratha, in the Pilbara region of Western Australia. The facility was 66.6% owned by Agip and the balance by Whim Creek. Mining was expected to begin in 1990 at a rate of 220,000 tons per year (TPY) of ore for 7 years. This was expected to produce more than 50,000 TPY of concentrate at 6% nickel and 3.6% copper, with minor quantities of cobalt and platinum-group metals.

Following Western Mining Corporation Ltd.'s purchase of the Leinster mining center (formerly called Agnew) in late 1988, the company recommissioned the mill in early 1989 and began developing the mines. Production began in mid-1989.

Canada

In August, Falconbridge Ltd. was jointly purchased by Noranda Inc., a large, Toronto-based resource firm and Trelleborg AB, a large Swedish metals producer.

Falconbridge announced plans to open a mine at its Sudbury operations. The new mine, to be called the Craig, was to provide more than 22,500 tons of nickel per year from late 1993 until beyond 2000. This quantity, which represented about 60% of Falconbridge's Sudbury production, was to replace production from other mines with diminishing reserves.

Falconbridge increased its ownership of New Quebec Raglan Mines Ltd. from 73.8% to 100%. The Raglan property was a nickel-copper deposit in the Ungava region of northern Quebec.

Inco Ltd. announced plans for the development of a major new mine near its nickel production complex at Sudbury, Ontario. The new mine, named the McReedy East, was to involve the largest known undeveloped high-grade nickel-copper sulfide deposit in the Sudbury basin. The engineering and preliminary development began in December, and production was to begin in 1993. Full production of 7,000 tons of ore per day was expected to be reached by 1996, resulting in the production of 20,000 tons of nickel per year. Because of the mine's size, grade, and use of the latest mining technology, the company expected the McReedy East to operate at a productivity level double the average of the other Inco mines.

Inco was forced to decrease production at its Thompson complex in Manitoba after encountering unacceptably high levels of arsenic at the Thompson Open Pit North Mine.

Inco reopened the Shebandowan Mine, which was west of Thunder Bay, Ontario. The mine was operated by McIsaac Exploration, which sent concentrates by truck to Inco's Sudbury smelter.

The 10-year contract, under which Sherritt Gordon Ltd. toll-refined nickel for Inco, expired at the end of the year. The contract had provided the Sherritt refinery with just over one-half of its

raw materials. In a search for additional raw material, Sherritt secured a new source of feedstock for its refinery in Fort Saskatchewan, Alberta. The Redstone Mine, located near Timmins, Ontario, a joint venture between Timmins Nickel Inc. and BHP-Utah Mines Ltd., was expected to produce about 5,000 tons per year of nickel in concentrate. Sherritt stated that, based on the projected quantities from its then current sources, feed supplies were sufficient to permit its refinery to operate at full capacity in 1989 and at 70% of capacity for the following 5 years.

Another source of Sherritt feed, the Namew Lake Mine in northern Manitoba, experienced production difficulties caused by water problems in the deepest part of the mine.

Finland

Outokumpu Oy signed an agreement to receive nickel concentrate from Nikkel and Olivin AS, a Norwegian company operating in Sweden. The Arnessjellet Mine, near Ballangen, Sweden, was expected to begin trial production in March. Outokumpu was to receive 16,500 tons of concentrate in 1989 and about 33,000 tons in each of the next 2 years. The concentrate was to go to Outokumpu's Harjavalta nickel smelter in southwest Finland.

Outokumpu formed a joint venture with the U.S.S.R. to develop a nickel mine in the Kola Peninsula, about 50 miles from Pechenga, in the eastern U.S.S.R. Subject to the successful conclusion of a feasibility study, Outokumpu was to exploit the underground part of the Tundrovoje deposit, which had been mined as an open pit for more than 30 years. Outokumpu was building a nickel flotation plant for Pechenga Nickel in the town of Zapolyarnvy.

Outokumpu was also actively involved in Australian projects (See Australia).

Indonesia

PT Aneka Tambang, a state-owned company, was planning to expand the capacity of its ferronickel plant and open a new nickel mine. The expansion would require the construction of a second furnace at the Pomalaa, Sulawesi, plant. The new mine was to be developed on Gag Island with the assistance of Queensland Nickel Joint Venture (QNJV). Nickel ore was to be shipped to the Queensland nickel refinery in Yabalu, Queensland, Australia.

Inco Ltd. was proceeding with plans to offer up to 20% of the ownership of its 78%-owned subsidiary, PT Inco Indonesia, to the Indonesian public.

Japan

Pacific Metals Co. Ltd., was planning to increase its ferronickel capacity and production in 1990 from the 1989 capacity of 40,000 TPY to a capacity of 44,000 TPY.

Sumitomo Metal Mining Co. Ltd. was converting a refinery in Hososhima, which had been used to treat cobalt concentrates to a 360-short-ton-per-month electrolytic nickel refining unit. This was to increase nickel cathode output capacity to a total of 2,400 tons per month.

Korea

Korea's first nickel refinery came online in June, with production reaching 375 tons. The Korea Nickel Corp. plant, jointly owned by Inco Ltd., (25%), Korea Zinc Co. Ltd., and Keo-Yang Co. Ltd., reached a capacity of 13,000 tons of nickel per year late in 1989.

Philippines

The Philippine Government agency, Asset Prioritization Trust (APT), which was responsible for selling the Nonoc Mining & Industrial Corp.'s nickel mine and refinery, made several unsuccessful attempts to sell the facility.

TABLE 10

NICKEL: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Short tons of nickel content)

Country	1985	1986	1987	1988[p]	1989[e]
Albania (content of ore)[e]	10,600	10,700	9,900	9,900	9,900
Australia (content of concentrate)	94,531	84,590	82,182	68,738	[2]73,900
Botswana (content of ore milled)	[r]28,991	[r]28,173	28,572	28,628	28,700
Brazil (content of ore)	[r]18,158	[r]23,262	22,215	22,963	23,100
Burma (content of speiss)[e]	60	52	55	115	110
Canada[3]	187,361	180,381	208,431	240,917	224,371
China[e]	27,600	27,600	27,600	[r]27,600	27,600
Colombia (content of ferroalloys)	17,013	20,975	21,301	18,300	16,500
Cuba (content of oxide, sinter, sulfide)	[r]35,370	35,514	37,285	46,030	47,400
Dominican Republic	27,992	24,116	35,848	[e]32,300	35,300
Finland (content of concentrate)	9,421	13,102	11,637	12,897	13,200
German Democratic Republic[e]	2,200	2,200	2,200	2,200	1,700
Greece (recoverable content of ore)[e]	[r]24,300	[r]15,900	[r]10,100	[r]9,900	9,900
Indonesia (content of ore)[4]	44,463	59,171	63,674	63,914	70,900
New Caledonia (recoverable content of ore)	79,800	68,100	62,700	74,600	137,800
Norway (content of concentrate)	468	483	[e]440	[e]440	440
Philippines	31,039	14,099	8,619	[e]11,900	15,400
Poland (content of ore)[e]	2,200	2,200	2,200	2,000	2,000
South Africa, Republic of[e]	27,600	[r]34,200	37,800	38,400	39,100
U.S.S.R. (content of ore)[e]	[r]204,000	[r]215,000	[r]226,000	[r]237,000	237,000
United States (content of ore shipped)	6,127	1,175	—	—	—
Yugoslavia (content of ore)[e]	4,200	4,200	4,300	4,300	4,200
Zimbabwe (content of concentrate)[e]	[2]12,253	[r]4,100	[r]6,900	[r]8,300	8,800
Total	[r]895,747	[r]869,293	909,959	961,342	1,027,321

[e]Estimated. [p]Preliminary. [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 May 4, 1989.

[2]Reported figure.

[3]Refined nickel and nickel content of oxides and salts produced, plus recoverable nickel in exported matte and speiss.

[4]Includes a small amount of cobalt not reported or recovered separately.

TABLE 11

NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY[1]

(Short tons of nickel content)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Albania: Metal	—	—	—	[e]3,500	[e]5,000
Australia:					
Metal	25,302	23,864	[e]27,149	25,400	[4]24,250
Oxide	19,680	22,540	[e]21,936	20,900	22,000
Total	44,982	46,404	[e]49,085	46,300	46,250
Brazil:[3]					
Ferronickel	10,363	10,559	10,735	10,161	10,400
Metal	4,150	4,284	4,942	4,893	5,000
Total	14,513	14,843	15,677	15,054	15,400
Canada:					
Metal	99,285	107,323	122,119	126,595	114,600
Oxide	19,810	15,341	22,834	43,143	41,900
Total	119,095	122,664	144,953	169,738	[4]156,500
China: Metal[e]	24,800	24,800	24,800	27,600	27,600
Colombia: Ferronickel	13,007	20,975	21,301	[e]18,300	18,700
Cuba:[5]					
Oxide	9,733	9,240	6,509	13,911	14,300
Oxide sinter	7,777	9,137	12,477	12,358	13,300
Total	[r]17,510	[r]18,377	18,986	26,269	27,600
Czechoslovakia: Metal[e]	5,000	5,000	[r]5,000	4,700	4,400
Dominican Republic: Ferronickel	28,450	24,239	32,519	32,347	[4]34,450
Finland: Metal	17,258	19,611	16,967	17,329	17,600
France:					
Metal	8,598	8,631	8,267	9,700	[4]9,480
Salts	992	1,069	1,323	1,543	[4]1,543
Total	[r]9,590	[r]9,700	9,590	11,243	[4]11,023
German Democratic Republic:[e]					
Unspecified[e]	3,300	3,500	3,800	3,800	3,300
Germany, Federal Republic of: Salts[e]	800	—	—	—	—
Greece: Ferronickel	17,584	11,380	10,141	[4]14,474	17,744
Indonesia: Ferronickel	5,293	4,980	1,855	5,407	[4]5,472
Japan:					
Ferronickel	60,174	54,708	54,460	63,445	[4]69,263
Oxide	16,755	20,892	24,583	26,659	25,400
Metal	25,636	25,577	23,586	22,003	23,800
Total	102,565	101,177	102,629	112,107	118,463
Korea, Republic of: Metal	—	—	—	—	4,600
New Caledonia: Ferronickel	39,797	36,377	32,552	41,173	39,700
Norway: Metal	41,351	42,118	49,124	57,871	57,300
Philippines: Metal	18,732	2,288	—	—	—
Poland: Unspecified[e]	2,200	2,100	2,100	1,800	1,800
South Africa, Republic of: Metal[e]	[r]25,400	[r]27,600	30,200	30,700	30,800
U.S.S.R.:[e 6]					
Ferronickel	27,500	27,500	27,500	27,500	27,500
Oxide	16,500	16,500	16,500	16,500	16,500
Metal	176,000	186,000	196,000	218,000	217,000
Total	220,000	230,000	240,000	262,000	261,000

See footnotes at end of table.

CURRENT RESEARCH

Outokumpu and ACM developed a process, which, if successful, could have a significant effect on the way sulfide deposits are developed. (See Australia section.) The Mt. Keith deposit in Western Australia is a low-grade sulfide deposit. Historically, nickel produced from a sulfide deposit has nearly always been in elemental form, and laterite deposits have been used to produce ferronickel. Pilot-scale metallurgical testing in Australia demonstrated the feasibility of producing a high-grade nickel concentrate with a low magnesium content. The low magnesium content was necessary to prevent the ore from being too refractory, because a high magnesium content would significantly raise the melting point of the concentrate. This process gave Outokumpu the ability to smelt the concentrate to ferronickel, effectively eliminating the traditional, and costly, midstage of processing concentrate into matte.

According to reports, Ford Motor Co. placed verbal orders for zinc-nickel coated sheet steel with Japanese steel mills. The zinc-nickel sheet is to be used in a 1990 model. The electroplated coating contains about 13% nickel; the balance is zinc. Zinc-nickel coated steel is already extensively used in Japan and Europe. Ford said that, after the initial 3 months of production, the company would be looking for domestic sources. Bethlehem Steel Corp., Pittsburgh, PA, is the only domestic steel producer known to have scheduled commercial production of zinc-nickel coated sheet steel for automobile applications. Other steel producers may be giving it consideration.

NKK Corp., formerly Nippon Kokan KK, Japan's second largest steel producer, used new technology that enabled the company to use nickel ore in place of ferronickel. The company was converting a mothballed converter at its Fukuyama facility to a 5,500-ton-per-month stainless steel production facility. The new process is said to cut costs by as much as 10% from conventional methods.

NKK also developed the world's first stainless steel-base shape-memory alloy for practical use.[1] A shape-memory alloy is one which when heated, returns to a previously formed or "remem-

TABLE 11—Continued

NICKEL: WORLD PLANT PRODUCTION, BY COUNTRY[1]

(Short tons of nickel content)

Country[2]	1985	1986	1987	1988[p]	1989[e]
United Kingdom: Metal	19,621	34,130	32,518	30,534	32,000
United States:					
Ferronickel	5,214	1,651	—	—	382
Metal	31,168	—	—	—	—
Total	36,382	1,651	—	—	382
Yugoslavia: Ferronickel[e]	2,650	2,750	2,750	2,750	2,750
Zimbabwe: Metal	10,340	10,725	11,457	12,666	13,000
Grand total	[r]840,220	[r]817,389	858,004	947,662	952,834
of which:					
Ferronickel	210,032	195,119	193,813	215,557	226,361
Oxide	90,255	93,650	104,839	133,471	133,400
Metal	532,641	521,951	552,129	591,491	586,430
Salts	1,792	1,069	1,323	1,543	1,543
Unspecified	5,500	5,600	5,900	5,600	5,100

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Refined nickel plus nickel content of ferronickel produced from ore and/or concentrates unless otherwise specified. Table includes data available through May 12, 1989.

[2] In addition to the countries listed, North Korea is believed to have produced metallic nickel and/or ferronickel, but information is inadequate for formulation of 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: 1984—56,330 (estimated); 1985—56,858; 1986—54,078; 1987—52,728; and 1988—50,000 (estimated; Botswana: 1984—20,507; 1985—21,567; 1986—20,913; and 1987—18,230; 1988—24,845; Indonesia: 1984—27,854 (revised); 1985—34,567 (revised); 1986—30,837; 1987—29,213; and 1988—31,000 (estimated); and New Caledonia: 1984—6,021; 1985—9,816; 1986—10,097; 1987—9,130; and 1988—11,541.

[3] Refined nickel plus the nickel content of oxide.

[4] Reported figure.

[5] Nickel content of ferronickel only; no refined nickel was produced.

[6] Revised to include nickel content of granular nickel oxide, nickel oxide powder, and nickel oxide sinter. Cuba also produces nickel sulfide, but it is not included in order to avoid double counting. Output of processed sulfide was as follows, in short tons: 1984—15,971; 1985—17,835; 1986—18,588 (revised); 1987—19,500 (estimated, revised); and 1988—19,850 (estimated).

[7] Includes nickel content of nickel alloys.

[8] Includes nickel content ferronickel, refined nickel, and nickel oxide.

[9] Nickel content of ferronickel or matte only; no refined nickel was produced.

bered" shape, produced through bending and heating the alloy to roughly 500° C. Because conventional shape-memory alloys, nickel-titanium and copper-base alloys had disadvantages, such as high cost and poor workability, their use as structural materials had not become widespread. The new stainless steel-base shape-memory alloy overcame problems associated with shape-memory alloys used in 1989. Its advantages included: high corrosion resistance, lower cost than nonferrous alloys, superior workability, and variable composition.

A superplastic duplex stainless steel, named SuperDux64, was developed by Nippon Yakin Kogyo Co. Ltd. in Japan.[2] The new alloy, when compared to the superplastic materials Ti-6Al-4V (titanium with 6% aluminum and 4% vanadium) and 7475Al (an aluminum alloy), can be formed into shapes at least twice as fast as the titanium alloys and eight times faster than aluminum alloys. It also has superior elongation and ductility properties.

Sumitomo Metal Mining Co. Ltd., a Japanese nickel producer, developed new refining technology that allowed the company to produce nickel chloride from nickel matte through chlorine leaching.[3] The next step, using conventional technology, was electrowinning to produce metallic nickel.

Metallgesellschaft AG, of the Federal Republic of Germany, developed an alloy that retained its integrity to between 1,300° and 1,350° C compared with then currently used alloys that could withstand temperatures of up to 1,200° to 1,250° C.[4] The new alloy, targeted for use in next-generation gas turbine engines, was produced without using conventional melting processes. Instead, individual crystals of nickel, chromium, cobalt, iron, and aluminum were compacted under extremely high pressure.

Bureau of Mines researchers have determined that the addition of 4% aluminum to a 17% chromium, 9% nickel stainless steel in a high-temperature, wet sulfur atmosphere reduced surface corrosion rates by a factor of 3 to 10.[5] A study of the morphology and composition of corrosion scales indicated that the aluminum addition allowed the stainless steel to form a compact, tightly adherent layer at the metal-scale interface that limited both inward diffusion of oxygen and sulfur to the base metal and outward diffusion of nickel. The aluminum-bearing alloy provided significantly better corrosion resistance, under the above conditions, than AISI type 310 stainless steel, which is used in high-temperature, corrosive environments and which contains 25% chromium and 20% nickel.

OUTLOOK

Stainless steel accounts for just over 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 consensus 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. 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. World nickel consumption in 1990 is expected to decline from the record level of 1989, and, because of the cyclical nature of nickel demand, may not turn upward for a few years. Therefore, nickel demand through 1993 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, owing to 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 in the next 3 to 5 years is expected to rise faster in the Far East and in Eastern Europe than in the rest of the world.

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 76% or 90% nickel.

Economic Factors

Prices.—Table 12 shows the time-price relationship for nickel over a 49-year span. The upward price trend in the 1970's reflected generally strong demand. In the early 1980's excess production capacity caused nickel prices to drop. In terms of constant dollars, nickel prices in the mid-1980's 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 2 years. Prices soared along with demand.

[1] Nickel, A World's First: Stainless Steel-Base Shape-Memory Alloy for Practical Use. V. 5, No. 1, Sept. 1989, pp. 8–9.

[2] ———. Develop Superplastic Stainless in Japan. V. 5, No. 2, Dec. 1989, pp. 10–11.

[3] Furukawa, Tsukasa. Sumitomo Rolls Out New Nickel Refining Method. Amer. Met. Mark., v. 93, No. 186, Sept. 25, 1989, p. 20.

[4] Amer. Met. Mark. MG Develops High-Grade Alloy. V. 98, No. 46, Mar. 7, 1989, p. 4.

[5] Dunning, J. S., and S. C. Rhoads. Effects of Al Additions on Sulfidation Resistance of Some Fe-Cr-Ni Alloys. BuMines RI 9278, 1989, 19 pp.

OTHER SOURCES OF INFORMATION

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TABLE 12

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	.32	2.01
1950	.45	1.87
1955	.66	2.41
1960	.74	2.39
1965	.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

[1] Constant dollar price determined from gross national product implicit price deflator.

NITROGEN

By Raymond L. Cantrell

Mr. Cantrell joined the Bureau's Chemical Materials group in June 1988 in the capacity of physical scientist, nitrogen commodity specialist. Ray's background in fertilizer market research and planning, technical services, and chemical research spans 25 years. He holds a B.S. in Chemistry from the University of Tennessee, Knoxville (1964). Ms. Tonya Hardin, Mr. Joseph Daniels, and Mr. Michael McTootle, mineral data assistants, prepared domestic data tables. Ms. Virginia Woodson, international data assistant, prepared international data tables.

Planet Earth is surrounded by an atmosphere rich in nitrogen. Nitrogen gas, in fact, accounts for about 78% of the Earth's atmosphere by volume. Nitrogen is an inert gas and reacts chemically only under conditions of high temperature, pressure or through biological processes to produce fixed nitrogen compounds. Ironically, fixed nitrogen (N) compounds are an absolute requirement for life on our planet. A natural phenomenon known as the nitrogen cycle provides a balance between fixed N forms on Earth and atmospheric nitrogen.

Global synthetic ammonia production approached 134 million short tons in 1989 and was valued at about $15 billion. Fixed nitrogen in the form of synthetic anhydrous ammonia provided the base for the production of food and fiber required to support Earth's estimated 5.2 billion inhabitants. Ammonia also provided for a significant industrial chemicals industry. Synthetic fibers and resins, explosives, and an enormous array of inorganic and organic compounds were dependent upon ammonia feedstock.

U.S. ammonia plants operated at 96% of rated capacity in 1989, in producing 16.8 million product tons. Domestic demand for anhydrous ammonia and downstream nitrogen conversion products was buoyant during the spring of 1989, and producers operated above capacity in meeting demand. Import demand for anhydrous ammonia reached record proportions and the ammonia trade deficit soared to a record 3.4 million tons for the year. An oversupply situation developed in the domestic ammonia market following a disappointing spring fertilizer season, prompting a cutback in production and imports during the second half of 1989.

Ammonia prices fell precipitously during the second quarter and ammonia sold at near producer cash costs f.o.b. plant through the third quarter of the year. Ammonia export and import data were withheld from public disclosure by the U.S. Department of Commerce in 1989, and many industry analysts believed that the loss of strategic trade data required for the monitor of domestic ammonia supply-demand fundamentals served to exacerbate the oversupply situation.

Persian Gulf countries landed 240,000 tons of ammonia in the United States during 1989, representing an increase of 330% above that of the prior year. Kuwait and Bahrain were new entries into the U.S. marketplace and accounted for about 70% of the Persian Gulf total. Saudi Arabia provided the remaining tonnage.

India rejected a Moroccan phosphoric acid price increase in 1989 and opted to purchase record quantities of U.S. diammonium phosphate (DAP) instead. This unforeseen geopolitical event was fortuitous for both the U.S. nitrogen and phosphate industries and prevented a significant rise in the total U.S. nitrogen trade deficit, while tempering oversupply development in the domestic nitrogen and phosphate markets.

Significant restructuring continued to be experienced in the U.S. ammonia industry during 1989 as evidenced by a flurry of activity in the areas of acquisition and leveraged buyouts that led to further consolidation. Several projects designed to improve energy efficiency and capacity were either completed or in progress.

The U.S. ammonia industry experienced one of its more pronounced

TABLE 1

SALIENT AMMONIA STATISTICS[1]

(Thousand short tons of contained nitrogen unless otherwise specified)

	1985	1986	1987	1988	1989[p]
United States:					
Production	14,236	11,909	[r]13,232	[r]13,827	13,830
Exports	1,010	531	848	642	381
Imports for consumption	2,306	2,048	2,357	3,032	3,154
Consumption, apparent[2]	15,441	13,714	15,193	16,250	16,687
Stocks, Dec. 31: Producers'	1,795	1,507	1,053	1,020	936
Price per ton, yearend, f.o.b. gulf coast[3]	$108	$75	$90	[r]$128	$87
Net import reliance[4] as a percent of apparent consumption	8	13	13	15	17
Natural gas price: Wellhead[5]	$2.51	$1.94	$1.67	[r]$1.69	$1.71
World:					
Production	[r]100,287	[r]100,944	103,879	[p]108,448	[e]109,720
Trade[6]	9,040	7,920	9,080	10,210	[p]10,830

[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 welihead in dollars per thousand cubic feet.

[6]International Fertilizer Industry Association statistics—World Anhydrous Ammonia Trade.

downturns and volatile business cycles during the 1980's. In the early 1980's, domestic commodity businesses were beset by a number of mutual problems, including inordinate energy costs, double digit inflation, global recession, growing international competition, surplus capacity, and rising inventories. The U.S. ammonia industry, in particular, was negatively impacted by prohibitive natural gas feedstock prices, an embargo on U.S.S.R. grain trade, surplus grain inventories, and the emergence of new ammonia capacity in the energy-rich, Government-controlled countries. Obsolete capacity was closed, plants were streamlined, and the industry was restructured. The downcycle ended in 1986, and supply-demand fundamentals gradually improved throughout the remainder of the decade.

DOMESTIC DATA COVERAGE

Domestic production data for anhydrous ammonia were developed by the Bureau of the Census, U.S. Department of Commerce. Preliminary monthly data are published under product code 28731 31 in Current Industrial Reports, Inorganic Fertilizer Materials and Related Products, M28B. Final monthly data are subsequently published in the companion annual report MA28B. The Bureau of the Census surveyed approximately 270 known producers of inorganic fertilizer materials during 1989. Production data are shown in table 1.

LEGISLATION AND GOVERNMENT PROGRAMS

The Natural Gas Wellhead Decontrol Act of 1989, Public Law 101-60, was signed into law on July 26, 1989.[1] This act took the final step in the wellhead decontrol of natural gas by removing those price and nonprice controls that remained in place following the partial wellhead decontrol implemented under the Natural Gas Policy Act of 1978, 15 U.S.C. 3301-3432 (1988). Congress enacted the 1978 legislation in response to severe shortages of gas in the interstate market that occurred in the early to mid-1970's. The act restructured the regulation of natural gas by merging the interstate and intrastate markets, provided for phased deregulation of most "new" (postenactment) gas, and provided for the continued regulation of "old" (preenactment) gas. The Decontrol Act will serve to repeal the remaining controls by January 1, 1993.

The Environmental Protection Agency (EPA) disclosed the first annual Toxic Release Inventory of chemicals discharged to U.S. air, water, and land required under Title III of the Superfund Amendments and Reauthorization Act (SARA), known as the "Emergency Planning and Community Right-to-Know Act." More than 233 million pounds of ammonia was reportedly emitted into the air by industries in 1987. Ammonia emissions were second only to toluene according to the report. Nitric acid, ammonium nitrate, and ammonium sulfate were also included under title III.

The International Trade Commission rescinded an Antidumping Duty Order imposed against Chilean sodium nitrate in 1983.[2] The antidumping duties invoked against sodium nitrate landed by Sociedad Química y Minera de Chile, S.A. (SQM) were to be rescinded, retroactive to March 1, 1987.

DOMESTIC PRODUCTION

U.S. ammonia producers operated at 96% of design capacity in 1989. Ammonia production exceeded design during the spring because of an expected 6%-10% increase in domestic fertilizer consumption. Production declined markedly in the fall in response to a significant buildup in field inventories. Field inventories were exacerbated by record ammonia imports and marginal growth in fertilizer consumption. Approximately 90% of domestic ammonia production was for fertilizer use. Louisiana, Oklahoma, and Texas provided 60% of U.S. ammonia production; the Southeast and Midwest, 15% each; and the Western States, 10%.

Both ammonium nitrate and ammonium phosphate production was up 6%, in 1989. Urea production declined marginally. Ammonium nitrate demand improved because of its use in the popular urea-ammonium nitrate (UAN) fertilizer solutions and ammonium nitrate fuel oil explosives (ANFO). New production and export records were established for ammonium phosphates in 1989. About 3.5 million tons of ammonia was required to meet the demand for ammonium phosphate production. Acrylonitrile and caprolactam performed well in the industrial sector.

Fertilizer Industries was formed during the year and was reported to have become the largest nitrogen solutions producer in the United States, and second only to Farmland Industries in ammonia production. Between May and November, the conglomerate negotiated the purchase of five nitrogen fertilizer producers in six States. The Arcadian Corporation name was adopted, and headquarters were established in Memphis, TN.

TABLE 2

FIXED NITROGEN PRODUCTION IN THE UNITED STATES

(Thousand short tons of contained nitrogen)

	1985	1986	1987	1988	1989[p]
Anhydrous ammonia, synthetic:[1]					
Fertilizer	13,024	10,852	[r]12,019	[r]12,566	12,503
Nonfertilizer	1,212	1,057	[r]1,213	[r]1,261	1,327
Total	14,236	11,909	[r]13,232	[r]13,827	13,830
Byproduct ammonia, coke plants:[2]					
Ammonium sulfate[e]	50	50	50	60	60
Ammonia liquor[e]	5	4	5	5	6
Total[e]	55	54	55	65	66
Grand total	14,291	11,963	13,287	13,892	13,896

[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 (1985-89) based on reported coke production trend.

TABLE 3

MAJOR DOWNSTREAM NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand short tons)

Compound	1985	1986	1987	1988	1989[p]
Urea:					
Gross weight	6,975	6,264	7,433	[r]7,914	7,753
Nitrogen content	3,209	2,881	3,419	[r]3,640	3,566
Ammonium nitrate:					
Gross weight	7,149	6,091	6,547	[r]7,504	7,966
Nitrogen content	2,502	2,132	2,291	[r]2,626	2,788
Ammonium phosphates:[2]					
Gross weight	13,738	11,001	[r]13,352	[r]15,121	16,001
Nitrogen content	2,310	1,861	[r]2,296	[r]2,591	2,721
Ammonium sulfate:[3]					
Gross weight	2,093	2,080	2,189	[r]2,333	2,354
Nitrogen content	440	437	460	[r]490	494
Nitric acid, direct use:[4]					
Gross weight	2,015	1,939	2,069	[r]2,082	1,743
Nitrogen content	448	431	460	[r]463	387
Acrylonitrile:					
Gross weight	1,174	1,157	1,275	1,288	1,304
Nitrogen content	310	305	337	340	344
Caprolactam:					
Gross weight	545	425	580	631	656
Nitrogen content	68	53	72	78	81
Total:					
Gross weight	33,689	28,957	[r]33,445	[r]36,873	37,777
Nitrogen content	9,287	8,100	[r]9,335	[r]10,228	10,381

[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.

The firm purchased the plants of Arcadian Corp. at Geismar, LA, and LaPlatte, NE; Columbia Nitrogen Corp. at Augusta and Savannah, GA; Hawkeye Chemical, Clinton, IA; Nitrex at Memphis, TN, and Wilmington, NC; and Olin Corp., Lake Charles, LA. Arcadian's annual production capabilities were reported to be 2.1 million tons of ammonia, 2.9 million tons as nitrogen solution, and 0.8 million tons as urea and ammonium nitrate. The Geismar, LA, facility was also equipped to produce wet-process phosphoric acid and DAP.

Freeport-McMoRan-Agrico announced plans for the sale of its large nitrogen plants at Blytheville, AR, and Verdigris, OK. A new firm, Agricultural Minerals Corp., was organized by Agrico executives to purchase and run the plants. Big River Inc. was revamping the ammonia plant it had purchased at Helena, AR, and planned to start up late in the year.

El Dorado Chemical Co. purchased American Cyanamid's idle nitric acid plant at Hannibal, MO, and moved the plant and equipment to El Dorado, AR. Ammonium nitrate annual capacity was to increase to 360,000 tons agricultural-grade and 250,000 tons industrial-grade in separate prilling towers. LaRoche Industries Inc. purchased Chevron's idle 550-ton-per-day nitric acid plant at Fort Madison, IA, and moved the unit to its Cherokee, AL facility for nitrogen solutions production. Atlas Powder Co. sold its 230,000-ton-per-year ammonium nitrate plant at Joplin, MO, and associated explosives business to Imperial Chemical Industries of the United Kingdom. Coastal Chemical Co. expanded ammonia, urea, and ammonium nitrate capacity at Cheyenne, WY. A new 320-ton-per-day nitric acid unit, together with a 400-ton-per-day ammonium nitrate plant, was under construction. Coastal was considering a new nitric acid and ammonium nitrate plant near Elko, NV. Unocal Corp. closed its ammonia plant at Brea, CA, and was constructing new ammonium nitrate capacity at West Sacramento, CA.

The Tennessee Valley Authority (TVA) permanently closed ammonia, urea, and ammonium nitrate plants at Muscle Shoals, AL. TVA reportedly planned to sell the plants.

Cargill Ltd. of the United States and the Province of Saskatchewan announced plans for the construction of a 1,500-metric-ton-per-day ammonia plant and a 2,000-metric-ton-per-day urea plant. The Saferco Products joint-venture plant was to be built in Belle Plaine, Saskatchewan, at an estimated cost of $400 million. Construction was scheduled to commence during 1990. Government and industry sources from both Canada and the United States debated the potential impact of major new nitrogen fertilizer capacity development in North America.

CONSUMPTION AND USES

Apparent domestic consumption of ammonia in 1989 was 16.7 million tons N. Of this total, 14.2 million tons N, about 85%, could be accounted for in downstream ammonia conversion products and in direct application ammonia fertilizer. Unaccounted disappearance amounted to 2.5 million tons N and was attributable to miscellaneous applications, shifts in field inventories, process losses, and statistical discrepancies.

Approximately 80% of accountable domestic ammonia conversion products was for fertilizer consumption and export. The remaining 20% was consumed in the industrial sector for synthetic fiber and resin manufacture, explosives use, animal feed supplements, and for the production of a wide variety of organic and inorganic compounds.

Urea is the most popular ammonia conversion compound in domestic use because of its versatility and high analysis (46% N). The material is used

extensively as a fertilizer in both solid and liquid form. UAN liquid blends enjoy a commanding share of the nitrogen fertilizer solutions market. In the industrial sector, urea forms the base for urea-formaldehyde resin adhesives and other polymeric materials and finds extensive use as a nonprotein nitrogen source in ruminate animal feeds.

Ammonium nitrate and ammonium phosphates are second to urea in N use. Ammonium nitrate is used predominately in the fertilizer and explosives sectors. Ammonium phosphates are primary to domestic fertilizer use and export. Nitric acid is used principally for ammonium nitrate production, but about 0.5 million tons, as N, are used for other purposes, including organic chemical synthesis and metal treatment.

Acrylonitrile and caprolactam are used to produce acrylic and nylon fibers, resins, and plastics. Sodium azide (NaN_3) has surfaced as the propellant of choice for air bags, utilized by the U.S. transportation industry for vehicular safety. The material is currently imported, but Virtex Oil & Gas Corp. planned a 2-million-pound-per-year facility at Bristol, VA.

STOCKS

Producer ending inventories did not change between 1988–89 according to available statistics. Field inventories, however, were believed to have increased substantially because of a combination of high domestic capacity utilization, record ammonia imports, and flat domestic fertilizer demand.

TRANSPORTATION

The U.S. Department of Transportation (DOT) reversed an earlier decision to reclassify anhydrous ammonia from a nonflammable gas to a poisonous gas after substantial protest by the public and private sectors. The Research and Special Programs Administration of DOT elected to maintain the current nonflammable classification with the addition of an "INHALATION HAZARD" as a mechanism for hazard communication. DOT, however, extended the response period from October 24,

TABLE 4

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1989

(Thousand short tons per year of ammonia)

Company	Location	Capacity[1]
Freeport-McMoRan (Agrico)	Blytheville, AR[2]	r350
Do.	Donaldsonville, LA	r450
Do.	Verdigris, OK[2]	r950
Air Products and Chemicals Inc.	New Orleans, LA	r290
Do.	Pace Junction, FL	100
Allied Chemical Corp.	Hopewell, VA	r402
American Cyanamid Co.	Fortier, LA	r425
Arcadian Corp.[3]	Augusta, GA	r545
Do.	Clinton, IA	256
Do.	Geismar, LA	352
Do.	Lake Charles, LA	r460
Do.	LaPlatte, NE	r190
Do.	Woodstock, TN	340
Big River, Inc.[4]	Helena, AR[5]	210
Borden Chemical Co.	Geismar, LA	400
Carbonaire Co. Inc.	Palmerton, PA	35
CF Industries Inc.	Donaldsonville, LA	1,590
Do.	Terre Haute, IN	[6]150
Chevron Chemical Co.	El Segundo, CA	20
Do.	Pascagoula, MS[7]	—
Do.	St. Helens, OR	80
Do.	Finley, WA	140
Coastal Chemical Co.[8]	Cheyenne, WY[9]	r200
Cominco American Inc.	Borger, TX[5]	r420
E.I. du Pont de Nemours & Co. Inc.	Beaumont, TX	520
Farmland Industries Inc.	Beatrice, NB	237
Do.	Dodge City, KS	210
Do.	Enid, OK	840
Do.	Fort Dodge, IA	210
Do.	Hastings, NE	[6]140
Do.	Lawrence, KS	r400
Do.	Pollock, LA[5]	420
First Mississippi Corp. (Ampro)	Donaldsonville, LA[5]	400
Green Valley Chemical Corp.	Creston, IA	35
IMC Fertilizer Group Inc.	Sterlington LA	1,050
Jupiter Chemicals	West Lake, LA	30
LaRoche Industries Inc.	Cherokee, AL	175
Mississippi Chemical Corp.	Yazoo City, MS[5]	r473
Monsanto Co.	Luling, LA[5]	460
Occidental Chemical Co.	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.	Lima, OH[5]	r530
Tennessee Valley Authority[11]	Muscle Shoals, AL	71
Terra International Inc.	Port Neal, IA	230
Do. (Oklahoma Nitrogen)	Woodward, OK	450
Triad Chemical Co.	Donaldsonville, LA	364

See footnotes at end of table.

TABLE 4—Continued

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1989

(Thousand short tons per year of ammonia)

Company	Location	Capacity[1]
Union Chemical Co. (Unocal)	Kenai, AK	1,200
Do.	Brea, CA[11]	280
Wil-Grow Fertilizer Co.[10]	Pryor, OK	94
Total		r17,606

r Revised.
[1] Engineering design capacity adjusted for 340 days per year of effective production capability.
[2] In late November, Freeport-McMoRan announced plans to sell Blytheville, AR-Verdigris, OK plants.
[3] Plants purchased late May through early November by Fertilizer Industries, holding company for the Sterling Group and Unicorn Venture Funds.
[4] Closed March 1989; expected on-stream early 1990 under new ownership.
[5] Revamp-Retrofit.
[6] Plant idle.
[7] Large 530,000 ton per year plant idle for over 2 years; status indefinite.
[8] Wycon Chemical Co. assumed parent company's name, midyear.
[9] Expansion; 35,000 tons per year.
[10] Former N-Ren Corp. plants acquired by Great American Management and Investment, August 1987.
[11] Plant closed midyear.

Source: Economics and Marketing Research Section, Tennessee Valley Authority. World Fertilizer Capacity, Ammonia. Muscle Shoals, AL, Dec. 1989.

1989, to January 30, 1990, following a joint request by the Railway Labor Executives' Association and the Environmental Policy Institute/Friends of the Earth. The status of DOT's plans to formulate a final decision on the issue was indefinite.

Opponents of the original reclassification supplied information that showed anhydrous ammonia retail prices rising by at least $10 per ton as a result. In addition to a direct price increase at the retail level, the U.S. farmer would have absorbed an added cost in transporting anhydrous ammonia to the farmgate.

Ammonia is transported by rail, truck, refrigerated barge, and pipeline. Koch Industries was operating the Gulf Central Pipeline it purchased in 1988. The 1,900-mile pipeline extends from

TABLE 5

CONSUMPTION TRENDS FOR MAJOR NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand short tons of contained nitrogen)

	1985	1986	1987	1988	1989[p]
Fertilizer materials:					
Urea:					
Solid	1,746	1,529	1,904	r2,028	1,930
Solution	1,156	1,033	1,137	r1,201	1,208
Total	2,902	2,562	3,041	r3,229	3,138
Ammonium phosphates[2]	2,310	1,861	r2,296	r2,591	2,721
Ammonium nitrate:					
Solid	850	623	626	r776	782
Solution	1,198	963	r1,012	r1,193	1,265
Other[3]	7	43	r53	r10	104
Total	2,055	1,629	r1,691	r1,979	2,151
Ammonium sulfate:					
Synthetic and byproduct	440	437	460	r490	494
Coke oven byproduct[e]	52	47	51	59	60
Total	492	484	511	549	554
Total fertilizer	7,759	6,536	r7,539	8,348	8,564
Nonfertilizer materials:					
Urea:[2]					
Feed	131	107	142	r171	98
Industrial	175	212	237	r241	331
Total	306	319	379	r412	429
Ammonium nitrate[2]	447	503	600	r647	637
Nitric acid	448	431	460	r463	387
Acrylonitrile	310	305	337	340	344
Caprolactam	68	53	72	78	81
Total nonfertilizer	1,579	1,611	1,848	1,940	1,878
Grand total[4]	9,339	8,147	r9,386	r10,287	10,441

[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.

Source: Current Industrial Reports, MA28B and M28B, Bureau of the Census, and International Trade Commission.

TABLE 6

U.S. NITROGEN FERTILIZER CONSUMPTION, BY PRODUCT TYPE[1]

(Thousand short tons nitrogen)

Fertilizer material[2]	1988[r]	1989[p]
Single-nutrient:		
Anhydrous ammonia	3,772	3,800
Aqua ammonia	95	100
Urea	1,529	1,555
Ammonium nitrate	600	649
Ammonium sulfate	158	173
Nitrogen solutions[3]	2,167	2,051
Other	34	142
Total	8,355	8,470
Multiple-nutrient:[4]	2,157	2,163
Grand Total	10,512	10,633

[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] 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. 1989.

TABLE 7

U.S. PRODUCER STOCKS OF FIXED NITROGEN COMPOUNDS AT YEAREND[1]

(Thousand short tons nitrogen)

Material[2]	1988	1989[p]
Ammonia	1,020	936
Nitrogen solutions[3]	401	442
Urea	170	171
Ammonium phosphates[4]	124	138
Ammonium nitrate	33	64
Ammonium sulfate	49	53
Total	1,797	1,804

[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.

the gulf coast into the Midwest, as far north as Iowa. About 3 million tons of ammonia can be transported and stored along its length annually. Mid-America Pipeline Co. (Mapco) was operating a 1,000-mile pipeline that extended from Oklahoma to Minnesota. The Mapco system transports about 1 million tons of ammonia annually. Seminole Fertilizer Corp. and the Royser Co. operate a joint-venture ammonia pipeline that serves ammonium phosphate producers in Florida. IMC Fertilizer Group Inc. operates a second ammonia pipeline in Florida for the same purpose.

PRICES

Prices for nitrogen products in all forms were firm during the first quarter of 1989. Ammonia prices declined significantly during the second quarter and approached cash costs by mid-May. Urea prices followed a similar trend. Ammonia and urea prices began to improve moderately during the fourth quarter.

Ammonium nitrate was in tight supply for much of the year, and prices were firm through August, after which there was a gradual downturn. DAP prices remained firm through early April, but trended downwards for the remainder of the year.

FOREIGN TRADE

The U.S. Department of Commerce, Bureau of the Census, adopted the new international Harmonized Commodity Description and Coding System (Harmonized System), effective January 1, 1989. The Harmonized System was designed to standardize product codes for items traded in international commerce. Fertilizer and industrial grades of anhydrous ammonia and ammonium nitrate could no longer be distinguished because they were each reported under one code (fertilizer). Several other nitrogen classifications formerly grouped under one code were subdivided.

Total suppression of anhydrous ammonia export and import tonnage data was effected by the Bureau of the Census on January 1, 1989, following the review of a complaint filed by a domestic fertilizer producer. The producer believed that U.S.S.R. ammonia import price information that could be calculated from trade statistics was proprietary and should be withheld from the public domain. Value data by country continued to be reported. The U.S. Fertilizer Institute, the Canadian Fertilizer Institute, industry sources, and the Bureau of Mines worked cooperatively with the Bureau of the Census to develop a base for judging ammonia trade. Tables 9 and 10 were developed as a result of that effort. Late in the year, the Bureau of the Census announced that anhydrous ammonia export and import tonnage data would again be made available to the public in 1990. U.S.S.R. ammonia import tonnage data, however, continued to be suppressed.

The United States experienced a record ammonia trade deficit of 3.4 million tons during 1989. Ammonia

TABLE 8

PRICE QUOTATIONS FOR MAJOR NITROGEN COMPOUNDS AT YEAREND

(Per short ton product)

Compound	1988	1989
Ammonium nitrate: F.o.b. Corn Belt	$128-$135	$105-$115
Ammonium sulfate: Do.	95- 105	100- 120
Anhydrous ammonia:		
F.o.b Corn Belt	143- 150	110- 115
F.o.b. gulf coast[1]	126- 129	86- 88
Diammonium phosphate: F.o.b. central Florida	165- 173	125- 126
Urea:		
F.o.b. Corn Belt, prilled	150- 155	110- 120
F.o.b. gulf coast, granular[1]	153- 155	115- 117
F.o.b. gulf coast, prilled[1]	139- 145	98- 105

[1] Barge, New Orleans.

Source: Green Markets, Fertilizer Market Intelligence Weekly, Dec. 26, 1988, and Dec. 25, 1989.

TABLE 9

U.S. EXPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand short tons ammonia)[1]

Country	1988	1989[p]
Korea, Republic of	343	171
South Africa, Republic of	101	160
Belgium	94	29
Denmark	—	23
France	—	22
Norway	75	—
Japan	—	23
Morocco	20	—
Tunisia	39	—
Brazil	21	—
Other[2]	88	35
Total	781	463

[p] Preliminary.
[1] Value data suppressed by Bureau of the Census.
[2] Twenty-six countries; principally: El Salvador, Venezuela, Costa Rica, Trinidad, Canada, Spain, Taiwan, and Mauritius.

Source: Bureau of the Census (1988); Bureau of the Census and The Fertilizer Institute (1989).

exports declined by 40% and dipped to 0.46 million tons, whereas ammonia imports reached a record 3.84 million tons. A major disruption in world ammonia trade patterns was precipitated in 1989 when India rejected an increase in Moroccan phosphoric acid prices and declined to take the product used to produce domestic supplies of ammonium phosphates. Ammonia shipments from the Persian Gulf that would have normally been landed in India were diverted to the United States and other countries. About 240,000 tons of ammonia was shipped from the Persian Gulf to the United States, a 330% increase over that of 1988. Kuwait and Bahrain, countries that were believed to have never landed ammonia in the United States, accounted for more than 160,000 tons of the total. Ammonia imports from Trinidad also increased substantially. Many industry analysts believed that domestic ammonia oversupply and deteriorating prices were exacerbated by the suppression of U.S. ammonia trade data in 1989.

Overall, the U.S. total nitrogen trade deficit in 1989 was 1.6 million tons N, a moderate 3% improvement over that of 1988. The total nitrogen trade deficit peaked at 2.2 million tons in 1986. Record U.S. export shipments of DAP during 1989 were fortuitous and prevented a significant increase in the total N deficit position. India negotiated record tonnages of U.S. DAP in response to its phosphoric acid price standoff with Morocco. China also imported record tonnages of U.S. DAP.

Urea antidumping actions imposed in 1987 against the German Democratic Republic (GDR), Romania, and the U.S.S.R. protected U.S. producers from unfair trade practices. The GDR was the only country in this group reported to land urea in 1989. According to Bureau of the Census data, the GDR shipped 11,434 tons of urea to the Baltimore, MD, Customs District.

WORLD REVIEW

Global ammonia production exceeded 133 million tons in 1989, establishing a new record. Production facilities in 71 countries provided the vast quantities of ammonia required to supply Earth's 5 billion inhabitants with food and fiber and industrial products. Asia and Eastern Europe commanded 62% of the global ammonia market; North America and Western Europe, 25%; and Latin America and the Middle East, about 10%. Approximately 88% of world ammonia disappearance was for nitrogen fertilizers, and about 12% was for industrial products. About 40% of world ammonia production was converted to urea, and another 10% was traded. International trade of synthetic nitrogen materials in all forms accounted for about 30% of total world ammonia demand.

The ammonia industry operated at 83% of design capacity in 1989, one percentage point below the prior year, and indicative of a relatively soft market. Ammonia production increased 1.5 million tons (1%) between 1988 and 1989, modest in comparison with the 9.1 million ton, 4% average annual growth experienced between 1986 and 1988. Major growth in supply capability has occurred in the centrally planned economies and in other energy-rich, Government-controlled countries during the past decade, whereas negative growth was experienced in the developed economies of North America, Western Europe, and Japan.

Population explosion and feedstock availability have been major factors for capacity development and demand in the developing nations. China and In-

TABLE 10

U.S. IMPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand short tons ammonia)[1]

Country	1988		1989[e p]	
	Gross weight	Value[2] (thousands)	Gross[1] weight	Value[2] (thousands)
Canada	1,571	$140,131	[3] 1,428	[3 4] $136,308
Trinidad and Tobago	618	66,599	795–980	92,270
U.S.S.R.	943	91,150	886–898	84,028
Mexico	346	34,512	253–268	22,830
Venezuela	34	3,577	31–57	3,578
Kuwait	—	—	99–133	14,644
Saudi Arabia	56	5,322	61–75	7,166
Bahrain	—	—	32	4,230
Other[5]	121	13,956	26–69	[6] 22,498
Total	3,689	355,247	[7] 3,714–[8] 3,837	387,552

[e] Estimated. [p] Preliminary.
[1] Tonnage data suppressed by Bureau of Census effective Jan. 1, 1989; alternate sources as described.
[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] Fifteen countries.
[6] 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).
[7] Sum of data reported by The Fertilizer Institute.
[8] Sum of data reported by Bureau of Mines.

Sources: Bureau of the Census, 1988. Bureau of the Census, The Fertilizer Institute, Bureau of Mines, and Statistics Canada: 1989.

dia compose 40% of world population and are notable examples. Indonesia provided significant quantities of nitrogen fertilizers for domestic use and export. The U.S.S.R. and other Eastern European countries produced ammonia for domestic use and generated strategic supplies of hard currency in the export market.

Significant growth in ammonia supply capability has developed in the Persian Gulf countries where abundant reserves of natural gas feedstock are available. Natural gas was once considered an insignificant byproduct of petroleum production in the Persian Gulf and was commonly flared. Today, natural gas is used to produce value-added ammonia and petrochemical products and liquefied natural gas (LNG) that generate foreign exchange. Iran and Iraq were poised to capture an increasing share of the ammonia market following the signing of a peace accord in 1988.

Ammonia plants in Trinidad and Tobago were strategically positioned to land ammonia in North America and Western Europe. Canada shipped major quantities of ammonia and finished fertilizers to the United States, while Mexico shipped surplus ammonia to the United States.

Capacity

The data in table 12 are rated capacity for ammonia plants 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.

World anhydrous ammonia capacity stood at 160 million tons by yearend. Approximately 2 million tons of new capacity came on-stream in 1989, and about 1 million tons of obsolete capacity was permanently closed. Another 5 million tons of ammonia capacity was scheduled to come on-stream during 1990 and 1991. The major feedstock sources for ammonia production were natural gas, naphtha, fuel oil, and re-

TABLE 11

U.S. EXPORTS AND IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1989

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
EXPORTS			
Fertilizer materials:			
Ammonium nitrate[2]	145	49	NA
Ammonium sulfate[2]	853	179	NA
Anhydrous ammonia	463	381	NA
Diammonium phosphate	9,141	1,645	NA
Monoammonium phosphate	892	98	NA
Nitrogen solutions	283	85	NA
Sodium nitrate	2	(3)	NA
Urea	1,257	578	NA
Mixed chemical fertilizers[4]	327	51	NA
Other ammonium phosphates[5]	23	4	NA
Other nitrogenous fertilizers[6]	183	7	NA
Total	13,569	3,077	NA
Industrial chemicals:			
Ammonia, aqua (ammonia content)	29	24	$1,827
Ammonium compounds[7]	2	1	3,628
Ammonium phosphate (ortho)	1	(3)	1,197
Potassium cyanide	2	(3)	2,673
Sodium cyanide	62	18	71,424
Other cyanides and cyanates	1	(3)	3,395
Hydrazine, hydroxylamine, and related inorganic salts	14	7	24,299
Bismuth-silver nitrates	(3)	(3)	8,918
Potassium nitrate	11	2	4,223
Other nitrates	31	6	7,812
Nitric-sulfonitric acids	36	5	19,150
Nitrites	2	(3)	2,266
Total[8]	192	64	150,813
Grand total[8]	13,760	3,141	NA
IMPORTS			
Fertilizer materials:			
Ammonium nitrate[2]	453	152	$48,396
Ammonium nitrate-limestone mixtures	12	3	1,155
Ammonium sulfate[2]	336	71	27,827
Anhydrous ammonia[9]	3,837	3,154	387,552
Calcium nitrate	e98	e15	11,637
Diammonium phosphate	16	3	3,903
Monoammonium phosphate	33	4	10,524
Nitrogen solutions	656	197	60,112
Potassium nitrate	41	5	10,953
Potassium nitrate-sodium nitrate mixtures	44	7	5,453
Sodium nitrate	165	26	20,009
Urea	2,174	1,000	262,407
Mixed chemical fertilizers[4]	214	26	28,523
Other ammonium phosphates[5]	57	9	9,529
Other nitrogenous fertilizers[6]	190	32	32,807
Total[8]	8,325	4,702	920,785

See footnotes at end of table.

TABLE 11—Continued

U.S. EXPORTS AND IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1989

(Thousand short tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
IMPORTS—Continued			
Industrial chemicals:			
Ammonia, aqua (ammonia content)	e62	e51	4,939
Ammonium compounds[7]	14	3	23,800
Calcium cyanamide	1	(3)	431
Potassium cyanide	2	(3)	3,830
Sodium cyanide	29	8	46,736
Other cyanides and cyanates	10	3	11,735
Hydrazine, hydroxylamine, and related salts	4	2	6,221
Bismuth/silver nitrates	(3)	(3)	4,750
Strontium/other nitrates	2	(3)	1,645
Nitric/sulfonitric acids	11	2	2,045
Sodium-other nitrites	4	1	2,259
Total[8]	138	71	108,392
Grand total[8]	8,464	4,773	1,029,177

e Estimated. NA Not available

[1] Export values f.o.b.; Import values c.i.f.

[2] Includes industrial chemical products.

[3] Less than 1/2 unit.

[4] Harmonized codes 3105.10.0000 and 3105.20.0000.

[5] Codes 3105.51.0000, 3105.59.00 (exports and imports); 3105.40.0050 (imports).

[6] Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, 3102.90.0000 (exports and imports); 3105.90.0050 (imports).

[7] Carbonates, chloride, fluorides, and tungstate (exports and imports); bromide, molybdate, orthophosphate, and perrhenate (imports).

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

[9] Anhydrous ammonia tonnage data as reported by Bureau of Mines; value data, Bureau of Census. Includes industrial ammonia.

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).

finery off gases and condensates. Other sources included coal gasification, coke oven gases, and electrolysis.

In Canada, ammonia plants totaling 530,000 annual tons were closed by Glacier Ammonia Ltd. at Pincher Creek, Alberta, and by C-I-L Inc. at Courtright, Ontario. Cyanamid Canada Inc. planned to close its 220,000-ton-per-year plant at Welland, Ontario, in 1990. Cargill Limited of the United States and the Province of Saskatchewan let bids for a $400 million ammonia and urea plant at Belle Plaine, Saskatchewan.

China brought 360,000 annual tons on-stream at Puyang, Hunan, and added 130,000 tons in small plants at various locations. China planned to start up 320,000 tons of small plant capacity in 1990–91 and 360,000 tons at Heijiang, Sichuan, in 1991. In Indonesia, Kaltim started up 360,000 tons at Bontang and PURSI let contracts for 500,000-ton ammonia and 650,000-ton urea plants at Palembang. In India, Nagarjuna Fert. was to open 330,000 tons at Kakinada in early 1991. In Bangladesh, Jamuna Fert. Co. was to start up 390,000 tons at Jamalpur in late 1991. In the Republic of Korea, Yong Nam closed 120,000 tons at Ulsan in 1989.

Iran was to commence operation of two revamped 360,000-ton-per-year plants at Bandar Khomeni in 1989 and 1990. Iraq was to bring a 360,000-ton plant into operation at Baiji. In Turkey, a 360,000-ton plant was to be brought on-stream by Tugas at Gemlik in late 1990. Libya was to restart its damaged 440,000-ton plant at Marsa-El-Brega in early 1991.

The U.S.S.R. plan to bring 520,000 annual tons on-stream at Rovno, Ukraine, in 1990. Several debottlenecking projects were under way that would result in the addition of another 390,000 tons of capacity during 1991.

In Egypt, SEMADCO was to bring

TABLE 12

WORLD ANHYDROUS AMMONIA ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand short tons per year of ammonia)

	Rated capacity[1]
North America:	
Canada	4,700
United States	17,606
Total	[2]22,310
Latin America:	
Argentina	90
Brazil	1,380
Colombia	170
Cuba	440
Mexico	3,290
Peru	180
Trinidad and Tobago	1,950
Venezuela	900
Total	8,400
Europe, Western:	
Austria	570
Belgium	530
Finland	90
France	2,470
Germany, Federal Republic of	2,880
Greece	470
Iceland	10
Ireland	510
Italy	2,100
Netherlands	4,250
Norway	610
Portugal	450
Spain	960
Switzerland	60
United Kingdom	2,230
Total	18,190
Europe, Eastern:	
Albania	100
Bulgaria	1,830
Czechoslovakia	1,110
German Democratic Republic	2,070
Hungary	1,090
Poland	3,020
Rumania	5,120
U.S.S.R.	33,790
Yugoslavia	1,630
Total	49,760
Africa:	
Algeria	1,130
Egypt	1,150
Libya	380

See footnotes at end of table.

TABLE 12—Continued

WORLD ANHYDROUS AMMONIA ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand short tons per year of ammonia)

	Rated capacity[1]
Africa—Continued	
Nigeria	380
South Africa, Republic of	830
Zambia	60
Zimbabwe	70
Total	4,000
Asia:	
Afghanistan	80
Bangladesh	1,100
Burma	280
China	25,660
India	11,630
Indonesia	3,840
Japan	2,320
Korea, North	1,200
Korea, Republic of	1,060
Malaysia	380
Pakistan	1,680
Taiwan	340
Vietnam	70
Total	49,640
Middle East:	
Abu Dhabi	380
Bahrain	450
Iran	870
Iraq	810
Israel	90
Kuwait	1,120
Qatar	670
Saudi Arabia	1,170
Syria	380
Turkey	820
Total	6,760
Oceania:	
Australia	730
New Zealand	100
Total	830
Total world	159,890

[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, Bureau of Mines, and International Fertilizer Industry Association (IFA).

150,000 tons per year into production at Suez in 1990. A 360,000-ton plant was due on-stream at Abu Qir in early 1991.

Kemira opened a new 280,000-ton-per-year plant at Hull, United Kingdom in mid-1989 and ICI closed 560,000 tons of annual capacity at Billingham and Severnside.

FERTRIN planned to debottleneck its plant at Point Lisas, Trinidad, adding 140,000 tons per year of capacity by 1992. In Chile, a joint-venture project between Kap Resources Ltd. and Atacama Resources Ltd, of Vancouver, Canada, was formed to exploit nitrate deposits in the Atacama Desert. North Lily Mining Co. of San Bruno, CA, was to operate the project. Davy McKee determined that the Yolanda deposit contained in excess of 20 million tons of "caliche" grading 11.8% sodium nitrate. Additional reserves were expected to be discovered on the property. Sodium nitrate and sodium nitrate-potash chemicals were to be produced.

CURRENT RESEARCH

The M. W. Kellogg Co. of Houston, TX, placed the first large-scale, centrifugal compressor ammonia plant in service in July 1965. The early plants cut ammonia production costs in half and began to replace the smaller and less efficient reciprocal compressor plants. Since that time, the Kellogg large-capacity, single-train ammonia plant design has been used in plants responsible for about one-half of the world's new fertilizer ammonia output.[3]

Kellogg has recently introduced a new Reduced Energy Ammonia Process that is expected to have a similar revolutionary impact on the nitrogen fertilizer industry worldwide. The total energy requirement is less than 25 million British thermal units (Btu) per ton of ammonia and represents a 25% improvement over feed-plus-fuel values found in conventional plants. Because the feed value is fixed at 18 million Btu per short ton, a 50% savings in the fuel requirement is realized. Kellogg to date has built Reduced Energy Ammonia Process plants in Canada, Belgium, and the Netherlands.

Kinetics Technology International (KTI), Monrovia, CA, has licensed the revolutionary new Leading Concept Ammonia (LCA) process developed by Imperial Chemical Industries (ICI) of the United Kingdom. The LCA process has been hailed as the most significant breakthrough in small-scale ammonia plant technology in the past quarter century. The total energy requirement for a 500-ton-per-day plant was demonstrated to be 25.2 million Btu per ton. The LCA process separates the ammonia manufacturing operations from the utilities section of the plant, resulting in a low-cost, flexible design.[4]

Deshen International Inc. of Newton, MA, was developing novel technology based on the Birkeland and Eyde electric arc nitrogen fixation process fostered in Norway at the turn of the century. Mr. Mosche Alamaro, Deshen President and Principal Scientist, gave a number of seminars on the subject during 1989. An electric arc in air causes ionization of the nitrogen and oxygen. These charged particles are accelerated by the electric and magnetic fields, resulting in heating of the air. When the temperature of the air rises to 3500 degrees Kelvin, it becomes, according to chemical equilibrium, a mixture including about 5.25% nitric oxide (NO). Rapid cooling results in a solution of nitric acid.

Mr. Alamaro proposed building portable electric arc plants for use in areas where low-cost electricity could be obtained during off peak periods. Deshen reported the potential for the production of nitrogenous fertilizers in several forms using an ammonia-free electric arc process. Mr. Alamaro pointed out that in some respects the process was still in its infancy, allowing for technological breakthroughs in the 1990's that could lead to a competitive advantage for the U.S. industry.[5]

OUTLOOK

World ammonia supplies are expected to be more than adequate to meet global nitrogen demand during the period 1990–95. Ammonia demand in the past has tracked population growth, and this trend is expected to continue. The forecast was developed by taking into account supply and demand projections of the Food and Agriculture Organization of the United Nations (FAO), the International Fer-

TABLE 13

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons of contained nitrogen)

Country	1985	1986	1987	1988[p]	1989[e]
Afghanistan[e]	50	44	44	44	44
Albania[e]	88	88	88	88	88
Algeria	[e]165	[e]165	192	217	[2]145
Argentina	72	69	79	86	[2]82
Australia	446	375	456	425	440
Austria[e]	550	495	495	495	490
Bahrain	121	318	304	340	340
Bangladesh	395	430	480	742	830
Belgium	428	337	296	402	[2]320
Brazil	1,042	972	1,049	1,031	[2]1,079
Bulgaria	1,254	1,203	1,180	[r e]1,160	1,160
Burma	139	147	130	[r e]140	130
Canada	3,280	3,208	3,182	3,636	[2]3,673
China[e]	16,500	[r]17,100	16,000	[r]17,900	18,700
Colombia	110	103	98	93	[2]101
Cuba	180	180	164	149	165
Czechoslovakia	895	838	855	[e]850	848
Egypt	754	789	869	[e]830	830
Finland	72	[r]74	55	47	55
France	2,217	2,229	2,237	[r e]2,020	1,630
German Democratic Republic	1,329	1,315	1,296	1,274	1,270
Germany, Federal Republic of	2,103	1,731	2,129	1,929	1,650
Greece	268	266	280	290	250
Hungary	871	840	867	761	830
Iceland	8	9	10	10	9
India[3]	4,707	5,438	5,842	[e]6,840	7,400
Indonesia	2,268	2,534	2,606	2,609	[2]2,785
Iran	30	73	131	160	[2]370
Iraq[e]	66	66	66	345	[2]522
Ireland	[r]373	391	440	460	440
Israel	63	63	68	63	66
Italy	[r]1,339	[r]1,712	1,582	1,720	[2]1,594
Japan	1,814	1,662	1,715	1,680	1,700
Korea, North[e]	500	500	500	500	500
Korea, Republic of	487	470	523	558	[2]529
Kuwait	356	497	637	530	[2]733
Libya	453	388	386	[e]300	[2]230
Malaysia	59	276	354	331	[2]307
Mexico	2,049	1,766	1,922	2,279	2,310
Netherlands	2,773	2,968	3,117	3,258	[2]3,308
New Zealnad	80	80	[e]80	[e]80	83
Nigeria	—	—	142	342	350
Norway	505	330	383	467	[2]421
Pakistan	1,220	[r]1,273	1,300	1,325	1,320
Peru[e]	94	110	88	105	100
Philippines	[e]19	—	—	—	—
Poland	1,997	2,341	2,400	[e]2,425	2,425
Portugal	170	130	171	210	190

See footnotes at end of table.

TABLE 13—Continued

AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons of contained nitrogen)

Country	1985	1986	1987	1988[p]	1989[e]
Qatar	578	600	618	657	660
Romania	3,175	3,352	3,073	[r e]3,090	2,870
Saudi Arabia	481	514	702	956	965
Somalia[e]	[r]29	[r]17	[r]8	—	—
South Africa, Republic of[e]	[r]640	[r]640	[r]600	520	[2]502
Spain	664	512	495	525	[2]608
Sri Lanka	6	—	—	[e]—	—
Sweden	20	51	37	—	—
Switzerland[e]	34	33	43	39	39
Syria	146	151	102	87	[2]135
Taiwan	228	292	268	307	225
Tanzania[e]	([4])	([4])	([4])	([4])	—
Trinidad and Tobago	[r]1,190	1,258	1,243	1,528	1,700
Turkey	239	218	365	311	330
U.S.S.R.	20,172	21,605	22,050	[r e]22,160	22,160
United Arab Emirates	311	[r]321	333	330	[2]357
United Kingdom	1,948	1,530	1,560	1,218	[2]1,143
United States[5]	14,236	11,909	[r]13,232	[r]13,827	[2]13,830
Venezuela[e]	452	530	[r]580	[2]481	[2]586
Vietnam[e]	40	40	40	40	40
Yugoslavia	844	897	1,033	946	750
Zambia	19	27	37	18	22
Zimbabwe	76	54	59	71	[2]68
Total	[r]100,287	[r]100,944	103,879	108,448	109,720

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through May 30, 1990.
[2] Reported figure.
[3] Data are for years beginning Apr. 1 of that stated.
[4] Revised to zero.
[5] Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

tilizer Industry Association Limited (IFA), and Wharton Econometric Forecasting Associates (WEFA). Steady-state conditions were assumed for weather and macroeconomic trends, demographics, and geopolitics.

During the period 1985–90, the growth in demand slightly exceeded the growth in supply capability. Demand averaged 2.1% per year, while supply capability averaged 1.5% per year. Population growth averaged 2.0% per year. The forecast period shows a reversal in the historical trend with growth in supply capability slightly outpacing the anticipated growth in demand. Supply capability is forecast to grow at an average annual rate of 2.5% between 1990–95 and demand at 1.9%. This trend is indicative of a surplus supply situation during the forecast period. Population growth is forecast to average 1.9% per year, in line with the expected growth in demand.

New ammonia capacity will come on-stream predominately in Asia, Eastern Europe (U.S.S.R.), and the Middle East, in order of importance. The brunt of growth in world demand will be concentrated in Asia and Eastern Europe (U.S.S.R.), followed by selected countries in the Middle East, Africa, and Latin America. Western Europe may experience a moderate decline in demand.

Domestic nitrogen fertilizer consumption in the United States was expected to reach 11.0 million tons N in 1990, a 4% increase. Industry analysts were forecasting 11.2 million tons N consumption for 1991, a 2% increase. The U.S. farm economy has experienced dramatic recovery since 1985. Net cash farm income now stands at about $55 billion, and there is a good balance between planted and idled acreage. Planted acreage was expected to approximate 332 million acres in 1990 and 1991, and was projected to range between 330 to 340 million acres in the future. Domestic demand in the industrial sector should continue to grow at an average annual rate of 2%–3% between 1990–95.

A continued resurgence in the U.S. nitrogen sector will be critically dependent upon a number of strategic domestic and international issues and events that unfold during the 1990's. Farm legislation to be enacted in 1990 will establish new domestic agricultural fundamentals for most of the decade. Natural gas deregulation mechanisms will determine the economics and availability of feedstock for domestic ammonia production. Clean air and ground water legislation will influence

TABLE 14

WORLD ANHYDROUS AMMONIA SUPPLY-DEMAND RELATIONSHIPS[1]

(Million short tons nitrogen)

	1985	1986	1987	1988	1989[e p]	1990[2]	1991[2]	1992[2]	1993[2]	1994[2]	1995[2]
Capacity[3]	122.9	125.8	126.4	129.9	131.4	132.3	135.0	137.9	141.5	142.6	144.9
Demand:[4]											
Fertilizer	88.7	89.7	92.4	96.8	98.0	98.9	100.9	102.9	104.8	106.7	108.4
Industrial	11.6	11.2	11.5	11.6	11.7	11.8	11.9	12.1	12.3	12.5	12.6
Total	100.3	100.9	103.9	108.4	109.7	110.7	112.8	115.0	117.1	119.2	121.0
Operating rate[5]	82%	80%	82%	83%	83%	84%	84%	83%	83%	84%	84%
Consumption:											
Pounds per capita[6]	41.8	41.2	41.6	42.5	42.2	41.8	41.8	41.8	41.8	41.8	41.7
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.
[1] Calendar years.
[2] Forecast
[3] Design capacity, 340 days-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 1989; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, Bureau of Mines.

domestic production economics and agricultural practices. The impact of consolidation in the European Community in 1992 and the profound restructuring in the Eastern European countries present both problems and opportunities. Capacity development in the energy-rich, Government-controlled sectors will affect supply-demand fundamentals.

BACKGROUND

Nitrogen is mined from the atmosphere through cryogenic air separation and membrane technologies. The global industrial nitrogen gas sector is significant, and in the United States alone, an annual 26-million-ton, $0.7 billion industry has developed. Industrial nitrogen gas and liquid nitrogen find a variety of uses in the metals, chemicals, electrical, aerospace, food, and cryogenic sectors.

By the early 1900's, global demand for food and fiber had begun to outstrip nature's available supply of fixed nitrogen. World population had doubled in less than a century and approached 2 billion. Fortunately, a major technological breakthrough involving the direct synthesis of ammonia from air and hydrocarbons materialized in Germany. The Haber-Bosch process revolutionized the concept of synthetic fixed nitrogen manufacture and fostered the technology responsible for today's economic production of ammonia on a large-scale basis.

The basic process for producing ammonia involves the catalytic reaction of a hydrocarbon, usually natural gas, with steam and air to produce hydrogen and nitrogen in the proper ratio to effect ammonia (NH_3) synthesis.

Natural gas is desulfurized and reacted catalytically with steam and then air at about 500 psig to produce raw synthesis gas in a primary and secondary reforming operation. Air is introduced into the secondary reformer in an amount required for ammonia synthesis.

Raw synthesis gas flows to a two-stage carbon monoxide (CO) shift converter for further production of hydrogen. The combined use of high and low temperature shift catalysts permits residual CO to be converted to carbon dioxide (CO_2). The gas is then treated with a regenerative solution for CO_2 removal using physical absorption techniques. Methanation is then effected to convert residual carbon oxides to methane.

Methane is removed, along with argon, from the air in a purge stream from the synthesis loop. Final purification includes the use of molecular sieve drying. The purified synthesis gas is then compressed and mixed with synthesis loop recycle gas. The combined flow after additional compression is delivered to the synthesis loop where it is converted to ammonia in a horizontal catalytic reactor. Nominal operation pressures are 2000 psig and 3000 psig. Mechanical refrigeration, using ammonia as refrigerant, is used to condense the product ammonia.

Economic Factors

The data of table 15 provide historical trends in ammonia prices f.o.b. plant, natural gas feedstock prices at the wellhead, and their mathematical relationship. Ammonia production costs are variably dependent upon natural gas feedstock prices which account for about 70% of the total. Ammonia market prices and indicative profitability are dependent upon natural gas prices, energy efficiency, and market forces.

Ammonia prices experienced a generally upward trend between 1970 and the early-1980's. The cyclical trends in prices are indicative of market conditions and the degree of profitability, and natural gas prices. Ammonia prices and profit margins reached record proportions in 1974–75 when ammonia was in extremely short supply. A firm balance between supply and demand during 1980–81 led to another surge in prices and profitability. Prices trended downwards for

67the remainder of the decade and profit margins were generally weak in spite of declining natural gas prices.

Energy efficiency in the U.S. ammonia industry has been significantly improved during the past 10 years through the closure of obsolete plants and through revamps and retrofits of existing plants. The decline in ammonia-natural gas price ratios between 1970 and the early-1980's demonstrated the sensitivity of ammonia costs to rising natural gas prices. The ratio leveled in 1982 and has been relatively constant since. A return to favorable profit margins in the U.S. ammonia industry will be dependent upon an improvement in world nitrogen supply-demand fundamentals.

[1] Federal Register. Federal Energy Regulatory Commission (Dep. Energy). Order Implementing the Natural Gas Wellhead Decontrol Act of 1989; Final Rule. V. 55, No. 80, Apr. 25, 1990, pp. 17425-17431.

[2] ———. International Trade Administration/Import Administration (Dep. Commerce). Sodium Nitrate From Chile; Final Results of Changed Circumstances Administrative Review and Revocation of Antidumping Duty Order. V. 54, No. 67, Apr. 10, 1989, p. 14264.

[3] The M. W. Kellogg Co. The Reduced Energy Ammonia Process, 1989.

[4] Kinetics Technology International. Ammonia Technology for the 1990's, 1989.

[5] Alamaro, M. (Deshen International Inc.). Private Communication, 1989-90; available upon request from Deshen International Inc., Box 128, Newton, MA 02159.

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TABLE 15

TIME-PRICE RELATIONSHIPS FOR U.S. AMMONIA AND NATURAL GAS

(Dollars per ton and dollars per million Btu)

Year	Ammonia		Natural gas		Ammonia-natural gas ratio	
	Actual value[1]	Constant 1989 dollars	Actual value[2]	Constant 1989 dollars	Actual value[3]	Constant 1989 dollars
1970	34.00	102.24	0.17	0.51	200	200
1971	34.00	96.72	.18	.51	189	190
1972	35.00	95.06	.19	.52	184	183
1973	43.00	109.72	.22	.56	195	196
1974	93.00	217.52	.30	.70	311	311
1975	148.00	315.22	.44	.94	336	335
1976	107.00	214.17	.58	1.16	184	185
1977	102.00	191.42	.79	1.48	129	129
1978	102.00	178.43	.91	1.59	112	112
1979	107.00	171.94	1.18	1.90	91	90
1980	130.00	191.59	1.59	2.34	82	82
1981	146.00	196.17	1.98	2.66	74	74
1982	141.00	178.08	2.46	3.11	57	57
1983	139.00	168.97	2.59	3.15	54	54
1984	152.00	178.25	2.66	3.12	57	57
1985	140.00	159.44	2.51	2.86	56	56
1986	102.00	113.20	1.94	2.15	53	53
1987	98.00	105.43	1.67	1.80	59	59
1988	105.00	109.33	1.69	1.76	62	62
1989[p]	100.00	100.00	1.71	1.71	58	58

[p] Preliminary
[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.

Sources: Bureau of the Census (ammonia prices); Department of Energy (natural gas prices); Council of Economic Advisors (1989 implicit price deflators for gross national product).

PEAT

By Raymond L. Cantrell

Mr. Cantrell is a physical scientist and has served as the peat commodity specialist since joining the Bureau in June 1988. His professional experience includes 23 years in the private sector. Ms. Maureen Nash, mineral data assistant, monitored the survey and prepared domestic survey data. Ms. Pamela Shorter, mineral data specialist, monitored the survey and collected preliminary survey forms. International data tables were prepared by Ms. Audrey Wilkes, international data assistant. Ms. Jane Willard prepared the peat manuscript for publication.

U.S. peat demand peaked at 1.5 million tons in 1987, following a 4-year period of record growth. Demand improved by an average of 12% per year during the period, eclipsing previous records. Growth in domestic production was also strong, increasing at an average annual rate of 9%.

Domestic peat supply-demand fundamentals weakened in 1988, and the industry experienced a downturn that was still in evidence at the end of 1989. U.S. economic growth slowed, and there was a decline in housing starts and in the development of commercial properties that negatively impacted the domestic peat industry. An increase in competition from commercial composting operations and from recycled yard wastes was also experienced. Twenty-four domestic peat producers out of a total of 103 were idle in 1989.

Canadian sphagnum imports as a percent of total U.S. peat consumption increased 5% between 1985 and 1989, and now command a record 41% share of the market. Minnesota continued to bring in new sphagnum operations at profitable margins: sales were up $0.4 million, 38%, in 1989.

Domestic demand for horticultural peat should gradually regain momentum during the 1990's. New trends are developing in the areas of peat use for electric power generation and for specialty chemicals and consumer products. Peat fuel could capture a commanding share of the U.S. peat market, assuming that announced plans for the construction of powerplants in central Florida materialize.

DOMESTIC DATA COVERAGE

The Bureau of Mines conducts an annual survey of domestic peat producers. Information compiled from the Bureau's voluntary canvass was used to develop data tables for publication. Of the 111 domestic peat producers surveyed in 1989, 79 were reported to be active and 24 idle. Eight producers were reported to have closed permanently. Estimates were made taking into consideration historic information and macroeconomic trends, for active producers that did not report data in 1989.

PRODUCTION

Peat was harvested in 22 of the 48 contiguous States during 1989. The number of active producers dropped 10% to a total of 79, and production declined 11% to 755,000 tons. Florida and Michigan accounted for 65% of total production; Minnesota and Wisconsin, 7%; the Eastern States, 12%; the Midwest 11%; and the Western

TABLE 1

SALIENT PEAT STATISTICS

		1985	1986	1987	1988[r]	1989[p]
United States:						
Number of active operations		99	92	92	88	79
Production	thousand short tons	839	912	955	844	755
Sales by producers	do.	882	1,038	958	908	769
Bulk	do.	396	522	499	457	378
Packaged	do.	486	516	459	451	391
Value of sales	thousands	$21,892	$23,988	$21,020	$20,320	$17,636
Average per short ton		$24.81	$23.11	$21.94	$22.37	$22.94
Average per short ton, bulk		$20.29	$16.44	$17.72	$18.14	$19.11
Average per short ton, packaged or baled		$28.49	$29.86	$26.51	$26.67	$26.63
Imports for consumption	thousand short tons	477	553	515	590	530
Consumption, apparent[1]	do.	1,255	1,548	1,544	1,468	1,391
Stocks, Dec. 31: Producers'	do.	638	555	481	447	341
World: Production	do.	204,517	216,392	209,090	214,864	[e]213,931

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Apparent consumption equals U.S. primary production plus imports minus exports plus adjustments for industry stock changes.

States, 5%. More than 90% of the total output was generated by 50% of the producers from operations of 5,000 tons per year or greater. Reed-sedge peat accounted for 64% of production; humus, 18%; sphagnum moss, 13%; and other forms, 5%.

According to the State Division of Geological and Geophysical Surveys in Fairbanks, AK, Alaskan producers harvested 51,000 cubic yards of marketable peat, valued at $0.4 million. Production in 1989 was down about 7% from the previous year.

During 1989, 23% of domestic peat producers were idle. The principal reasons cited for idle status included environmental constraints, competitive economics of domestic and foreign sources, payment deficiencies by bulk consumers, and the new emphasis placed on composting and the recycling of yard wastes.

Minnesota Sphagnum Inc. brought its new sphagnum moss bog and processing plant in St. Louis County, MN, into full production during 1989. Milled peat was collected by vacuum harvesters and transported to the plant for processing. Harvested peat was fed to a radar screen for sifting and removal of large debris. Crude sphagnum peat was fed to a double deck vibrating screen and hammermilled to produce marketable quality peat. Dust was removed overhead through a closed circuit vacuum system. Product-grade sphagnum peat was compressed and baled for shipment.

Peatrex Ltd. was operating its new $2 million state-of-the-art sphagnum processing plant in Carlton County, MN. This plant was designed to run for an extended period from sphagnum stockpiled during the harvest season. Before the plant came into operation, harvested peat was shipped to another producer for processing. Milled sphagnum moss was collected from the bog by a large Vapo vacuum harvester. Michigan Peat Co., the largest sphagnum producer in Minnesota, was operating a large bog and processing in Carlton County, MN.

Atkin Agri-Peat in Aitkin County, MN, is the largest bulk producer of peat in Minnesota. Reed-sedge peat was extracted from the bog by bulldozer and shaped into windrows. Conditioned peat was screened and stockpiled for bulk shipment. Davidson Peat was harvesting a combination of humus and reed-sedge peat under contract in Rice County, MN. Peat was extracted by power shovel, windrowed, and shipped by truck to Davidson's processing plant at Kenyon, MN. Davidson's product line included top dressing mixtures, heavy sand mixtures, and fine milled peat.

Hyponex Corp. was operating a large reed-sedge bog near the town of Montverde in Lake County, FL. Conventional agricultural disking equipment was used to loosen and aerate the peat. Wide-track bulldozers moved conditioned peat and prepared stockpiles for shipment to the processing plant. Peat was screened, hammermilled, and packaged for shipment. Peat was also prepared for bulk sales. Hyponex is owned by the O. M. Scott & Sons Co., the manufacturer of a popular line of lawn and garden fertilizers.

First Colony Farms' large fuel-grade peat property near Creswell, NC, was purchased in bankruptcy proceedings by The Conservation Fund for a reported $8.8 million in September.[1] The Japanese firm, Nissho-Iwai American, joined with Westinghouse to bid $8.6 million for the property, but fell $0.2 million short. The tract consists of about 104,000 acres in Tyrrell, Hyde, Washington, and Dare Counties, NC. First Colony had envisioned the development of a 200-megawatt electric powerplant on the site.

The total area available for peat harvesting was about 18,000 acres, less than 20% of the acreage bought by The Conservation Fund. Approximately 38 million dry tons of peat reserves had been identified on the property.[2] Various parties negotiated for mining rights to a portion of the peat reserves on the property.

The Conservation Fund, a nonprofit organization, in coordination with the Richard King Mellon Foundation, proposed donating the property to the U.S. Fish and Wildlife Service, Department of the Interior, as an addition to the National Wildlife Refuge System.[3] A decision as to whether the rights to the peat on the property should also be donated to the Service, had not been reached.

TABLE 2

RELATIVE SIZE OF PEAT OPERATIONS IN THE UNITED STATES

Size in short tons per year	Active operations		Production (thousand short tons)	
	1988	1989	1988	1989
25,000 and over	r10	8	r367	349
15,000 to 24,999	r13	9	r237	154
10,000 to 14,999	6	7	71	86
5,000 to 9,999	r12	15	r90	108
2,000 to 4,999	20	13	62	43
1,000 to 1,999	7	6	10	9
Under 1,000	20	21	7	8
Total	88	79	r844	[1]755

r Revised.
[1] Data do not add to total shown because of independent rounding.

CONSUMPTION AND USES

Apparent domestic consumption of peat declined 5% for the second year in a row. A 10% decline in both domestic production and imports was partially offset by a 24% draw down in producer inventories. Domestic sales were off by 15% in 1989, but prices held steady. Bulk and packaged product commanded equal shares of the market.

Sphagnum moss sales by domestic producers were up 61% in 1989. Minnesota's sphagnum supply capability increased as new operations were brought into full production. Sphagnum was the material of choice for use by nurseries and also found extensive use in general soil improvement and as an ingredient for potting soils.

The demand for peat in general soil improvement, potting soils, and for use by nurseries generated 94% of the total domestically produced product sales in 1989. Reed-sedge peat commanded 67% of the market and was the most popular material used for general soil improvement in potting soils, on golf courses, as a seed inoculant medium, and for mushroom beds. Peat was also used for packing flowers, plants, and shrubs; as a fertilizer; for vegetable cultivation; and as an earthworm culture medium. Other uses for peat included chemical processing and medicine, environmental protection, and fuel.

STOCKS

Peat stocks in all forms declined 24% and stood at 5 months' production

TABLE 3

U.S. PEAT SALES BY PRODUCERS IN 1989, 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	2,200	$33	209	$6	2,409	$39
General soil improvement	128,509	2,377	364,962	9,266	493,471	11,642
Golf courses	20,582	529	219	14	20,801	543
Ingredient for potting soils	144,245	2,951	13,120	601	157,365	3,552
Mixed fertilizers	3,170	50	982	17	4,152	67
Mushroom beds	6,425	106	355	32	6,780	138
Nurseries	66,860	1,011	4,314	245	71,174	1,256
Packing flowers, plants, shrubs, etc.	1,614	21	711	65	2,325	86
Seed inoculant	1,126	56	5,524	156	6,650	213
Vegetable growing	592	12	864	14	1,456	26
Other	2,320	73	—	—	2,320	73
Total[1]	377,643	7,218	391,260	10,417	768,903	17,636

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

TABLE 4

U.S. PEAT PRODUCTION AND SALES BY PRODUCERS IN 1989, BY STATE

State	Active operations	Production	Sales		
		Quantity (thousand short tons)	Quantity (thousand short tons)	Value[1] (thousands)	Percent packaged
Colorado	4	W	W	$412	57
Florida	10	243	235	4,515	16
Georgia	2	W	W	W	98
Illinois	3	W	W	W	99
Indiana	5	35	34	607	54
Iowa	2	W	W	W	66
Maine	2	W	W	W	—
Maryland	1	2	3	W	22
Massachusetts	1	W	W	W	100
Michigan	14	244	286	6,082	66
Minnesota	7	31	27	1,415	58
Montana	1	W	W	W	—
New Jersey	3	W	W	638	97
New York	2	1	W	10	—
North Carolina	1	W	W	W	100
North Dakota	1	W	W	W	18
Ohio	3	W	8	182	—
Pennsylvania	8	21	20	746	59
South Carolina	1	W	W	W	86
Washington	3	5	W	W	—
West Virginia	1	W	—	—	—
Wisconsin	4	24	13	309	29
Total or average	79	755	[2]769	17,636	51

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1] Values are f.o.b. producing plant.
[2] Data do not add to total shown because of independent rounding.

equivalent by yearend. Reed-sedge peat ending inventories were 64% of the U.S. total, humus 18%, sphagnum 13%, and other forms, 5%. U.S. ending inventories have averaged about 7 months' production equivalent during the past 5 years.

PRICES

The average value of domestic peat sales f.o.b. plant, was about $23 per ton in 1989, an increase of 2.5% over the previous year. Packaged and baled prices were approximately 40% above bulk prices. Baled sphagnum moss sold for about $13 per cubic yard, and packaged reed-sedge for about $11 per cubic yard, f.o.b. plant.

FOREIGN TRADE

More than 99% of U.S. peat imports were from Canada. Quebec and New Brunswick in Eastern Canada accounted for about 75% of total Canadian shipments, while Manitoba, Alberta, and Saskatchewan, to the west, provided more than 20%. Canadian peat was also shipped from Newfoundland, Prince Edward Island, Nova Scotia, Ontario, and British Columbia. Approximately 75% of Canadian out-

put was exported, and the U.S. received about 90% of the total.

Canadian sphagnum trade fills a large void in the U.S. domestic peat market created by a deficiency in U.S. sphagnum moss supplies. Peat imports have captured an increasing share of the total U.S. domestic supply, rising from 36% in 1985 to 41% at present.

WORLD REVIEW

Global peat production remained level at an estimated 214 million tons in 1989. The U.S.S.R. was estimated to have accounted for about 93% of total world production, Europe 6%, and North America 1%. Data were not available for China.

In the U.S.S.R., harvesting 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 produced for agricultural use, as a fuel source, and for use by the chemical industry. Peat was burned in thermal powerplants in European U.S.S.R. and was also used to fire industrial boilers and to fuel large heating plants. Peat briquets were manufactured for use in home heating. The use of peat as an energy source in the U.S.S.R. was 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.[4]

Ireland and Finland accounted for about 70% of global peat production outside the U.S.S.R. in 1989. Each country was dominant in fuel peat production for use in power generation plants and other industrial applications and for home heating.

Bord na Móna was formed in 1946 to develop Ireland's peat resources. It produces peat fuel for use in the Electricity Supply Board's (ESB) peat-burning powerplants and machine turf and briquets for general industrial and domestic use. It also produces horticultural moss peat and a variety of fertilized peat products for the world market. ESB is Bord na Móna's major customer, accounting for 54% of annual revenues. In 1987–88, peat accounted for 36% of the Irish solid fuel market in terms of primary energy usage, down from 41% in 1986–87. The major

FIGURE 1

PRODUCTION AND IMPORTS OF PEAT IN THE UNITED STATES

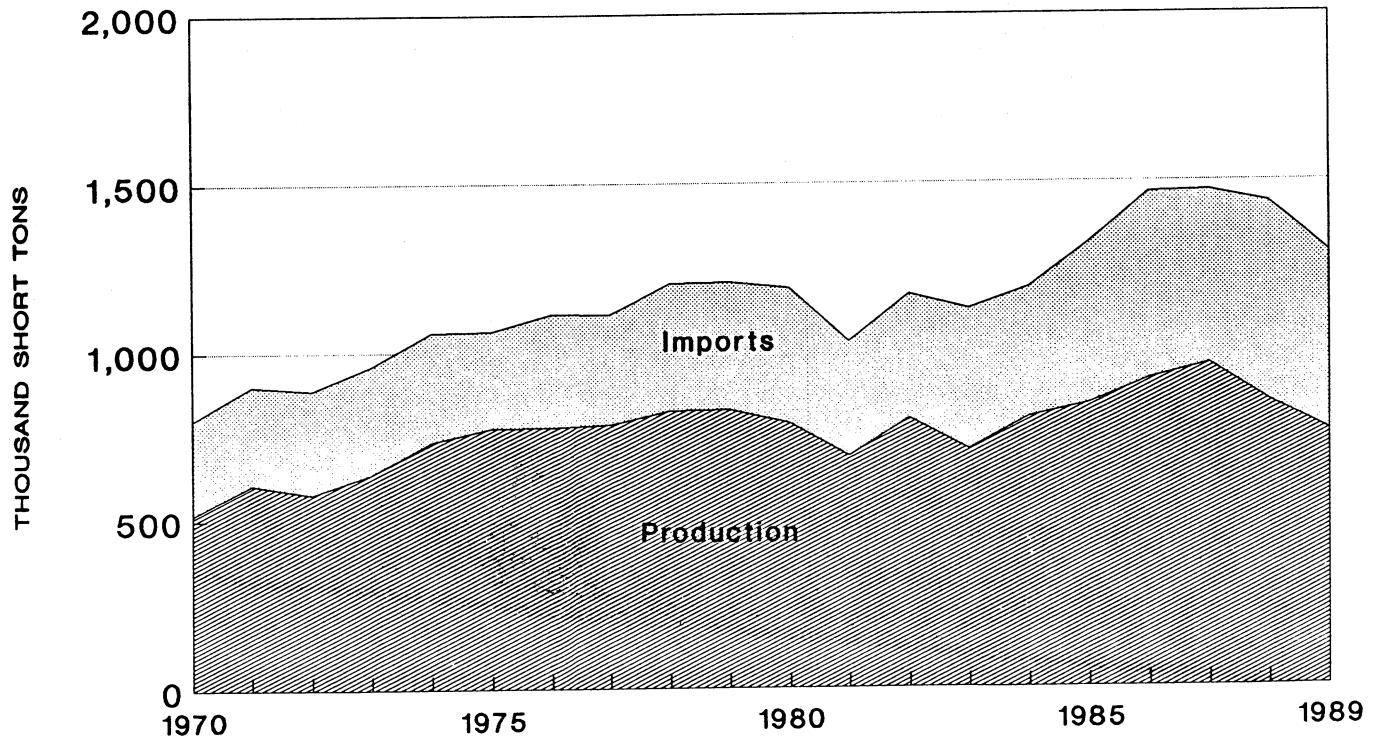

TABLE 5

U.S. PEAT SALES BY PRODUCERS IN 1989, BY 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	700	1,000	$9	—	—	—	842	1,715	$17
General soil improvement	30,134	142,743	1,637	12,800	25,300	$518	349,748	736,528	8,260
Golf courses	1,015	2,050	18	920	1,900	27	16,104	33,946	332
Ingredient for potting soils	969	3,370	62	11,920	23,900	508	116,310	251,262	2,590
Mixed fertilizers	—	—	—	170	400	12	—	—	—
Mushroom beds	355	1,481	32	1,275	3,000	45	5,150	9,755	61
Nurseries	51,931	86,104	769	516	1,092	18	16,428	32,624	422
Packing flowers, plants, shrubs, etc.	711	2,963	65	—	—	—	36	75	1
Seed inoculant	—	—	—	—	—	—	6,650	13,487	213
Vegetable growing	—	—	—	50	100	1	142	300	5
Other	1,385	2,950	51	—	—	—	935	1,885	22
Total[2]	87,200	242,661	2,644	27,651	55,692	1,128	512,345	1,081,577	11,923

Use	Humus			Other			Total[2]		
	Quantity		Value (thousands)	Quantity		Value (thousands)	Quantity		Value (thousands)
	Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)		Weight (short tons)	Volume (cubic yards)	
Earthworm culture medium	867	1,654	$14	—	—	—	2,409	4,369	$39
General soil improvement	96,289	138,282	1,205	4,500	9,000	$22	493,471	1,051,853	11,642
Golf courses	2,762	5,502	166	—	—	—	20,801	43,398	543
Ingredient for potting soils	26,966	43,078	380	1,200	2,000	12	157,365	323,610	3,552
Mixed fertilizers	3,982	6,964	55	—	—	—	4,152	7,364	67
Mushroom beds	—	—	—	—	—	—	6,780	14,236	138
Nurseries	2,299	4,278	47	—	—	—	71,174	124,098	1,256
Packing flowers, plants, shrubs, etc.	978	1,660	14	600	1,000	6	2,325	5,698	86
Seed inoculant	—	—	—	—	—	—	6,650	13,487	213
Vegetable growing	1,264	2,528	20	—	—	—	1,456	2,928	26
Other	—	—	—	—	—	—	2,320	4,835	73
Total[2]	135,407	203,946	1,900	6,300	12,000	40	768,903	1,595,876	17,636

[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 6

U.S PEAT PRODUCTION AND PRODUCERS' YEAREND STOCKS IN 1989, BY KIND

Kind	Active operations	Production (short tons)	Percent of production	Yearend stocks (short tons)
Sphagnum moss	12	94,714	12.5	27,015
Hypnum moss	7	27,035	3.6	22,600
Reed-sedge	37	486,266	64.4	270,796
Humus	25	138,555	18.3	13,708
Other	3	8,750	1.2	6,950
Total	[1]79	755,320	100.0	341,069

[1] Data do not add to total shown because some plants produce multiple kinds of peat.

TABLE 7

PRICES[1] FOR PEAT IN 1989

(Dollars per unit)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other	Average
Domestic:						
Bulk:						
Per short ton	14.30	21.86	24.32	11.07	10.00	19.11
Per cubic yard	8.39	12.08	11.54	8.08	6.00	10.39
Packaged or baled:						
Per short ton	76.24	62.48	22.59	20.96	4.89	26.63
Per cubic yard	12.98	27.79	10.69	11.48	2.45	11.56
Average:						
Per short ton	30.32	40.81	23.27	14.03	6.35	22.94
Per cubic yard	10.90	20.26	11.02	9.32	3.33	11.05
Imported, total, per short ton[2]	132.02	XX	XX	XX	XX	132.02

XX Not applicable.
[1] Prices are f.o.b. plant.
[2] Average customs value.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY COUNTRY[1]

Country	1988		1989	
	Quantity (short tons)	Value[2] (thousands)	Quantity (short tons)	Value[2] (thousands)
Austria	96	$15	619	$15
Canada	588,965	74,446	526,903	69,688
Ireland	43	5	484	116
Norway	—	—	1,356	30
Other[3]	542	99	344	82
Total	589,646	74,565	529,706	69,931

[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, and Vatican City.

Source: Bureau of the Census.

factor for this decline was the downward movement in international fuel prices. Horticultural peat products are currently the most dynamic growth component of the business. Twenty-seven countries now import Ireland's horticultural peat products.[5]

The development of Finland's peat industry has been dramatic. Peat production has increased twenty-fold since the mid-1970's. Peat accounts for about 4% of Finland's present energy supply, but the significance and relative proportion of peat is expected to increase despite declining world energy prices. Finland was planning to increase peat output substantially during the next 4 years. Finland's main product, milled peat, accounts for 80% of production, and sod peat, 20%. The use of peat in horticulture and as a raw material for different industrial and environmental purposes is increasing as well.[6]

Kemira Oy started up an 88,000-ton-per-year ammonia plant in Oulu, Finland, that was based on peat fuel synthesis gas.

Capacity

The data in table 10 are rated capacity for peat operations 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.

CURRENT RESEARCH

The Natural Resources Research Institute (NRRI), University of MN, Duluth, assists in the expansion of natural resource industries in rural Minnesota by developing markets for peat, forest products, and minerals. Peat research activities were focused in four major areas: technical assistance to the local peat industry; peatland utilization and reclamation; waste treatment, including sewage effluent, oil absorption, and

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS, BY CUSTOMS DISTRICT[1]

Customs district	1988		1989	
	Quantity (short tons)	Value[2] (thousands)	Quantity (short tons)	Value[2] (thousands)
Boston, MA	48	$11	22	$2
Buffalo, NY[3]	58,979	7,169	15,793	2,471
Chicago, IL	—	—	1,393	33
Cleveland, OH	—	—	161	23
Detroit, MI[3]	53,553	7,108	55,282	7,905
Duluth, MN[3]	7,114	927	1,518	177
Great Falls, MT[3]	90,517	13,538	79,862	10,901
Honolulu, HI[3]	—	—	23	5
Los Angeles, CA	1	2	286	89
Milwaukee, WI	—	—	131	13
New Orleans, LA[3]	—	—	12	3
New York, NY	245	40	619	14
Ogdensburg, NY[3]	195,509	23,214	190,934	23,928
Pembina, ND[3]	82,907	10,203	79,813	10,385
Philadelphia, PA	—	—	18	5
Portland, ME[3]	56,253	6,099	57,320	7,114
San Juan, PR[3]	635	103	96	26
Savannah, GA	59	17	17	8
Seattle, WA[3]	16,756	2,570	20,365	3,068
St. Albans, VT[3]	26,842	3,527	25,981	3,750
U.S. Virgin Islands[3]	20	2	60	11
Other[4]	208	35	—	—
Total	589,646	74,565	529,706	69,931

[1] Poultry and fertilizer grade.
[2] Customs value.
[3] Predominantly of Canadian origin.
[4] Includes Laredo, TX, Miami, FL, Minneapolis, MN, San Francisco, CA, and Tampa, FL.

Source: Bureau of the Census.

TABLE 10

WORLD PEAT ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(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	4,000
France	250
Germany, Federal Republic of	2,500
Hungary	100
Ireland	7,000
Netherlands	500
Norway	50
Poland	300
Spain	60
Sweden	70
U.S.S.R.	200,000
Total	214,890
Asia: Israel	30
Africa: Burundi	20
Oceania: Australia	20
World total	216,785

[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, Bureau of Mines.

composting; and chemical derivatives. Experiments were conducted in environmental chambers to test the growth of various plant species in mixtures of peat and composted natural organic materials. NRRI researchers also reported that sphagnum moss became hydrophobic when dried, producing an excellent medium for oil absorption. An experiment was to be conducted with a mechanical peat dewatering device in cooperation with the Minnesota Department of Natural Resources.

NRRI operated the Fens Research Facility north of Duluth, MN, on a virgin bog. Researchers conducted field experiments with various crops and trees. Blueberries, raspberries, and strawberries grew well in the reed-sedge bog. Hybrid willows and poplar trees also flourished in the bog environment. Wildlife had returned to the bog because of the increased food supply and cover.

The Center for Environmental Studies at Bemidji State University, Bemidji, MN, hosted its third International Symposium on Peat/Peatland Characteristics and Uses, May 16–19, 1989. Approximately 100 scientists from 14 nations attended. The subject matter dealt with peatland ecology and utilization; peat structure, composition and analysis; industrial products from peat; and plant-peat relationships. Some of the more interesting papers dealt with the extraction and properties of peat waxes, progress in the uses of peat resources in China, use of pretreated peat for oil removal, and the use of biofilters in odor and volatile organic solvent control. Johnson & Johnson was reported to have numerous patents for peat-based disposable diapers and was reportedly gearing up to manufacture biodegradable diapers using peat as the absorbent.

The Bureau of Mines developed porous polymeric beads, designated BIO-FIX beads, containing sphagnum moss. The beads have been demonstrated to effectively remove metal contaminants from mining and mineral processing wastewaters. The beads were utilized in a three-column fixed-bed circuit to remove cadmium, manganese, and zinc from wastewater emanating from an inactive zinc mining operation. The removal of toxic and heavy metal contaminants from aqueous waste streams is one of the most important environmental issues facing the United States today.[7]

The United States National Committee of the International Peat Society announced that an international peat

TABLE 11

PEAT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina: Agricultural use	4	3	4	2	2
Australia[3]	17	8	10	11	12
Burundi	11	14	19	19	19
Canada: Agricultural use (shipments)	709	814	714	811	766
Denmark: Agricultural use (sales)	43	53	[e]55	55	55
Finland:[e]					
Agricultural use	[4]378	385	385	385	385
Fuel	[4]3,461	3,500	3,500	3,500	3,500
France: Agricultural use[e]	220	240	230	220	220
Germany, Federal Republic of:					
Agricultural use	1,671	2,223	2,207	[e]2,200	2,000
Fuel	313	271	265	[e]220	200
Hungary: Agricultural use[e]	77	77	77	77	77
Ireland:					
Agricultural use	350	360	410	[e]390	400
Fuel	2,944	5,193	6,765	[e]6,000	6,000
Israel: Agricultural use[e]	22	22	22	22	22
Netherlands[e]	500	440	440	440	440
Norway:[e]					
Agricultural use	33	33	33	33	33
Fuel	1	1	1	1	1
Poland: Fuel and agricultural use[e]	220	220	275	220	220
Spain	60	57	[e]57	[e]58	58
Sweden: Agricultural use[e]	44	66	66	66	66
U.S.S.R.:					
Agricultural use[e]	175,000	180,000	180,000	180,000	180,000
Fuel	17,600	21,500	12,600	19,290	18,700
United States:					
Agricultural use	828	912	955	844	[4]755
Fuel	11	—	—	—	—
Total	204,517	216,392	209,090	214,864	213,931
Fuel peat included in total	24,550	30,685	23,406	29,231	28,621

[e] Estimated. [p] Preliminary.

[1] Table includes data available through May 30, 1990.

[2] In addition to the countries listed, Austria, Iceland, and Italy produce negligible quantities of fuel peat and the German Democratic Republic 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.

symposium would be held in Duluth, MN, August 19–23, 1991. The symposium site will be the new Convention Center, located on the shore of Lake Superior. Prospective speakers and attendees were encouraged to contact Mr. Donald N. Grubich, Organizing Chairman, c/o IRRRB, P.O. Box 441, Eveleth, MN 55734, U.S.A.

OUTLOOK

The global outlook for peat supply-demand is shown in table 12. Demand was developed by assuming that per capita peat consumption would continue to decline at an average annual 0.9 pounds per capita, experienced between 1984 and 1988. World peat demand should grow at about 1% per year between 1985 and 1990, about half that of world population. Under the forecast scenario, peat demand will grow at an average annual 0.7%, and world population at 1.9%, between 1990 and 1995.

About 50% of the projected growth in demand can be accounted for by announced plans in Finland and the United States. In addition, demand for agricultural peat in the U.S.S.R. should also increase. Peat reserves in Bangladesh, China, Indonesia, and Malaysia are also expected to be developed and expanded during the forecast period. Canada should expand dependent primarily on U.S. sphagnum requirements. The Bureau's demand forecast appears to be both reasonable and moderate, based on information currently available. Geopolitical events that unfold in the U.S.S.R. and in the developing countries during the forecast period, however, could impact forecast demand in either a positive or negative direction.

Global peat reserves under cultivation are sufficient for about another 20 years at current production rates. The identified reserve base of 528 billion tons, however, could theoretically support current production rates for more than 2000 years. New bogs will be developed to replace depleting bogs and to expand world peat production. Total world resources of peat are estimated to be 2.1 trillion tons. The deposits in the U.S.S.R. are estimated at 850 billion tons and in Canada at about 560 billion tons. Domestic deposits of peat occur in all 50 States, with estimated resources of 340 billion tons, about 16% of the world total.

U.S. production and primary demand turned up in 1984, and peaked at record highs during 1986 and 1987. The market turned down, in 1988 and 1989, in line with a slowdown in U.S. economic growth. Housing starts and the development of commercial properties slowed, and peat demand declined. The market is expected to stabilize during the forecast period, and demand for horticultural and agricultural peat products should return to, or exceed, 1986–87 levels by 1995. Demand will be impacted by industrial composting and residential recycling of yard wastes. Fuel-grade peat demand should in-

TABLE 12

WORLD PEAT SUPPLY-DEMAND RELATIONSHIPS[1]

(Million short tons peat)

	1985	1986	1987	1988	1989[p e]	1990[2]	1991[2]	1992[2]	1993[2]	1994[2]	1995[2]
Capacity[3]	215.0	216.8	216.8	216.8	216.8	217.5	220.0	221.5	223.0	224.0	225.0
Demand:											
Agricultural	179.9	185.7	185.7	185.7	185.3	186.6	187.7	188.9	190.0	190.9	191.8
Fuel	24.6	30.7	23.4	29.2	28.6	29.1	29.6	30.0	30.4	30.8	31.2
Total	204.5	216.4	209.1	214.9	213.9	215.7	217.3	218.9	220.4	221.7	223.0
Operating rate[4]	95%	100%	96%	99%	99%	99%	99%	99%	99%	99%	99%
Consumption:											
Lbs. per capita[5]	85.2	88.3	83.6	84.3	82.3	81.4	80.5	79.6	78.7	77.8	76.9
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.
[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, 1989; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, Bureau of Mines.

crease by at least 0.5 million tons as new peat-fired electrical power generation plants come on-stream in central Florida. If current plans for the implementation of peat fuel powerplants materialize, peat fuel could become the dominant end-use sector in the U.S.

TABLE 13

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	46	500
Ireland	171	900
U.S.S.R.	5320	160,000
Other	23	16,600
Total	5,630	185,000
World total	5,670	528,000

[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).

peat industry during the 1990's.

BACKGROUND

Peat deposits were developed by the gradual decomposition of biomass materials under anaerobic conditions in shallow basins. Most of the peat deposits in existence today have formed since the last ice age, approximately 10,000 years ago. Peat bogs 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 is a precursor of lignite and coal. Humates are found in the Upper Cretaceous coal-bearing sediments of the San Juan Basin in New Mexico. Humates are humic acid-rich carbonaceous shales or claystones. They are used for a variety of purposes, including soil conditioning. Peats are commonly classified as sphagnum moss, hypnum moss, reed-sedge, and humus. Sphagnum moss is a high-fiber, low-density, acidic peat, while humus, at the opposite end of the scale, is a high density, moderately acidic material.

Specifications

Peat has various definitions and the term is often misused. Peat scientists use a selected set of physical and chemical criteria to characterize peat materials. Standards established by the American Society for Testing and Materials (ASTM) are usually followed in characterizing peat in North America. ASTM Classification of Peats, Mosses, Humus, and Related Products requires the use of three parameters: ash content; fiber content, and botanical composition. The ash content must be less than 25% by dry weight. The botanical composition of the peat, especially of the peat fibers, is critical to determining whether the peat is "sphagnum moss peat" (greater than 66% fiber, all of which must be derived from the genus Sphagnum), "hypnum moss peat" (minimum of 33% fiber, of which 50% must be derived from the genus Hypnum), or "Reed-Sedge Peat" (minimum of 33% fiber containing more than 50% reed-sedge and other nonmoss fibers). Many researchers endorse the use of von Post's humification factors as a direct method for defining peat types and properties in the field.

Sphagnum peat moss is a low density, fibrous material with excellent water retention properties. Sphagnum bogs are found in the northern latitudes of the United States. Sphagnum is an acidic, chemically active peat. Reed-sedge peat is less fibrous than sphagnum, has a much higher density and is mildly acidic. Reed-sedge bogs are abundant in both

TABLE 14

U.S. PEAT 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	r844	1,468
1989p	755	1,391
1990e	820	1,330
1995f	[4]1,450	[4]2,150

e Estimated. f Forecast. 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] Includes 500,000 tons fuel grade peat required to operate two, 52-megawatt power generation plants at 70% of capacity in central Florida. A total of three, 52-megawatt units are reportedly under contract.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, Bureau of Mines.

the temperate and warm southern climates of the United States. Hypnum moss has properties similar to reed-sedge. Humus peat is highly decomposed and is the most dense peat.

TABLE 15

TIME-VALUE[1] RELATIONSHIPS FOR U.S. PEAT

Year	Average annual price, dollars per short ton	
	Actual price	Based on constant 1989 dollars
1970	11.39	34.25
1971	11.69	33.25
1972	11.72	31.83
1973	12.16	31.03
1974	15.56	36.39
1975	16.49	35.12
1976	16.52	33.07
1977	17.25	32.37
1978	17.32	30.30
1979	19.44	31.24
1980	20.54	30.27
1981	24.82	33.35
1982	21.94	27.71
1983	25.73	31.28
1984	24.47	28.70
1985	24.81	28.26
1986	23.11	25.65
1987	21.94	23.60
1988	22.37	23.29
1989p	22.94	22.94

p Preliminary.

[1] U.S. producer price, f.o.b. plant; average all kinds of peat.

Sources: Bureau of Mines; Council of Economic Advisors (1989 implicit price deflators for Gross National Product).

Technology

Down East Peat commenced operation of North America's first peat-fired electric powerplant at Deblois, ME, at midyear. The plant output design is 22.8 megawatts and can be fueled by peat or a combination of peat and woodchips. Pelleted sod peat from the adjacent Denbo Heath bog provided fuel for the boilers. The $55 million project took 6 years to complete. The plant will employ about 50 full-time and 40 seasonal workers and will generate about $500,000 in revenues annually.

An agreement was reportedly reached between Florida Power Corp. and General Peat Resources LP, for the utility to purchase power from three peat-fueled plants to be built in central Florida. The action paved the way for General Peat of St. Petersburg, FL, to build three, 52-megawatt generating units near Lake Placid at an estimated cost of $300 million. General Peat will harvest peat in the immediate area where bogs contain a 50-year supply of the fuel. At full capacity, the powerplants would require more than 1 million dry tons of peat annually, more than double current U.S. peat output.[8]

[1] Coastland Times, Manteo, NC. Apr. 29, 1990, p. 1A.

[2] ———. Apr. 26, 1990, p. 10A.

[3] Environmental Assessment for the Proposed Pocosin Lakes National Wildlife Refuge, U.S. Fish and Wildlife Service, Dep. of the Interior, Atlanta, GA, May 1990.

[4] U.S.S.R. Energy Atlas, Central Intelligence Agency, Jan. 1985, p. 45.

[5] 42nd Annual Report and Accounts, 1987-1988, Bord na Móna, Dublin, Ireland.

[6] Mutanen, K. Increased Investments in Peat Research. Finnish Trade Review: Energy. The Finnish Foreign Trade Association, Helsinki, Aug. 1987, pp. 42-43.

Mutanen, K. Advanced Peat Technology, Mintech '89. The Annual Review of International Mining Technology and Development, Sterling Pubs. Ltd. London 1989, pp. 127-128.

[7] Bennett P., and T. Jeffers. Removal of Metal Contaminants from a Waste Stream Using BIO-FIX Beads Containing Sphagnum Moss. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-Jun. 1, 1990. Salt Lake City Research Center, BuMines, Salt Lake City, UT, Feb. 1990.

[8] Engineering News Record, McGraw Hill. Jan. 18, 1990, p. 38.

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Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, PA, annual.

Testing of Peats and Organic Soils, American Society for Testing and Materials, Philadelphia, PA, June 1982.

Peat Resources of the United States, A Joint Proposal to the U.S. Department of the Interior from the University of North Dakota Energy. Research Center and U.S. Geological Survey, Apr. 1986.

NRRI Now, Natural Resources Research Institute, Univ. of Minnesota, Duluth, Quarterly.

TABLE 16

AVERAGE DENSITY OF DOMESTIC PEAT SOLD IN 1989

(Pounds per cubic yard)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other
Bulk	1,174	1,105	949	1,460	1,200
Packaged	340	890	946	1,096	1,000
Bulk and packaged	719	993	947	1,328	1,050

PERLITE

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 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 4% in quantity and decreased 8% in value. Expanded perlite sales increased 8% in quantity and were virtually unchanged in value. Construction uses of processed perlite accounted for 64% of total domestic sales in 1989.

DOMESTIC DATA COVERAGE

Domestic production data for perlite are developed by the 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 68 expanding plants canvassed, 61 were active; of these, 42 plants, or 69% responded, representing 64% of the total expanded perlite sold or used shown in table 1.

PRODUCTION

Perlite mined for processing came from 9 companies with 10 operations in 6 Western States and totaled 722,000 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 1989 increased 6% to 641,000 tons compared to that of 1988.

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 61 plants in 33 States increased 7% in quantity compared with 1988. Value of expanded perlite decreased slightly in 1989. Leading States, in descending order of sales, were Mississippi, Pennsylvania, Illinois,

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
1985	678	309	10,714	209	6,821	518	461	459	81,000
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

[1]Crude ore mined and stockpiled for processing.

California, Georgia, Arizona, Kentucky, Virginia, and Minnesota.

CONSUMPTION AND USES

Construction-related uses, the major market for expanded material, increased 5% to 336,600 tons. Expanded perlite used as filter aid, fillers, and in agricultural markets totaled 148,600 tons, an increase of 7% compared to 1988.

FOREIGN TRADE

Perlite exports, primarily to Canada, were estimated to be 5,000 tons. Imports of perlite ore from Greece were estimated to be 65,000 tons compared with 62,000 tons in 1988.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mineral Commodity Summaries, annual.
Minerals Yearbook, annual.
Mineral Industry Surveys, annual.

Other Sources

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Industrial Minerals Magazine (London).
Mining Engineering.
Mining Journal (London).
World Mining.

TABLE 2

EXPANDED PERLITE PRODUCED AND SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988				1989			
	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	40,700	41,600	$7,841	$188	41,200	44,700	$8,363	$187
Florida	26,600	26,600	5,509	206	23,200	23,100	4,817	208
Indiana	19,400	19,400	5,499	283	22,200	22,200	5,839	263
Kansas	1,100	1,100	380	354	W	W	W	365
Pennsylvania	50,300	50,200	9,776	194	50,900	50,900	10,461	205
Texas	16,000	15,600	4,108	263	25,900	24,700	5,424	219
Utah	900	900	239	274	4,500	4,500	1,234	274
Other[2]	324,900	323,290	55,548	172	349,800	347,300	51,876	149
Total[3]	480,000	479,000	88,900	186	518,000	517,000	88,014	170

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	1988	1989
Concrete aggregate	10,400	11,100
Fillers	27,100	28,200
Filter aid	62,900	70,800
Formed products[1]	283,100	291,200
Horticultural aggregate[2]	49,300	49,600
Low-temperature insulation	6,200	6,100
Masonry and cavity-fill insulation	10,400	10,200
Plaster aggregate	10,800	18,000
Other[3]	18,800	32,000
Total	479,000	[4]517,000

[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 do not add to total shown because of independent rounding.

TABLE 4

PERLITE: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Australia[3]	3	4	6	5	6
Czechoslovakia	[e]49	46	46	48	49
Greece	178	203	230	[e]230	230
Hungary[3]	104	121	124	133	132
Italy[e]	88	81	77	78	78
Japan[e]	83	83	83	83	85
Mexico[3]	41	51	43	43	44
Philippines[e]	[4]4	4	4	4	4
Turkey	66	115	159	202	220
U.S.S.R.[e]	660	660	660	660	660
United States (processed ore sold and used by producers)	518	507	533	576	[4]601
Total	1,794	[r]1,875	1,965	2,062	2,109

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Unless otherwise specified, figures represent processed ore output. Table includes data available through May 16, 1990.
[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 19 years Bureau of Mines experience, has been the commodity specialist for phosphate rock since 1974. Domestic survey data were prepared by William Fields, mineral data assistant, and the international data table were prepared by Peter Roetzel, international data assistant.

Phosphate rock production in the United States increased almost 10% in 1989 over that of 1988. The production of 49,817,000 tons[1] was consumed in several markets. The estimated U.S. demand pattern was 19,180,000 tons used in domestically consumed fertilizer, 20,803,000 tons was converted to fertilizer and exported, 1,647,000 tons was used domestically in other than fertilizer applications, and 512,000 tons was exported as other than fertilizer chemicals.

The United States exported 7,842,000 tons of phosphate rock and imported 704,000 tons preserving the general trends of declining phosphate rock exports and increasing imports.

World production of phosphate rock was similar to that of 1988. Production remained at a plateau of about 162 million tons.

DOMESTIC DATA COVERAGE

Domestic production data for phosphate rock are developed by the 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.

LEGISLATION AND GOVERNMENT PROGRAMS

Section 3001(b)(3)(A)(ii) of the Resources Conservation and Recovery Act (RCRA), known as the Bevill Exclusion, excludes "solid waste from the extraction, beneficiation, and processing of ores and minerals" from regulation as hazardous waste under subtitle C of RCRA, pending completion of certain studies by the Environmental Protection Agency (EPA). In 1980, the EPA interpreted this exclusion on a temporary basis to encompass "solid waste from the exploration, mining, milling, smelting, and refining of ores and minerals." On September 1, 1989, EPA published the final criteria and took final action on all but 20 mineral processing waste streams. The wastes proposed for removal from the Bevill Exclusion were furnace offgas solids from elemental phosphorus production, phosphogypsum from phosphoric acid production, and furnace slag from elemental phosphorus production.

As of September 1, 1989, the status of previously proposed Bevill mineral processing wastes in the phosphoric

TABLE 1

SALIENT PHOSPHATE ROCK STATISTICS[1]

(Thousand metric tons and thousand dollars unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Mine production (crude ore)	175,227	135,683	148,426	162,299	170,268
Marketable production	50,835	40,320	40,954	45,389	49,817
P_2O_5 content	15,634	12,248	12,470	13,833	15,116
Value	[2]$1,235,800	[2]$897,131	[2]$793,280	$887,809	$1,084,022
Average per metric ton[3]	$24.31	$22.25	$19.37	$19.56	$21.76
Sold or used by producers[4]	46,634	41,776	43,673	48,441	49,280
P_2O_5 content	14,363	12,750	13,286	14,760	14,935
Value	[2]$1,133,675	[2]$929,621	[2]$845,812	$947,721	$1,072,454
Average per metric ton[3 5]	$24.31	$22.25	$19.37	$19.56	$21.76
Exports[6]	9,136	7,848	8,454	8,092	7,842
P_2O_5 content	2,931	2,521	2,737	2,608	2,522
Value[2]	$263,631	$211,701	$194,691	$206,984	$227,272
Average per metric ton[3]	$28.86	$26.97	$23.03	$25.58	$28.98
Imports for consumption	[7]34	528	464	[r]676	705
C.i.f. value	$1,747	$25,435	$22,134	[r]$26,310	$29,878
Average per metric ton	[8]$51.54	[8]$48.18	$47.70	[r]$38.92	$42.44
Consumption[9]	37,532	34,456	35,683	41,022	42,143
Stocks, Dec. 31: Producers	15,534	13,277	10,884	9,323	11,027
World: Production	148,842	138,870	144,228	[p]163,673	[e]162,000

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Data for the same items appearing in this and other tables may not reconcile because of manual or computer rounding.

[2] The total value is based on a weighted value.

[3] Computer-calculated average value based on the weighted sold or used values.

[4] Includes domestic sales and exports.

[5] Weighted average of sold or used values.

[6] Exports reported to the Bureau of Mines by companies.

[7] Bureau of the Census data, excluding reported Canadian and Israeli imports.

[8] Average unit value obtained from unrounded data.

[9] Expressed as sold or used plus imports minus exports.

acid and elemental phosphorus sectors was as follows:

1. Furnace off-gas solids was conditionally retained because it passed high-volume criteria.
2. Furnace scrubber blowdown was removed because of low volume.
3. Process wastewater was removed because of low volume.
4. Slag was retained because it passed all criteria.
5. Phosphogypsum was retained because of high volume.
6. Process wastewater was conditionally retained because of high volume.

As of September 25, 1989, the proposed status of each of the phosphate commodity wastes and the basis for each were as follows:

1. Elemental furnace off-gas solids from 5 operations was not retained within the Bevill Exclusion.
2. Phosphoric acid process wastewater from 28 operations was retained within the Bevill Exclusion.

The Office of Radiation Programs, EPA, ruled that conditionally and pending further studies, a reduction of radon emissions from phosphogypsum stacks would not be required. The emissions were within the acceptable risk of 1 cancer death per year for every 10,000 people from radon-222 gas from an active phosphogypsum stack. The maximum mortality risk from radioactive particulates was estimated at about 2 in 1,000,000.

STRATEGIC CONSIDERATIONS

Phosphate rock is not strategically stockpiled. The United States is a net exporter of both phosphate rock and phosphate chemicals. There is concern, however, over the adequacy of domestic supply in future years when the deposits of phosphate rock in Florida that have sustained domestic and export markets for many decades are mined out. Phosphate rock deposits in Florida, after 100 years of production, have a limited supply of high-quality reserves remaining. (The subject of phosphate rock reserves is discussed in this publication under reserves.) A review of mine production plans of Florida mines shows that as years progress, the supply of phosphate rock from remaining mines will decline. The rate of decline will depend on future mining rates, if environmentally sensitive wetlands and hardwood stands will be permitted and mined, if technology to improve the quality of phosphate rock can be developed, and if the economics of mining and processing phosphate rock become sufficiently attractive to develop new mines in Florida and expand the capacity of the mine in North Carolina.

Raw material demand for phosphate rock is closely associated with production levels in the world's fertilizer industries. The demand for agricultural products is tied to population. A world population over 5 billion in 1989 is forecasted to reach 6.2 billion in the year 2000.

The increase in population and an anticipated increase in per capita income will increase the demand for food, feed, and fiber, increasing the pressure on world agriculture to produce the necessary quantities of these products. Programs and policies are needed to promote growth in fertilizer application and food production so that people, particularly in developing countries, can have higher nutritional levels in the year 2000.

ISSUES

The demand for U.S. phosphate rock in 1989 was more than expected when India discontinued receiving Moroccan phosphoric acid and purchased an additional 1.5 to 2 million metric tons of diammonium phosphate (DAP). The tonnage was supplied for the most part by U.S. producers, and with this windfall, prices were sustained during the main shipping period of the year. As shipments to India declined, prices for DAP fell, indicating overcapacity of the U.S. DAP industry. The decline in prices forced high-cost plants to close or reduce production. Overcapacity in the U.S. DAP industry was the reason, and it was forecasted that India's imports of DAP will be less in 1990. Low DAP prices will probably encourage sales into some areas; however, the quantities sold were not expected to increase in 1990 over that of 1989. Closing DAP plants in the United States may not resolve the issue as Morocco plans to double its DAP capacity at Jorf Lasfar in the next few years.

After 100 years of production from Florida's Bone Valley Formation, it is difficult to accept the prognosis of a decline in the supply of phosphate rock from the region. This decline was particularly difficult to accept in 1989 when efforts were made to replenish domestic grain stocks, depleted by the drought in 1988, and supply an exceptionally strong export market for phosphate fertilizers. At issue is the development of replacement mines to offset production losses as phosphate rock deposits are mined out in Florida. There are a limited number of remaining deposits from which acceptable products could be produced in Florida. Investors have been reluctant to develop new mines in Florida without assurance of a profitable return. Current selling prices and estimated production costs from a potential new mine do not encourage investments.

The future supply of phosphate rock could be increased by investment in North Carolina, where large reserves are available, to accommodate a mine expansion. Expansion of existing mines in Florida does not appear at this time to be economically feasible, and quality reserves are limited.

PRODUCTION

Compared with 1988, domestic production of marketable phosphate rock increased 10% in 1989 to 49.8 million tons. Production was 2 million tons higher than planned by producers as they responded to improved demand in the domestic and export sectors for phosphate fertilizers and elemental phosphorus derivatives. Most of the increased supply originated in Florida. Of the total U.S. production, Florida and North Carolina supplied 88%, and the balance was produced in Idaho, Montana, Tennessee, and Utah.

Florida and North Carolina

Phosphate rock was produced in Florida by Agrico Mining Co., a division of Agrico Chemical Co., owned by Freeport-McMoRan Resource Partners L.P.; CF Industries Inc.; Estech Inc., owned by C&G Holdings Inc.; Gardinier Inc.,

80% ownership by Cargill, Inc.; IMC Fertilizer Inc. (IMC); Mobil Mining and Minerals Co.; U.S. Agri-Chemicals Corp.; Seminole Fertilizer Corp., owned by Tosco Corp.; and Occidental Chemical Agricultural Products Inc. in northern Florida. Nu-Gulf Industries Inc., a subsidiary of Nu-West Industries Inc., shipped phosphate rock from inventory but did not produce it in 1989.

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 Aquitaine Inc., was the only producer of phosphate rock in North Carolina. Studies to deepen the harbor and channel at Morehead City, NC, for navigation by deeper draft vessels were in progress. Texasgulf produced phosphate rock from the Lee Creek Mine adjacent to the Pamlico River.

Western States

Phosphate rock was mined in Idaho, Montana, and Utah. Nu-West produced phosphate rock from a number of deposits in Idaho. The phosphate rock was beneficiated and calcined at Conda, ID. J. R. Simplot Co. produced phosphate rock from the Gay Mine, Fort Hall Indian Reservation, and the Smoky Canyon Mine, Caribou National Forest. The Gay Mine's main bed phosphate rock was used by Simplot, and the lower-grade shale was used in FMC Corp.'s electric furnaces. Monsanto Co. supplied its Soda Spring, ID, electric furnaces from the Enoch Valley Mine. Rhône-Poulenc Basic Chemicals Co. operated the Wooley Valley Mine, ID, to supply phosphate rock to its Silver Bow, MT, electric furnaces. Cominco American Inc. operated an underground mine, beneficiation, and drying plant near Garrison, MT. The dried product was exported to Canada. Chevron Resources Co. produced phosphate rock from the Vernal Mine, UT. It was transported by pipeline to Rock Springs, WY.

CONSUMPTION AND USES

The demand pattern for phosphate rock in the United States was stable during the past decade. Between 85% and 90% of phosphate rock consumed was used to produce phosphate fertilizer for domestic or export markets. Frequently, over 50% of the manufactured fertilizer was consumed domestically; however, there were several years during the past decade that fertilizer exports exceeded domestic consumption.

Phosphate rock exports have declined from a 14 million ton-per-year level in 1979 to about 8 million tons-per-year in recent years as the industry

TABLE 2

PRODUCTION OF PHOSPHATE ROCK IN THE UNITED STATES, BY REGION[1]

(Thousand metric tons and thousand dollars)

Region	Mine production		Marketable production							Ending stocks
			Used directly		Beneficiated		Totals[2]			
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Value[3 4]	
1988:	162,299	r20,951	3,832	1,045	41,557	12,787	45,389	13,833	887,809	9,323
1989:										
January–June										
Florida and North Carolina	r92,616	r16,279	266	81	r22,993	r7,029	r23,259	r7,111	r500,958	r9,954
Idaho, Montana, Tennessee, and Utah	4,912	1,225	1,555	416	1,412	431	2,967	847	r64,702	1,757
Total[2]	r97,527	r17,505	1,821	497	r24,405	r7,461	r26,226	r7,958	r565,660	r11,711
July–December										
Florida and North Carolina	68,115	8,840	292	88	20,088	6,155	20,380	6,242	458,657	9,541
Idaho, Montana, Tennessee, and Utah	4,626	1,145	1,785	473	1,426	442	3,211	916	58,479	1,486
Total[2]	72,740	9,986	2,078	561	21,514	6,597	23,591	7,158	517,137	11,027
Grand total[2]	170,268	27,490	3,899	1,058	45,919	14,058	49,817	15,116	1,084,022	XX

r Revised. XX Not applicable.

[1] Data for the same items appearing in this and other tables may not reconcile because of manual/computer rounding.

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

[3] Computer-calculated value based on the weighted sold or used value.

[4] The total value is based on a weighted value. The total value does not equal the sum of the regional or 1/2-year totals because weighted regional or overall 1/2-year unit values were used in the calculations. The regional and 1/2-year values are approximate.

converted more phosphate rock to higher value intermediates or finished fertilizer. The emergence of phosphate fertilizer industries in developing countries with domestic phosphate rock deposits caused major changes in trade patterns. Countries with indigenous phosphate rock deposits like Jordan, Morocco, Senegal, and Tunisia established fertilizer plants that competed in markets throughout the world. Phosphate rock imports, particularly shipments from Morocco and Togo, to plants on the Mississippi River increased in the last years of the decade to similar levels that existed at the beginning of the decade. The resumption of substantial imports was prompted by a need for higher quality phosphate rock than was available domestically to produce high purity fertilizers.

The balance of phosphate rock was consumed with silica and coke in electric furnaces to produce elemental phosphorus. Elemental phosphorus was used to produce high-purity phosphoric acid, salts, and phosphorus chemicals for industry and home consumption. These included detergents and cleaners, chemicals for food and beverages, and metal-treating chemicals.

The detergent builder, sodium tripolyphosphate, was the principal derivative of elemental phosphorus. The manufacture of thermal or furnace phosphoric acid accounted for 80% to 85% of U.S. elemental phosphorus production. About 10% of the elemental phosphorus production was used to produce phosphorus pentasulfide, phosphorus pentoxide, and phosphorus trichloride. About 50% of the elemental phosphorus produced was used to manufacture sodium tripolyphosphate.

The gradual decline in elemental phosphorus production and the quantity of phosphate rock consumed in electric furnaces during the past decade was caused by banning phosphates from home laundry products in some areas of the country. Several companies decided to construct plants to produce higher quality, lower cost, wet-process phosphorus acid purification plants that would produce a purified acid to replace thermal acid in food and detergent grade products. Thermal acid will continue to be used by semiconductor manufacturers and in other ultrahigh-purity markets. Where thermal acid competes with purified wet-process acid, lower cost wet-process acid will probably be the choice selected in the future.

TABLE 3

U.S. PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Distribution (percentage)

Grade (percent BPL[1] content)	Distribution (percentage)				
	1985[2]	1986	1987	1988	1989[2]
74 or more	2.9	4.5	3.4	2.0	0.8
72 to less than 74	4.2	4.0	5.4	5.6	7.4
70 to less than 72	12.0	7.8	7.1	8.8	6.2
66 to less than 70	62.9	57.5	61.6	59.7	61.7
60 to less than 66	13.1	20.3	17.5	14.9	19.3
Less than 60	4.8	5.9	5.0	9.0	4.7

[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)				
	1985[2]	1986	1987	1988	1989
74 or more	3.4	5.1	3.8	2.3	0.9
72 to less than 74	4.8	4.6	6.0	6.4	7.6
70 to less than 72	12.6	9.0	7.6	8.2	6.2
66 to less than 70	65.9	60.7	65.3	64.0	66.4
60 to less than 66	12.8	20.6	17.3	14.4	18.9
Less than 60	.6	—	(3)	4.7	—

[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.
[3] Less than 0.1 of 1%.

STOCKS

Phosphate rock was inventoried in wet rock piles adjacent to the beneficiation plants in Florida and North Carolina. The stocks were reclaimed for drying or calcining for export or for wet-grinding before wet-process phosphoric acid manufacture. Industry stocks peaked in 1981 when about 20 million tons was reported at yearend. Since 1981, the phosphate rock inventory tonnage declined each year, reaching 9.3 million tons in 1988. In the Western States, where the climate made it diffi-

TABLE 5

TENNESSEE AND WESTERN STATES PHOSPHATE ROCK SOLD OR USED GRADE DISTRIBUTION PATTERN

Grade (percent BPL[1] content)	Distribution (percentage)		
	1987	1988	1989
72 to less than 74	—	—	5.6
70 to less than 72	3.5	12.5	6.1
66 to less than 70	33.9	29.8	28.6
60 to less than 66	19.3	18.2	21.8
Less than 60	43.3	39.5	37.9

[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[1]

(Thousand metric tons and thousand dollars)

Grade (percent BPL[2] content)	Florida and North Carolina			Tennessee and Western States[3]			Total		
	Rock	P_2O_5 content	Value[4 5]	Rock	P_2O_5 content	Value[4 5]	Rock	P_2O_5 content	Value[4 5]
January–June 1988	20,472	6,275	369,224	2,850	817	53,973	23,322	7,092	423,197
July–December 1988	21,922	6,762	460,738	3,197	907	63,786	25,119	7,669	524,524
January–June 1989:									
74 or more	r205	r70	r6,440	—	—	—	r205	r70	r6,440
72 to less than 74	r2,385	r796	r67,575	—	—	—	r2,385	r796	r67,575
70 to less than 72	1,059	345	29,654	376	122	13,690	1,435	467	43,344
66 to less than 70	13,635	4,194	270,008	889	275	26,831	14,524	4,469	296,839
60 to less than 66	r4,790	r1,358	r106,283	582	166	6,314	r5,372	r1,524	r112,597
Below 60	—	—	—	871	221	13,974	871	221	13,974
Total[6]	r22,074	r6,763	r479,960	2,718	784	60,809	r24,792	r7,547	r540,769
July–December 1989:									
74 or more	189	66	5,332	—	—	—	189	66	5,332
72 to less than 74	894	300	28,489	346	116	12,776	1,240	416	41,265
70 to less than 72	1,611	522	47,503	—	—	—	1,611	522	47,503
66 to less than 70	15,005	4,600	311,557	869	269	21,631	15,874	4,869	333,188
60 to less than 66	3,357	934	79,153	757	213	9,237	4,114	1,147	88,390
Below 60	—	—	—	1,459	370	16,006	1,459	370	16,006
Total[6]	21,056	6,422	472,034	3,431	968	59,650	24,487	7,390	531,684

r Revised.

[1] Data for the same items appearing in this and other tables may not reconcile because of manual or computer rounding.

[2] 1.0% BPL(bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

[3] Includes Idaho, Montana, and Utah.

[4] F.o.b. mine.

[5] The total value is based on a weighted value. The total value does not equal the sum of the regional totals because weighted regional unit values were used in the calculations. The regional values are approximate.

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

TABLE 7

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE[1]

(Thousand metric tons)

Use	1988 total		1989					
			January–June		July–December		Total[2]	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
Domestic:[3]								
Wet-process phosphoric acid	36,721	11,083	r19,017	r5,732	18,914	5,662	37,931	11,394
Normal superphosphate	r840	r325	r384	r125	553	172	937	297
Triple superphosphate	r641	r159	r234	r77	176	60	410	137
Defluorinated rock	66	22	—	—	—	—	—	—
Direct applications	1	(4)	2	1	1	—	3	1
Elemental phosphorus	2,044	553	917	250	1,205	325	2,122	575
Ferrophosphorus	36	9	18	4	19	5	37	9
Total[2]	40,349	12,152	r20,571	r6,189	20,866	6,225	41,437	12,413
Exports[5]	8,092	2,608	4,222	1,358	3,620	1,164	7,842	2,522
Grand total[2]	48,441	14,760	r24,793	r7,546	24,487	7,389	49,280	14,935

r Revised.

[1] Data for the same items appearing in this and other tables may not reconcile because of manual or computer rounding.

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

[3] Includes rock converted to products and exported.

[4] Less than 1/2 unit.

[5] Exports reported to the Bureau of Mines by companies.

TABLE 8

PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE AND REGION[1]

(Thousand metric tons)

Use	Florida and North Carolina		Tennessee and Western States[2]		Total[3]	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1988:	42,395	13,036	6,047	1,723	48,441	14,760
1989:						
January–June:						
Domestic:[4]						
Agricultural	r17,943	r5,434	1,693	501	r19,636	r5,934
Industrial	11	3	924	252	935	255
Subtotal	r17,954	r5,437	2,617	753	r20,571	r6,189
Exports[5]	4,120	1,326	102	32	4,222	1,358
Total[3]	r22,074	r6,763	2,719	785	r24,793	r7,547
July–December:						
Domestic:[4]						
Agricultural	17,473	5,269	2,171	626	19,643	5,894
Industrial	34	10	1,190	320	1,223	330
Subtotal	17,507	5,279	3,361	946	20,866	6,224
Exports[5]	3,549	1,143	71	21	3,620	1,164
Total[3]	21,056	6,422	3,432	967	24,486	7,388
Grand total[3]	43,130	13,185	6,151	1,752	49,279	14,935

r Revised.
[1] Data for the same items appearing in this and other tables may not reconcile because of manual or computer rounding.
[2] Includes Idaho, Montana, and Utah.
[3] Data may not add to totals shown because of independent rounding.
[4] Includes rock converted to products and exported.
[5] Exports reported to the Bureau of Mines by companies.

TABLE 9

FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK SOLD OR USED BY PRODUCERS[1]

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[2] (thousands)	Average per ton f.o.b mine
1985	40,857	12,702	$972,748	$23.81
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	43,129	13,184	951,995	22.07

[1] Data for the same items appearing in this or other tables may not reconcile because of manual or computer rounding.
[2] The total value is based on a weighted value.

cult to unload frozen ore from trucks or rail cars, ore was stockpiled near the electric furnaces and chemical plants to permit year-round production.

During 1989, stock levels were about 9.5 million tons in January, 10.9 million tons in June, and stabilized at about 11 million tons for the balance of the year.

TRANSPORTATION

Phosphate rock was moved by rail from production centers in central and north Florida to terminals on Hillsborough Bay, FL and in Jacksonville, FL. The CSX Transportation Railroad moved phosphate rock from central Florida to Eastern Associated Terminals Co., Rockport Phosphate Terminal, International Minerals & Chemical Phosphate Terminal Co., and Agrico's Big Bend Terminal. Phosphate rock was shipped in bulk carriers to ports around the world and barged from Hillsborough Bay to chemical fertilizer plants on the Mississippi River. Freight, loading, and weighing charges were components of the cost of transporting phosphate rock from mine to vessel in central Florida. In 1974, the cumulative cost was $2.20 per ton. By 1990, the total cost increased to $6.98 per ton plus a Rockport Phosphate Terminal improvement charge of $0.36 per ton. Weighing charges were available at the shipper's request that reduced the cost from $0.22 per ton to about $0.02 per ton for a 20,000 ton cargo.

In north Florida, the Norfolk Southern Railroad transported phosphate rock from mine to vessel at Jacksonville, FL at a total cost of $9.08 per ton.

Specially designed barges with a capacity of 2,431 tons moved phosphate rock from the Lee Creek Mine to the Morehead City Port Terminal. The barge's capacity can move more than 15,400 tons every 3 days over the 93-kilometer section of the intercoastal waterway. Self-unloading barges discharged to conveyors for either direct delivery to a traveling shiploader or to a storage building. In Tennessee and the Western States, phosphate rock was moved by rail or truck from mine to beneficiation plant. Recently, two companies have installed slurry pipelines to convey concentrates to chemical fertilizer plants.

TABLE 10

TENNESSEE AND WESTERN STATES[1] PHOSPHATE ROCK SOLD OR USED BY PRODUCERS[2]

Year	Rock (thousand metric tons)	P_2O_5 content (thousand metric tons)	Value	
			Total[3] (thousands)	Average per ton f.o.b. mine
1985[4]	NA	NA	NA	NA
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	1,751	120,459	19.58

NA Not available.
[1] Includes Idaho, Montana, and Utah.
[2] Data for the same items appearing in this and other tables may not reconcile because of manual or computer rounding.
[3] The total value is based on a weighted value.
[4] Data for Tennessee and Western States were reported separately in the 1985 Minerals Yearbook chapter.

PRICES

The price or value of phosphate rock was obtained by semiannually surveying the industry to obtain domestic and export prices, f.o.b. mine, from each company in the United States. Price or value was obtained for each grade of phosphate rock produced by each company. Weighted averages were calculated for each grade and market. The average composite domestic and export f.o.b. actual mine price, dollars per ton, are shown in table 12.

The selling price of phosphate rock is negotiated between the buyer and seller. If exported from Tampa or Jacksonville, FL, the price included a freight, loading, and weighing cost of $6.53 per ton and $8.82 per ton, respectively. The severance tax included in the export price was $1.54 per ton.

TABLE 11

MARKETABLE PHOSPHATE ROCK YEAREND STOCKS

(Million metric tons)

Year	Quantity
1980	13.7
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

FOREIGN TRADE

Exports

The United States was a net exporter of phosphate rock in 1989. The demand for phosphate rock was principally tied to the demand of downstream phosphate fertilizer industries. India has, in past years, purchased phosphoric acid from Morocco. In a dispute over pricing, India stopped purchasing phosphoric acid and manufacturing DAP. It chose instead to purchase about 2.5 million tons of DAP, which was, for the most part, supplied by United States producers. In addition, shipments of DAP to China were 2.3 million tons. With large volumes being absorbed by the export market, plants operated in excess of 90% of capacity in the United States. It is probable that exported DAP will total about 8.3 million tons, the highest level achieved in any prior year.

Exports of triple superphosphate declined for the fifth consecutive year to

TABLE 12

TIME-PRICE RELATIONSHIPS FOR PHOSPHATE ROCK[1]

(Dollars per metric ton)

Year	Actual prices	Based on constant 1982 dollars
1969	6.14	15.43
1970	5.80	13.81
1971	5.80	13.06
1972	5.62	12.09
1973	6.24	12.61
1974	12.10	22.41
1975	25.35	42.75
1976	21.26	33.69
1977	17.39	25.84
1978	18.56	25.71
1979	20.04	25.50
1980	22.78	26.58
1981	26.63	28.33
1982	25.52	25.52
1983	23.97	23.07
1984	23.99	22.27
1985	24.31	21.92
1986	22.25	19.55
1987	19.37	17.34
1988	19.56	16.08
1989	21.76	17.23

[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)	1986[3]	1987[4]	1988[5]	1989[6]
75	$33.00	$32.00	$33.00	$38.00
72	31.00	29.00	31.00	35.50
70	27.00	27.50	28.00	32.00
68	25.50	24.00	26.00	31.00

[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 $2.51 severance tax.
[4] Estimated selling price including $2.46 severance tax.
[5] Estimated selling price including $1.49 severance tax.
[6] Estimated selling price including $1.54 severance tax.

TABLE 14

MOROCCAN PHOSPHATE ROCK EXPORT PRICES, U.S. DOLLARS PER METRIC TON, F.A.S. SAFI OR CASABLANCA,[e] BY GRADE

Grade (percent BPL[1] content)	1986	1987	1988	1989
Khouribga:				
76 to 77	45.00	42.00	45.00	49.00
70 to 71	36.00	34.00	38.00	42.00
Youssoufia:				
74 to 75	40.50	39.50	45.00	49.00
68 to 69	30.50	30.00	34.00	37.00

[e] Estimated.
[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

the range of 700 to 900 thousand tons.

Phosphate rock exports were 7.8 million tons, continuing the trend of gradually declining tonnages. After exports peaked in 1979 at 14 million tons, phosphate rock exports declined, and except for a small improvement in 1983, the trend persisted in recent years. The gradual loss of this market was attributed to converting more phosphate rock to higher value products, intense competition from other producing countries offering high-quality phosphate rock and positioned closer to markets than U.S. exporters, and the inability of U.S. companies to export phosphate rock of competitive grade and quality. Although the U.S. industry's supply problem will persist, overcapacity in all phosphate commodity lines will probably remain with the industry in the near term.

Imports

Phosphate rock imports had reached levels of 500 to 900 tons from 1978–80 when a company imported phosphate rock while developing its own mine. From 1981 through 1985, imports declined to a level of 9 to 34 thousand tons of low-fluorine material. Imports significantly increased to the 500 to 700 thousand ton level from 1986 through 1989. High-quality and grade phosphate rock was imported to satisfy a demand for phosphate rock that was unavailable domestically. It is probable that phosphate rock imports will increase in the future to plants in the United States located on water and with limited supplies of domestic high-grade and quality phosphate rock.

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)	1988			1989		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	29.40	30.51	30.15	27.70	38.63	29.87
72 to less than 74	20.31	26.35	24.57	25.73	30.57	29.29
70 to less than 72	25.97	27.30	26.92	25.04	29.47	28.90
66 to less than 70	16.94	22.16	17.38	19.68	26.73	20.31
60 to less than 66	18.67	18.59	18.66	22.83	20.82	22.76
Less than 60	27.56	—	27.56	—	—	—
Average	18.29	25.24	19.58	20.65	28.67	22.07

[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)	1988			1989		
	Domestic	Export	Average	Domestic	Export	Average
72 to less than 74	—	—	—	36.93	—	36.93
70 to less than 72	36.38	—	36.38	36.38	—	36.38
66 to less than 70	27.33	38.08	28.60	26.50	44.88	27.56
60 to less than 66	10.53	—	10.53	10.02	40.00	11.61
Less than 60	11.35	—	11.35	12.87	—	12.87
Average	18.79	38.08	19.47	18.91	42.87	19.58

[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)	1988			1989		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	29.40	30.51	30.15	27.70	38.63	29.87
72 to less than 74	20.31	26.35	24.57	28.93	30.57	30.02
70 to less than 72	30.45	27.30	28.60	30.99	29.47	29.83
66 to less than 70	17.57	23.54	18.08	20.08	27.42	20.73
60 to less than 66	17.33	18.59	17.43	21.05	24.61	21.19
Less than 60	18.71	—	18.71	12.87	—	12.87
Average	18.36	25.58	19.56	20.40	28.98	21.76

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

WORLD REVIEW

Phosphate rock production was maintained at about 162 million tons. Production was maintained from existing mines and from reactivating several that were closed. Not only were no new mines producing in 1989, there were no announcements of new mine development during the year. In the United States, demand for downstream products actually increased, but producers oversupplied the market in anticipation of an 8% to 10% growth rate after the drought of 1988. The oversupply caused DAP prices to drop after the Indian market was supplied.

The United States share of world production of phosphate rock declined to about 30%. The world supply of phosphate rock again exceeded demand allowing only a modest increase in prices. The Four Corners Mine in central Florida was restarted at the beginning of the year. The Wingate Creek Mine remained closed, and several other mines were scheduled to close in 1990 and 1991 as the deposits were mined out.

The principal producing countries in decreasing order of production were the United States, the U.S.S.R., Morocco, China, Tunisia, Jordan, Brazil, Togo, and the Republic of South Africa. No new mines were commissioned during the year. Production increases were achieved from existing mines.

Industry Structure

There were no significant changes in the structure of the phosphate industry

TABLE 18

U.S. EXPORTS OF GROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.20.0000)[1]

Country	1988		1989	
	Quantity[2]	Value	Quantity	Value
Australia	383		5	
Austria	62		—	
Belgium-Luxembourg	388		—	
Brazil	151		—	
Canada	1,186		165	
Finland	85		—	
France	855		586	
Germany, Federal Republic of	542		211	
India	404		10	
Italy	194		17	
Japan	1,028	NA	1	NA
Korea, Republic of	1,361		1	
Mexico	519		46	
Netherlands	872		361	
New Zealand	107		163	
Philippines	1		—	
Poland	542		—	
Romania	42		39	
Sweden	151			
Other	203		40	
Total[3]	8,092	206,984	1,645	57,708

NA Not available.

[1] In 1988, Schedule B No. 480.4500.

[2] Individual country exports furnished by Bureau of the Census will not add to totals.

[3] Total quantity and value f.o.b. mine reported to the Bureau of Mines in 1988 includes ground and unground phosphate rock. Total quantity and value of ground phosphate rock in 1989 were reported by the Bureau of the Census.

TABLE 19

U.S. EXPORTS OF UNGROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 2510.10.0000)[1]

Country	1988		1989	
	Quantity[2]	Value	Quantity	Value
Australia	383		282	
Austria	62		32	
Belgium-Luxembourg	388		294	
Brazil	151		—	
Canada	1,186		766	
Finland	85		37	
France	855		92	
Germany, Federal Republic of	542		353	
India	404		420	
Italy	194		88	
Japan	1,028	NA	790	NA
Korea, Republic of	1,361		1,267	
Mexico	519		610	
Netherlands	872		662	
New Zealand	107		42	
Philippines	1		—	
Poland	542		631	
Romania	42		—	
Sweden	151		196	
Other	203		117	
Total[3]	8,092	206,984	[4]6,678	231,282

NA Not available.

[1] In 1988, Schedule B No. 480.4500.

[2] Individual country exports furnished by Bureau of the Census will not add to totals.

[3] Total quantity and value, f.o.b. mine reported to the Bureau of Mines in 1988 includes ground and unground phosphate rock. Total quantity and value in 1989 were reported by the Bureau of the Census.

[4] Data do not add to total because of independent rounding.

other than ownership changes in the United States.

Capacity

The estimates of phosphate rock production capacity as shown in the accompanying table were not significantly changed from those of 1988. With an excess of capacity, there was no incentive to increase capacity.

Reserves

The availability of phosphate resources to support domestic fertilizer production for the U.S. agricultural sector and export demand has been questioned for a number of years. Both pessimistic and optimistic estimates have been made by scientists and businessmen. It appears, however, that the differences between estimates, if made with integrity, were frequently caused by what was being estimated rather than how much was there. Differences may relate to potential availability or currently available phosphate rock. Differences may be found in areas treated, in price assumptions or mining and beneficiation technology, in the quality of phosphate rock for different purposes, in the geologic assurance of existence or measurement, in the data used for estimates, and finally, in the methodology of assessing the resource.

Difficulties in producing compatible phosphate rock resource estimates also occur because of imprecise and confusing technical language. To eliminate the confusion, a sedimentary phosphate rock resource classification system was prepared to permit the differences to be analyzed. The principles of this classification system were presented in *U.S. Geological Survey Circular 831,* published in 1981 and prepared by the U.S. Geological Survey and the U.S. Bureau of Mines to facilitate the assessment of national phosphate rock resources. The criteria developed relate as much as possible to current industrial practice. Because industry practices vary from mine to mine, parameter limits will vary, and tradeoffs are possible. The criteria are guidelines that may be replaced for specific deposits.

As high-grade phosphate rock deposits are depleted, it is probable that technology will change to permit the mining and processing of lower quality phosphate rock. If favorable economics permit, this could change the classification criteria for the resource classes.

The classification system was based on the degree of geologic assurance and the feasibility of economic recovery. Phosphate rock resources were classified as identified or undiscovered. The varying degrees of geologic certainty were expressed as proved, probable, and possible. Resources can be classified according to their degree of economic feasibility. These include economic, marginally economic, and subeconomic resources.

Phosphate economic resources may be profitably extracted and produced under defined investment assumptions that are established or assumed with reasonable certainty. Phosphate reserves are that part of the demonstrated resource that can be profitably extracted or produced at the time of determination.

The phosphate reserve base is defined as that part of an identified phosphate resource that meets specified minimum physical and chemical criteria relating to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated resource from which reserves are estimated. It may include those parts of the resource that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Tables 28 and 29 show the United States and world phosphate reserves and reserve base estimates.

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)[1]

Country	1988		1989	
	Quantity	Value[2]	Quantity	Value[2]
Argentina	3		8	
Australia	(3)		56	
Bangladesh	205		102	
Belgium-Luxembourg	—		—	
Brazil	78		2	
Bulgaria	—		—	
Burma	40		—	
Canada	148		—	
Chile	206		110	
Colombia	13		8	
Costa Rica	10	NA	11	NA
Czechoslovakia	—		—	
Dominican Republic	11		2	
Germany, Federal Republic of	—		67	
Japan	57		48	
Mexico	—		—	
Pakistan	17		—	
Peru	25		21	
Poland	15		—	
Uruguay	4		6	
Other	85		76	
Total	917	140,934	517	149,377

NA Not available.
[1] In 1988, Schedule B No. 480.7050.
[2] All values f.a.s.
[3] Less than 1/2 unit.

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)[1]

Country	1988		1989	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Canada	18,868	NA	3,312	
Ecuador	—	—	2,983	
Spain	—	—	6,026	NA
Uruguay	—	—	4,012	
Other	4,302	NA	776	
Total	23,170	NA	17,109	$2,484

NA Not available.
[1] In 1988, Schedule B No. 480.7030.
[2] All values f.a.s.

Source: Bureau of the Census.

OUTLOOK

Mine production plans offer a reasonable guideline on what to expect from phosphate rock mines in future years. It is probably the most reliable method of forecasting future supply. However the industry responded to demand in 1989 and produced about 2 million tons more than was planned. Based on producer's plans, phosphate rock production estimates were 48, 48, 49, 53, 53, and 54 million tons in 1990, 1991, 1992, 1993, 1994, and 1995, respectively. It is probable that this supply scenario will be followed. During this period, some mines will deplete and close, others will be reactivated or remain closed.

In 1988, the Bureau of Mines contracted with Wharton Econometric Forecasting Associates to develop a model for projecting long-term and short-term demand for primary fertilizer nutrients and raw materials. The demand estimates were based on projected trends in world population, harvests of major crops, harvested area, and fertilizer application rates. The report concluded that North American phosphate rock demand will depend on North American phosphate rock production and demand for phosphates. Between 1975 and 1980, phosphate rock demand increased by 6% annually, reaching 38.4 million tons in 1980. However, since 1980, phosphate rock demand declined to 33.9 million tons, an average decline of 1.7% per year. Because North American phosphate fertilizer demand is projected to increase by 20% and world phosphate fertilizer demand is projected to increase by 16% through 1995, North American phosphate rock demand will increase to 41 million tons in 1995. Based on this supply-demand analysis, phosphate rock supply will exceed demand in 1995.

BACKGROUND

The United States phosphate rock industry entered the 1980 decade by producing a record 54.4 million metric tons in 1980, and the outlook for the decade was highly optimistic for the mining industry. The U.S. agriculture

sector drove the demand for phosphate fertilizers to feed an expanding world population. Farm land prices increased as more acreage was planted. Phosphate mining company representatives forecasted substantial new phosphate mining capacity to be developed in the southern extension of the Bone Valley Formation in central Florida.

At the end of 1980, President Carter embargoed grain shipments and phosphates to the U.S.S.R. to retaliate for the U.S.S.R.'s invasion of Afghanistan. By 1982, demand for farm products weakened, and demand for phosphate fertilizers declined substantially in the domestic and export markets. During the economic downturn in 1982, several phosphate rock mines were closed or operated at reduced levels. Annual phosphate rock production declined to 37.4 million tons. The industry began recovering in 1983 with the implementation of the Government's "payment-in-kind" program to attempt to reduce grain inventories and stimulate demand. In the eastern United States, unfavorable economic conditions, environmental concerns, and political attitudes virtually ensured that no new phosphate rock mines would be developed during the rest of the decade.

Although the phosphate mining industry increased production through 1985, the depressed state of the U.S. agriculture sector limited demand. The export market helped the industry survive; however, mines and plants were temporarily closed, some merged, and some closed to reduce inventories and bring about a supply-demand balance. The recession in the phosphate rock mining industry appeared to abate by 1985 when production reached 50.8 million tons. However, in 1986 the phosphate rock mining industry produced only 40.3 million tons as demand remained suppressed. Inventories were controlled by plant closings and reduced operating schedules. Employment declined as the industry attempted to minimize losses. Production stabilized as 41.0 million tons was produced in 1987. The demand for phosphate fertilizers improved in early 1988, but the drought of 1988 reduced phosphate fertilizer consumption. Production rose to 45.4 million tons. The recessionary decade of the 1980's ended for the phosphate rock mining industry in 1989 when 49.8 million tons was produced. Although some forecasters expected demand for phosphate fertilizers to exceed the 51 million tons consumed, production and consumption gains over those of 1988 were modified by continuation of the drought in some areas and excessive moisture in other areas. The export demand for manufactured fertilizers exceeded those of prior years, a windfall that was not expected to reoccur in 1990.

The phosphate rock mining industry exported 7.8 million tons, imported 705,000 tons, and consumed an apparent 42.1 million tons. A summary of the industry's production plans indicated that it would produce 48 million tons in 1989 or about 4% less than the 49.8 million tons actually produced.

U.S. production of elemental phosphorus produced from electric furnaces reached 565 thousand tons in 1969 and has gradually declined since that time. By 1988, production had leveled off at

TABLE 22

U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

(HTS No. 3105.30.0000)[1]

Country	1988		1989	
	Quantity	Value[2]	Quantity	Value[2]
Argentina	92		80	
Australia	133		246	
Belgium-Luxembourg	332		463	
Brazil	60		12	
Canada	256		614	
Chile	90		78	
China	1,778		2,337	
Colombia	160		104	
Costa Rica	29		19	
Dominican Republic	27		43	
Ecuador	35		26	
France	99		54	
Germany, Federal Republic of	31		34	
Guatemala	98		6	
India	582	NA	2,255	NA
Iran	293		128	
Ireland	21		45	
Italy	149		116	
Japan	396		367	
Kenya	53		74	
Mexico	22		51	
New Zealand	23		30	
Pakistan	576		33	
Peru	51		30	
Spain	102		90	
Thailand	46		88	
Turkey	201		268	
Uruguay	34		31	
Venezuela	45		100	
Yugoslavia	39		52	
Other	101		419	
Total	5,954	1,081,048	8,293	1,465,749

NA Not available.
[1] In 1988, Schedule B No. 480.8005.
[2] 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)[1]

Country	1988		1989	
	Quantity	Value[2]	Quantity	Value[2]
Argentina	3		6	
Australia	28		88	
Belgium-Luxembourg	11		10	
Brazil	49		3	
Canada	359		240	
Chile	1		5	
China	52		56	
Colombia	40		35	
Costa Rica	—		—	
Dominican Republic	—		—	
Ecuador	3		3	
France	—		—	
Guatemala	33		12	
Hungary	10		29	
India	—	NA	—	NA
Ireland	—		—	
Italy	96		61	
Japan	82		121	
Kenya	—		—	
Mexico	—		1	
New Zealand	1		5	
Pakistan	—		—	
Peru	—		—	
Saudi Arabia	46		62	
Spain	5		—	
Thailand	10		27	
Turkey	—		—	
Uruguay	3		2	
Venezuela	3		31	
Other	24		12	
Total	[3]857	159,691	809	142,515

NA Not available.

[1] In 1988, Schedule B No. 480.8005.

[2] All values f.a.s.

[3] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

about 320 thousand tons per year. The drop in production was attributed to restrictions on the use of phosphate detergents in an attempt to reduce environmental damage to receiving waters. About 85% of U.S. elemental phosphorus production was converted into thermal or furnace-grade phosphoric acid. About 50% of the phosphoric acid was used to produce sodium tripolyphosphate, the detergent builder.

Several processes have been developed to purify wet process phosphoric acid to an acceptable level for some applications normally served by phosphoric acid produced by the thermal process. The purified wet-process phosphoric acid can be used in the production of high-purity products for industrial cleaning markets. Thermal acid will probably continue to be used in electronic applications. A shift to production of more purified phosphoric acid appears probable in North America to reduce costs and minimize the impact on the environment.

Definitions

In Florida and North Carolina, the phosphate ore zone or bed is called the matrix. The industry practice in Florida, North Carolina, and Tennessee is to express production and reserves in terms of concentrated product. Chemical analysis of the product may be reported as percent P_2O_5 or tricalcium phosphate, $Ca_3(PO_4)_2$, also referred to as bone phosphate of lime (BPL).

The phosphate content or grade of phosphate rock is normally reported as percent P_2O_5, determined by chemical analysis. It may also be expressed as percent BPL, reminiscent of the time when bones composed the principal source of phosphate in fertilizer manufacture (percent BPL = 2.1853 × percent P_2O_5). It is the basis on which phosphate rock is sold, almost always as a beneficiated concentrate.

The chemical analysis of pebble, the plus 16-mesh washer product, and the 1 millimeter by 0.1 millimeter flotation concentrates, ranges from 25% to 34% P_2O_5 in Florida mines. Of interest is the percent P_2O_5, or percent BPL, and the CaO, Fe_2O_3, Al_2O_3, and MgO content. For phosphoric acid and DAP phosphate manufacture, a phosphate rock product with a ratio of Fe_2O_3 + Al_2O_3 + MgO to P_2O_5 less than 0.1 is preferred. This product specification can be achieved more easily from deposits in the Bone Valley Formation of central Florida than from deposits in the southern extension of the Bone Valley Formation in south-central Florida.

North Carolina phosphate rock concentrated by single anionic flotation analyzes about 28% P_2O_5 and contains some free silica, which is not particularly detrimental to phosphoric acid production. North Carolina phosphate rock, because of its high level of organic matter and other composition variations, is lower in grade than Florida rock. The organic matter may be burned off by calcining at 790° C to 820° C. Single flotation calcined rock of about 65% to 66% BPL (30% P_2O_5) is produced for captive phosphoric acid manufacture. It produces high-quality acid, but the capacity of the phosphoric acid plant may be reduced by lower filtering rates. Two-stage flotation cal-

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)[1]

Country	1988		1989	
	Quantity	Value[2]	Quantity	Value[2]
Australia	31		49	
Canada	2		12	
Colombia	13		34	
India	233	NA	455	NA
Indonesia	22		—	
Japan	20		19	
Venezuela	75		110	
Other	38		24	
Total	434	74,998	703	124,074

NA Not available.
[1] In 1988, Schedule B No. 480.7015.
[2] 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)[1]

Country	1988		1989	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Brazil	690	$1,348	434	$933
Canada	11	14	38	60
Japan	8,543	12,628	9,758	15,118
Korea, Republic of	3,076	4,486	1,746	2,863
Mexico	5,302	7,407	7,280	8,856
Taiwan	4	26	9	21
Other	1,016	1,630	669	443
Total	18,642	27,539	19,934	28,294

[1] In 1988, Schedule B No. 415.3500.
[2] All values f.a.s.

Source: Bureau of the Census.

cined rock analyzes about 72% BPL (33% P_2O_5) and is sold in the phosphate rock market or converted to clear phosphoric acid.

Phosphate ore mined in Tennessee was washed and classified to produce a sand sized product ranging from 0.044 to 6.35 millimeters. Washer feed ranges from 18% to 25% P_2O_5, and the sand-size product contains 23% to 32% P_2O_5. All of the sand-size product was agglomerated and blended with proportioned quantities of sized coke and quartz pebble before smelting in electric furnaces. The silica and calcium constituents combine to produce a fluid slag, the carbon oxidizes to carbon monoxide gas, and volatilized elemental phosphorus is conducted out of the furnace, condensed in cooling towers with water sprays, and collected under water. The slag and a ferrophosphorus byproduct are tapped periodically from the furnace.

Most Western U.S. phosphate ore was beneficiated by crushing, washing, classifying, and drying. Several mines also used a flotation circuit. The product from the beneficiation plant was normally calcined to reduce the hydrocarbon content before shipment to a chemical plant. To meet the demands of fertilizer plants and electric furnaces, western phosphate rock is classified as + 31% P_2O_5 acid or fertilizer grade; 24% to 31% P_2O_5 furnace grade; 18% to 24% P_2O_5 beneficiation grade; and 10% to 18% P_2O_5 low-grade shale. Acid-grade rock was used directly in fertilizer plants, furnace-grade rock was charged to electric furnaces, beneficiation-grade rock was upgraded to acid grade or furnace feed, and low-grade shales were stockpiled for possible future use.

Products for Trade and Industry

Phosphate rock was the raw material used to manufacture phosphate fertilizer, animal feed supplements, and industrial chemicals.

Manufactured fertilizers, or commercial fertilizers, contained one or more essential plant nutrients and were differentiated from green cover crops, farm manure, and ashes that also qualify under the definition of fertilizer, i.e., to make farming more productive. The primary plant nutrients are nitrogen, phosphorus, and potassium. Unfortunately, the phosphate mineral is very insoluble and, therefore, a poor source of phosphorus for plants. For this reason, phosphate rock is treated with an excess of sulfuric acid to produce merchant-grade, wet-process phosphoric acid that contains 52% to 54% P_2O_5 after water evaporation. It is used to make the monoammonium phosphate and DAP fertilizers and liquid mixed fertilizers.

Furnace-grade phosphoric acid is produced by smelting phosphate rock with fine free coke and silica in an electric furnace. Elemental phosphorus offgas is collected underwater. It is burned and converted to a relatively pure phosphoric acid that is used principally in the detergent and food industries.

Superphosphoric acid is produced by concentrating merchant-grade acid to 68% or 72% P_2O_5. It contains polyphosphates rather than orthophosphates, has the advantage of higher solubility, and can dissolve more impurities when making liquid fertilizers.

Triple superphosphate is produced by treating phosphate rock with phosphoric acid. The product has 44% to 46% P_2O_5 and is manufactured in granular or pow-

TABLE 26

U.S. IMPORTS FOR CONSUMPTION OF PHOSPHATE ROCK AND PHOSPHATE MATERIALS

(Thousand metric tons and thousand dollars)

Phosphatic materials	HTS NO.[1]	1988		1989	
		Quantity	Value[2]	Quantity	Value[2]
Natural calcium[3] phosphates unground	2510.10.0000	r676	r26,310	705	29,878
Natural calcium[3] phosphates ground	2510.20.0000	—	—	([4])	254
Dicalcium phosphate	2835.25.0000	r2	2,688	76	43,184
Phosphorus	2804.70.0000	18	24,837	—	—
Normal superphosphate	3103.10.0010	([4])	69	1	286
Triple superphosphate	3103.10.0020	105	17,271	([4])	22
Diammonium phosphate	3105.30.0000	10	r2,430	14	3,903
Fertilizer containing nitrates and phosphates	3105.51.0000	NA	NA	18	2,736
Phosphoric acid	2809.20.0010	1	r107	([4])	21

r Revised. NA Not available.
[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.

dered form.

Normal or ordinary superphosphate was for many years the leading commercial fertilizer because of its ease of manufacture; pulverized phosphate rock was mixed with sulfuric acid and cured. The popularity of this fertilizer declined because of its relatively low, 18% to 20% P_2O_5, analysis.

Ammonium phosphate is made by treating phosphoric acid with ammonia. The most popular ammonium phosphate product contains 18% nitrogen and 46% P_2O_5 (18-46-O) and is commonly called DAP. Other ammonium phosphate product compositions are 16-48-O, 11-48-O, and 12-52-0.

Nitrophosphates are produced by reacting nitric acid with phosphate rock to produce a 14% to 22% nitrogen, 10% to 22% P_2O_5, fertilizer.

Phosphorus products used to supplement animal feeds include diammonium and monoammonium phosphates, monohydrate and anhydrous monocalcium phosphate, dihydrate and anhydrous dicalcium phosphate, tricalcium phosphate, phosphoric acid, a number of sodium phosphates, sodium tripolyphosphate, and trisodium phosphate.

Industry Structure

The principal phosphate rock-producing countries in the world in order of decreasing production were the United States, the U.S.S.R., Morocco, China, Tunisia, Jordan, Brazil, and Israel. Thirty-four countries reported producing phosphate rock in 1989. World production was an estimated 162 million tons.

In the United States, phosphate rock was mined in Florida, Idaho, Montana, North Carolina, Tennessee, and Utah. In central Florida, 8 companies operated 14 mines that produced phosphate rock from the Bone Valley Formation. Agrico operated the Payne Creek and Fort Green Mines. CF Industries produced phosphate rock from its Hardee Complex Mine in Hardee County on a reduced operating schedule. Estech Inc. produced phosphate rock from its Silver City Mine and planned to produce in 1990 until the reserve was depleted. C&G Holdings own the Silver City Mine. Gardinier, operated its Fort Meade Mine in Polk County. Seminole purchased the assets of W. R. Grace & Co. in Florida and sold the company to Tosco Corp. in 1989. The company operated the Hookers Prairie Mine. Hopewell Land Partners Ltd. sold its mine to IMC. IMC will recover about 10 million tons of phosphate rock from its Hopewell Mine. IMC reopened its Four Corners Mine in central Florida and planned to pump matrix from its Lonesome deposit in southeast Hillsborough County to Four Corners in 1990. IMC closed the Haynsworth Mine, purchased the Hopewell Mine, and produced phosphate rock from Clear Springs, Kingsford, Noralyn/Phosphoria, and Four Corners Mines. The Lonesome Mine beneficiation plant was idle during the year. Mobil reactivated the Nichols Mine in 1989 and planned to reopen the Big Four Mine in 1990 to coincide with closing the Fort Meade Mine. The South Fort Meade deposit was projected to start producing in 1995 after the Big Four Mine was depleted. USX Agri-Chemical Div. was purchased by Sinochem U.S.A. Inc., was renamed U.S. Agri-Chemical Corp., and continued to mine the Rockland Mine. Nu-Gulf did not operate the Wingate Creek Mine, and it was reported for sale. Occidental operated the Suwannee River and Swift Creek Mines in north Florida to produce superphosphoric acid for export to the U.S.S.R.

In its 1988 annual report, Elf Aquitaine published that Texasgulf produced 4.9 million tons of phosphate rock in that year. Texasgulf installed bucket-wheel excavators to strip overburden in 1989.

The remaining phosphate companies in Tennessee, Occidental Chemical Corp., Columbia, TN, and Rhône-Poulenc (formerly Stauffer Chemical Co.), Mt. Pleasant, TN, mined phosphate rock from Giles, Williamson, and Maury Counties. After sizing and agglomeration, the phosphate rock was smelted in electric furnaces to produce elemental phosphorus.

In Idaho, Rhône-Poulenc produced

TABLE 27

WORLD PHOSPHATE ROCK ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989 RATED CAPACITY[1]

(Million metric tons per year)

Country	Capacity
North America:	
Mexico	1.0
United States	60.0
Total	61.0
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
Korea, North	1.0
Vietnam	1.0
Other	1.0
Total	34.0
Oceania:	
Australia	1.0
Nauru	2.0
Total	3.0
World total	200.5

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

phosphate rock from its Wooley Valley Mine for shipment to its electric furnace plant at Silver Bow, MT. Rhône-Poulenc is planning a purified wet-process plant at Geismar, LA, to increase its capacity of high-purity phosphoric acid. The Conda Partnership mined the Mountain Fuel and Maybie Canyon deposits. The phosphate rock was used in Nu West's fertilizer plant at Conda, ID. Monsanto mined phosphate rock from its Enoch Valley Mine and smelted the rock in its Soda Springs, ID, electric furnaces. J. R. Simplot operated the Gay and Smoky Canyon Mines. A slurry pipeline from the Conda Mine to Conda, ID, will be extended to Pocatello to replace the railroad system. Reserves of the Gay Mine on the Fort Hall Indian Reservation will permit the mine to produce through 1994. Thereafter, production will be increased at Smoky Canyon to supply J. R. Simplot's fertilizer plant demand, and FMC Corp. will develop a new mine in Dry Valley to supply phosphate rock to its Pocatello, ID, electric furnaces.

Chevron produced phosphate rock concentrates from its Vernal, UT, mine. The concentrates were pumped to Rock Springs, WY, for conversion to phosphoric acid and DAP.

Cominco installed a new beneficiation and drying plant to process phosphate ore from its underground mine near Garrison, MT in 1988 and exported to Canada in 1989.

Tariffs and Taxes

Phosphate rock and phosphate fertilizers were imported duty free. The phosphate industry was subject to the usual local, State, and Federal taxes. In addition, a severance tax of $1.35 per metric ton ($1.49 per short ton) was applied in Florida in 1989; 2% of the net value in Idaho, and $25 plus 0.5% of the gross value over $5,000 in Montana was assessed. A history of the severance tax in Florida indicates the tax rose from $0.102 per ton in 1971 to a peak of $2.52 per ton in 1985. The Florida severance tax is currently based on $1.35 per ton at point of severance, then was adjusted with the Producers Price Index to $1.54 per ton in 1989.

Technology

Production of phosphate rock was similar in each of the 14 operating mines in Florida. The phosphorus-containing component in the matrix is apatite, a calcium phosphate containing varying amounts of carbonates and fluorides. The phosphate bearing matrix varies from 1.5 to 6.1 meters in thickness under an overburden of sand, clay, and a leach zone. The total overburden thickness, including the leach zone, ranges from 5.6 to 8.6 meters.

Mine planning was accomplished by taking core samples and processing the cores through bench-scale washing and flotation procedures, similar to those of a commercial plant to determine recoveries, quality, and product grade. Stripping overburden and mining matrix was accomplished with electric walking draglines with 32-cubic-meter or larger buckets on 68 meter booms. Mining cuts, after overburden was progressively stripped, were 900 meters in length and 90-meters wide. Pumps were used to prevent the pits from flooding. The dragline fed matrix to a sump where water monitors operating at a pressure of 17 kilograms per square centimeter slurried the matrix. It was pumped in 900-meter stages in steel pipe to the washing plant.

Washing plants were designed to size the material pumped to them. Trommel screens were frequently used to scrub the phosphate from the sand and clay matrix and reject material over 19 millimeters. The trommel undersize was screened at 14 mesh. The 19 millimeter by 14-mesh material was further washed on screens and log washers to liberate the phosphate mineral. Minus 14 mesh material reported to cyclones. The separated cyclone overflow, minus 150-mesh colloidal material, was pumped to settling ponds. The flotation process was used to separate the sand from the phosphate mineral. The flotation feed was conditioned with fatty acids to create a hydrophobic surface, and the phosphate mineral was floated to produce a rougher

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. 1989, 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.

concentrate. The rougher concentrate was treated with sulphuric acid to strip the fatty acids. An amine flotation circuit was used to float carryover sand, and the phosphate mineral was depressed. Flotation concentrates were conveyed into silos for dewatering and loaded into railroad cars for export or a fertilizer plant. The beneficiation plants' products, pebble and concentrate, were used in Florida chemical fertilizer plants or barged to fertilizer plants on the Mississippi River.

Sulfur, either recovered or Frasch, was received from heated ships at Tampa terminals or receiving terminals on the Mississippi River. In Florida, liquid sulfur was pumped into road tankers that delivered molten sulfur to the chemical plants. The liquid sulfur was burned to produce sulfuric acid. The phosphate rock was digested in sulfuric acid to produce phosphoric acid and waste phosphogypsum. The phosphoric acid was passed through evaporators to increase the phosphorus pentoxide concentration to the commercial grade, 54% P_2O_5. Phosphoric acid was reacted with anhydrous ammonia to produce DAP or reacted with phosphate rock concentrates to produce triple superphosphate.

Mining procedure was similar in North Carolina; however, the overburden was about 30 meters, considerably thicker. Hydraulic dredges were used to remove the top 12 meters of overburden. The dredges were replaced in 1989 with bucketwheel excavators. Draglines were used to strip the remaining overburden and mine approximately 12 meters of matrix. The matrix was beneficiated to produce a 67%-BPL product. Some of this product was calcined to remove organic compounds, carbon dioxide, and water and raise the grade to 72% BPL.

All phosphate rock in the Western States of Idaho and Utah was surface mined. There is an underground mine in Montana. Operators in southeastern Idaho principally used scrapers and bulldozers to remove overburden and mine the ore. Main bed ore for consumption in wet-process phosphoric acid plants and adjacent bedded furnace shale for electric furnace feed were mined selectively. In Utah, the phosphate rock was quarried after the limestone caprock was drilled, blasted, and trucked to waste. Underground ore in Montana was mined, crushed, sized, and dried before rail shipment to Canada. Ore mined in the Western States was transported by truck or rail to beneficiation plants. Phosphate rock concentrates were moved by truck, rail, or slurry pipeline to chemical fertilizer plants. Electric furnace feed was received by truck or rail transport.

Phosphate rock in the Western States was beneficiated for electric furnace feed and to produce wet-process phos-

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. 1, 1989, 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				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Phosphate rock:										
Algeria	1,207	1,203	1,073	1,332	1,223	e381	e380	e336	e404	371
Australia	33	34	11	13	8	7	7	2	2	1
Brazil	4,214	4,509	4,777	e4,672	3,580	1,475	1,620	1,694	e1,663	1,290
Chile	7	7	10	9	10	1	1	e1	e1	1
China[e]	6,970	6,700	9,000	15,000	15,500	1,882	1,810	2,700	4,050	4,100
Christmas Island (Indian Ocean)	1,187	880	842	—	—	418	310	e295	—	—
Colombia	23	27	34	e35	30	6	7	8	e9	8
Egypt	e1,074	1,271	1,167	e1,146	1,146	270	315	e312	e293	293
Finland	512	527	e553	584	560	189	195	e195	215	200
India	929	667	679	678	700	307	222	226	re224	231
Indonesia	1	1	3	1	311	(r4)	(r4)	1	(4)	4
Iraq[e]	1,000	1,000	1,500	1,273	1,300	218	218	330	382	385
Israel	4,076	3,673	3,798	3,479	3,922	1,210	1,110	e1,214	e1,092	1,231
Jordan	6,067	6,249	6,800	6,611	6,000	2,010	2,072	2,260	e1,868	1,800
Korea, North[e]	500	500	500	500	500	160	160	160	160	160
Mali	7	3	8	10	10	e2	e1	e2	e2	2
Mexico[5]	787	747	689	842	851	236	224	207	253	255
Morocco[6]	20,737	21,178	e20,000	25,015	24,400	e6,574	e6,714	e6,650	8,061	8,000
Nauru	1,508	1,494	1,376	1,540	1,500	e581	e575	e530	e593	590
Pakistan	—	50	32	re35	35	—	16	10	e10	10
Peru	12	5	61	13	13	e4	2	20	re4	4
Philippines	6	2	e8	7	7	2	1	e2	e2	2
Senegal[7]	1,814	1,850	1,874	2,326	2,273	e617	e641	e680	re801	783
South Africa, Republic of	2,433	2,920	2,623	e2,850	2,900	e883	e1,060	e950	e1,010	1,040
Sri Lanka	14	15	e21	23	25	5	5	e7	7	8
Sweden	187	192	e221	142	160	74	72	e82	52	60
Syria	1,270	1,606	1,986	2,342	2,250	380	485	606	715	690
Tanzania	15	e10	18	4	5	e4	e3	re5	re1	2
Thailand	4	5	5	8	9	1	1	2	e2	3
Togo	2,452	2,314	2,644	3,464	33,355	890	840	e960	e1,257	1,208
Tunisia	4,530	5,951	e6,390	6,103	6,100	e1,303	e1,712	e1,836	e1,813	1,800
Turkey	e37	3	19	74	384	e12	e1	e6	e23	26
U.S.S.R.[e]	33,750	33,900	34,100	r34,400	34,400	10,650	10,700	10,750	r10,850	10,850
United States	50,835	38,710	40,954	45,389	348,866	15,674	11,857	12,491	13,833	314,893
Vietnam[e]	516	530	300	r330	400	170	175	105	r115	140
Zimbabwe, concentrate	135	136	155	125	135	e47	re47	e54	re44	47
Total	r148,849	r138,869	144,231	160,375	162,268	r46,643	r43,559	45,689	49,811	50,488
Basic (Thomas converter) slag:										
Argentina	e1	(4)	(4)	(e4)	(4)	(e4)	(e4)	(e4)	(e4)	(4)
Belgium[e]	3143	180	175	170	165	326	32	32	31	30
Egypt[e]	10	8	8	8	8	2	2	2	2	2
France	1,165	855	re555	re555	500	210	154	re100	re100	90
Germany, Federal Republic of	491	374	e370	e400	400	67	54	re50	re45	45

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				
	1985	1986	1987	1988[p]	1989[e]	1985	1986	1987	1988[p]	1989[e]
Basic (Thomas converter) slag—Continued										
Luxembourg	701	620	542	[e]540	550	126	112	98	[e]95	99
United Kingdom	[e]4	—	—	—	—	[e]1	—	—	—	—
Total	2,515	2,037	1,650	1,673	1,623	432	[r]354	282	273	266
Guano:										
Chile	3	8	6	4	4	(4)	1	[e]1	([e 4])	(4)
Kenya	(4)	—	—	—	—	(4)	—	—	—	—
Philippines	1	3	[e]1	1	2	(4)	1	([e 4])	([e 4])	(4)
Seychelles Islands[e]	5	5	5	5	5	2	2	2	2	2
Total	9	[r]16	12	10	11	2	[r]4	3	2	2

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through May 30, 1990. 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: 1985—355; 1986—131; 1987—191; 1988—119; and 1989—100 (estimated).

phoric acid. The technology was similar to that of Florida and Tennessee, although plant flowsheets were tailored to fit the characteristics of each deposit. Western phosphate rock used to produce phosphoric acid was calcined to reduce hydrocarbon levels. Phosphate rock, as mined or beneficiated, was agglomerated before charging electric furnaces to produce elemental phosphorus.

In Tennessee, 150,000- to 200,000-ton ore bodies were stripped of overburden and mined with small draglines. The small dragline bucket was able to remove phosphate bearing ore between limestone crevices and cones (cutters) in the bedrock and light enough to be easily transported by low-boy from one deposit to the next selected for mining. Bulldozers were used to clear access roads to the deposit and remove topsoil and clay overburden. Trucks loaded by dragline moved ore to either a field washer, a railroad loading tipple, or a washer at the electric furnace plant.

Tennessee phosphate rock was beneficiated by washing through a 25-centimeter grizzly screen. The screen undersize was passed through a series of log washers, scrubbers, screens, and cyclones to produce a 0.044- to 6.35- millimeter sand product. Washer feed ranged from 18% to 25% P_2O_5, and the sand concentrate analysis ranged from 23% to 32% P_2O_5. The sand concentrate was nodulized in rotary kilns to convert the sand to 1.9- to 5.1-centimeter nodules, which, after screening to remove oversize and undersize material, were charged to electric furnaces with fine free coke and quartz pebbles to produce elemental phosphorus.

[1] All quantities are in metric tons unless otherwise specified.

PLATINUM-GROUP METALS

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 15 years industry and Bureau of Mines experience, has been the commodity specialist for platinum-group metals for 9 years. Domestic survey data were prepared by Evangeline Hemphill, mineral data assistant. International data tables were prepared by Harold Willis, international data assistant.

The Republic of South Africa remained the leading producer of platinum and the U.S.S.R. remained the leading producer of palladium. In the future, most new production capacity for platinum-group metals (PGM) was expected to come from the Republic of South Africa.

Environmental legislation and concern over clean air continued to be a major factor driving PGM demand in the United States and Western Europe. With political changes sweeping Eastern Europe, it remains to be seen whether these countries will use catalytic converter technology to reduce automobile emissions. While the need is clear, the required capital to pay for clean air remains a problem.

LEGISLATION AND GOVERNMENT PROGRAMS

A bill authorizing the minting of a palladium commemorative coin was not approved by the House. The staff of the U.S. Mint testified that the coins would be difficult to produce. In addition, domestic sources of palladium are limited, and it is possible that some of the metal for the coin would have to come from sources originating in the U.S.S.R. or the Republic of South Africa.

The Administration's proposed Clean Air Bill called for decreasing the hydrocarbons limit for automobiles from the current 0.41 gram per mile to 0.24 gram per mile.

STRATEGIC CONSIDERATIONS

While domestic production of platinum and palladium from the Stillwater Mine increased, domestic mine production was refined in Belgium and in 1989 accounted for only 3% of U.S. imports of refined platinum and 9% of U.S. imports of refined palladium. Even though the Federal Government stockpiled platinum, palladium, and iridium, there were no Government programs engaged directly in the development or exploitation of mineral deposits. Exploration, development, and mining were considered to be functions of the private sector.

Import dependence on the Republic of South Africa and the U.S.S.R. remained an area of concern for the United States. The threat of disruption from South Africa appeared more related to mining labor unrest than any other factor. A disruption in supplies from the U.S.S.R. appeared unlikely given improvement in relations with that country and the need of the U.S.S.R. to generate foreign currency.

The Department of Defense, which oversees the National Strategic Stockpile, recommended to Congress that the Government purchase 933 kilograms of rhodium and 2,022 kilograms of ruthenium for the Stockpile.[1] In 1988, an advisory panel of the American Society of Metals also recommended the purchase. Stockpile goals remained unchanged at 40,746 kilograms of platinum, 93,311 kilograms of palladium, and 3,048 kilograms of iridium.

PRODUCTION

The only PGM mine in the United States, 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 platinum at the Stillwater Mine in 1989 was about 1,430 kilograms and production of palladium was about 4,850 kilograms. Small amounts of PGM were recovered as byproducts of domestic copper refining.

In 1989, SMC shipped its concentrates to Belgium for smelting and refining, but applied for permission to construct a $6 million smelter to process its PGM concentrates. The company hoped to complete construction by the end of 1990. Final refining of the precious-metal matte probably would still be done in Belgium.

CONSUMPTION AND USES

Platinum, palladium, and rhodium were used in emission catalysts for light trucks (trucks weighing 14,000 pounds or less, gross weight) and automobiles. A typical emission catalyst in 1989 contained approximately 1.77 grams of platinum, 0.47 gram of palladium, and 0.2 gram of rhodium, for a total of 2.44 grams PGM. These average quantities have not changed since 1985. There was variation in the quantities of PGM contained in each catalyst for any given year, depending on the year the vehicle was manufactured, the engine size, the normal operating temperature of the vehicle's engine, and the manufacturer of the catalyst. In 1989, there were 10.6 million vehicles produced in the United States that were subject to emissions control and outfitted with catalytic converters, of which about one-third were light trucks.

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

TABLE 1

SALIENT PLATINUM-GROUP METALS[1] STATISTICS

(Kilograms)

	1985	1986	1987	1988	1989
United States:					
Mine production:[2 3]					
Platinum	W	W	780	1,240	1,430
Palladium	W	W	2,330	3,730	4,850
Value[4] thousand dollars	W	W	$44,686	$67,622	$85,318
Refinery production:					
Primary refined	227	135	191	297	339
Secondary:					
Nontoll-refined	8,043	11,016	5,117	4,787	3,954
Toll-refined	32,293	35,924	44,935	46,403	46,253
Total refined metal	40,563	47,075	50,243	51,488	50,546
Stocks, yearend:					
Industry (refined)	35,106	40,187	38,412	35,515	32,543
National Defense Stockpile:					
Platinum	14,079	14,079	14,079	14,079	14,079
Palladium[5]	39,259	39,334	39,334	39,334	39,334
Iridium	920	920	920	920	920
Exports:					
Refined[6]	16,369	11,879	13,423	20,301	23,082
Total	27,640	23,349	22,031	28,787	38,128
Imports for consumption:					
Refined[6]	106,928	115,924	98,879	110,948	111,107
Total	124,090	139,256	118,397	124,324	113,278
Imports, general	124,090	136,824	118,397	124,324	113,278
Consumption (reported sales to industry)	70,650	64,705	60,280	70,998	78,439
Consumption, apparent[7]	104,511	109,904	95,457	103,302	101,230
Net import reliance[8] as a percent of apparent consumption	92	90	91	91	90
Price, dealer, average, per ounce:					
Platinum	$291	$461	$553	$523	$507
Palladium	$107	$116	$130	$123	$144
World: Mine production[9]	r246,988	r260,192	273,582	p281,854	e283,643

e Estimated. p Preliminary. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] The platinum-group comprises six metals: platinum, palladium, iridium, osmium, rhodium, and ruthenium.

[2] Byproduct of copper refining plus production from Stillwater Mining Co. for 1987–89.

[3] Estimates from published sources.

[4] Value based on dealer prices.

[5] Includes 75 kilograms purchased in 1985, but not added to inventory in that year.

[6] Excludes ores, scrap, and platinum grains and nuggets.

[7] 1985–1986 mine production excluded to avoid disclosing company proprietary data. 1987–1989 includes mine production plus nontoll-refined production plus refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

[8] Refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

[9] 1985–86 totals exclude U.S. mine production in order to avoid disclosing company proprietary data.

TABLE 2

PLATINUM-GROUP METALS REFINED IN THE UNITED STATES

(Kilograms)

	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[1]
PRIMARY METAL							
Nontoll-refined:							
1985	16	108	—	—	—	—	124
1986	19	116	—	—	—	—	135
1987	32	158	—	—	—	—	191
1988	46	248	2	—	(2)	—	297
1989	47	289	2	—	—	2	339
Toll-refined:							
1985	34	—	—	—	—	68	103
1986	—	—	—	—	—	—	—
1987	—	—	—	—	—	—	—
1988	—	—	—	—	—	—	—
1989	—	—	—	—	—	—	—
SECONDARY METAL							
Nontoll-refined:							
1985	1,629	6,263	8	—	97	46	8,043
1986	2,204	8,627	9	—	134	41	11,016
1987	1,180	3,743	4	19	123	49	5,117
1988	1,133	3,545	4	—	104	2	4,787
1989	1,149	2,670	6	—	94	35	3,954
Toll-refined:							
1985	15,259	15,270	218	(2)	1,130	415	32,293
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
1988 TOTALS[1]							
Total primary	46	248	2	—	(2)	—	297
Total secondary	24,017	24,468	256	19	1,930	501	51,191
Total refined metal	24,062	24,717	258	19	1,930	501	51,488
1989 TOTALS							
Total primary	47	289	2	—	—	2	339
Total secondary	25,207	22,707	225	1	1,659	408	50,207
Total refined metal	25,254	22,996	227	1	1,659	410	50,546

[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.

used for manufacturing thermocouples for precise temperature measurement.

For glass manufacturing applications, most of the PGM, specifically platinum, rhodium, and palladium, were used in bushings for the extrusion of textile or continuous filament glass fiber.

The nonautomotive catalyst applications of PGM were numerous. The petroleum refining industry used PGM, principally platinum, in reforming, cracking, and isomerization reactions. Chemical catalysts containing platinum and rhodium were used in inorganic syntheses of nitric acid and hydrogen cyanide. Palladium was used in the production of hydrogen peroxide. A wide variety of organic chemicals and pharmaceuticals were produced using PGM catalysts.

The Bureau of Mines does not collect data on domestic investor demand for platinum, but according to Johnson Matthey PLC, projected investor demand for 1989 in North America was expected to be about 1,866 kilograms, down from 2,644 kilograms in the previous year.[2] A summary of the typical uses for each PGM is shown in tables 4 and 5.

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 Bureau of Mines.

TABLE 3

PLATINUM-GROUP METALS[1] SOLD TO CONSUMING INDUSTRIES IN THE UNITED STATES[2]

(Kilograms)

Year and industry	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total
1985	31,905	32,980	332	28	2,745	2,662	70,650
1986	30,513	27,681	382	21	2,906	3,203	64,705
1987	25,471	30,956	250	29	2,692	882	60,280
1988:							
Automotive[3]	19,346	5,101	(4)	—	2,084	—	26,532
Chemical	3,184	3,669	117	—	109	604	7,683
Dental and medical	581	6,622	2	21	2	3	7,231
Electrical	3,494	13,049	190	—	123	1,067	17,923
Glass	681	11	(4)	—	85	1	779
Jewelry and decorative	385	196	20	—	177	14	792
Petroleum	1,072	1,438	75	—	1	—	2,587
Miscellaneous	2,383	4,156	89	2	710	132	7,471
Total	31,125	34,241	495	23	3,292	1,821	70,998
1989:							
Automotive[3]	18,774	4,886	—	—	1,982	—	25,643
Chemical	2,424	1,923	95	—	189	26	4,657
Dental and medical	632	8,424	105	57	1	15	9,233
Electrical	3,894	17,352	112	—	272	1,778	23,408
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	33,698	39,273	400	57	3,126	1,886	78,439

[1] Comprises primary and nontoll-refined secondary metals.
[2] Data may not add to totals shown because of independent rounding.
[3] 1985–89 platinum, palladium, and rhodium sales to the automotive industry are estimated based on U.S. light truck sales and U.S. automobile production.
[4] Less than 1/2 unit.

PRICES

In March, two scientists from the University of Utah announced that they had fused deuterium nuclei at a relatively low temperature using a palladium cathode immersed in heavy water. The process was regarded by some as a potential breakthrough in the decades-long search for a way of generating electricity from controlled nuclear fusion. While results of the experiment were being evaluated by other scientists, news of the announcement produced a flurry of speculation in palladium and caused dealer prices to increase from $135 per ounce in January to a high of $166 per ounce in April. As speculation tapered off, prices declined to about $137 per ounce by October.

The dealer price of rhodium began

TABLE 4

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		

increasing sharply in November and continued increasing in December, with spot prices approaching $2,000 per ounce. The increase was attributed to the reported technical difficulties at Johnson Matthey's newly commissioned Rustenburg refinery in Bophuthatswana. Also contributing to the price rise was the absence of rhodium sales by the U.S.S.R., the second largest supplier of rhodium after the Republic of South Africa.

WORLD REVIEW

In July, the European Community (EC) voted to require that all member nations comply with automobile exhaust emissions limits, comparable to those in the United States, by January 1, 1993, for cars with engine displacements less than 1.4 liters. Until now, most automobile catalytic converters in the EC were on cars with engine displacements greater than 1.4 liters. Consequently, the major producers of catalytic converters planned to expand capacity to meet the demand of what is potentially the world's largest automobile market. About 13 million new cars are sold per year in the EC. Plant expansions of autocatalyst facilities were anticipated in the Federal Republic of Germany, the Republic of Korea, Belgium, and France to meet the increased demand in Europe.[3]

According to the interim 1989 review on platinum published by Johnson Matthey, world investment demand for platinum decreased from 19,600 kilograms to only about 5,000 kilograms in 1989. Higher interest rates and less fear of a disruption in supply from South Africa contributed lower investor interest in platinum.

The International Precious Metals Institute (IPMI) of Allentown, PA sponsored a seminar on platinum-group metals January 29–31 in Las Vegas, NV. Presentations centered around the use of PGM in autocatalysts, industrial pollution control, fuel cells, jewelry, electronics, and health applications. Proceedings of the meeting are available for purchase through IPMI.

Capacity

Capacity for PGM is generally cited in terms of platinum capacity. The data in table 12 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.

South Africa, Republic of

Barplats Mines (formerly Lefkochrysos Ltd.) produced 933 kilograms of platinum at the Crocodile River Mine. Barplats is controlled by Rand Mines. All of Barplats' production was from the UG–2 reef, rather than from the more easily processed Merensky reef.[4] In the past, platinum producers have overcome the metallurgical problems of treating UG–2 ores by blending them with Merensky ores. It appears, however, that technical problems for treating pure UG–2 ores have been overcome.

Rustenburg Platinum Mines Ltd. decided not to develop the Maandagshoek platinum mine in the eastern Transvaal because of its inability to obtain tax concessions from the South African Government. The costs of developing the mine would have been too high without the tax concessions.

U.S.S.R.

The U.S.S.R. began marketing and selling a one-ounce palladium coin honoring Russian Ballet. The Ballerina palladium bullion coin is the world's first palladium bullion coin. Owing in part to the difficulties in minting, only about 30,000 coins were sold in 1989.[5]

TABLE 5

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 6

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[2]
1985	17,783	14,152	527	9	1,466	1,170	35,106
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	35,515
1989	14,791	15,182	522	36	1,096	916	32,543

[1] Includes metal in depositories of the New York Mercantile Exchange (NYMEX); on Dec. 31, 1989, this comprised 5,152 kilograms of platinum and 2,815 kilograms of palladium.
[2] Data may not add to totals shown because of independent rounding.

CURRENT RESEARCH

Nippon Mining Co. announced that it had developed a new corrosion resistant platinum magnet that contains 70% platinum and 30% iron. Its major application was expected to be in precision motors for use in ultravacuum and ultraclean environments.

TABLE 7

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
1985	475	291	127	107	915	929	600	438	101	915
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:										
January	600	492	150	124	1,275	1,187	420	333	67	602
February	600	452	150	119	1,275	1,238	420	326	65	610
March	600	491	150	121	1,275	1,235	420	310	62	603
April	600	492	150	124	1,275	1,230	420	315	62	509
May	600	545	150	122	1,275	1,231	420	310	60	580
June	600	576	150	127	1,275	1,266	420	309	61	590
July	600	543	150	124	1,275	1,185	420	304	65	625
August	600	529	150	124	1,275	1,214	420	302	45	625
September	600	506	150	119	1,275	1,218	420	305	67	625
October	600	522	150	120	1,275	1,191	420	286	63	580
November	600	566	150	125	1,275	1,232	420	287	60	580
December	600	557	150	131	1,275	1,190	420	287	60	580
Average	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

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.

Platinum-silicide was being investigated as a material that substitutes for cadmium-mercury-telluride in infrared detectors. Platinum-silicide performs better and is cheaper to produce than the traditional cadmium-mercury-telluride. Platinum-silicide detectors are made by depositing a layer of platinum only a few molecules thick over silicon integrated circuits. Infrared detectors made with platinum-silicide are used in military applications such as heat-seeking missiles.[6]

The Bureau of Mines investigated leaching PGM from scrapped automo-

TABLE 8

NYMEX TRADING VOLUME FOR FUTURES CONTRACTS, DECEMBER 31

(Number of contracts)

	1986	1987	1988	1989
Platinum[1]	1,624,635	1,361,546	1,460,455	1,190,529
Palladium[2]	145,562	160,284	139,883	200,892

[1] 50 troy ounces per contract.
[2] 100 troy ounces per contract.

bile catalysts using a solution of sodium cyanide. Recovery rates for platinum, palladium, and rhodium were over 90% and the process was environmentally safe. Work on the process to reduce recovery costs was progressing through 1990, at the Bureau's Reno Research Center.

OUTLOOK

World Supply of Platinum

The Republic of South Africa and the U.S.S.R. were the most important countries supplying platinum. Because of the planned opening of new mines and the expansion of existing ones, production of platinum in South Africa was projected to increase by one-third from about 83,000 kilograms in 1989 to about 111,000 kilograms by 1994.[7] For the U.S.S.R., sales of platinum to market economy countries was expected to decline because the Soviets are expected to boost their own consumption and/or increase sales to Eastern Europe, where platinum can be used to produce unleaded gasoline and reduce automobile emissions. Over the next 5 years, Canadian production of platinum should remain flat, while U.S. production could grow another 25% from expansion of the Stillwater Mine in Montana.

Jewelry demand for platinum in Japan should grow about 25% to 44,000 kilograms by 1994. Investment demand for platinum is probably the most volatile end use, subject to wide swings in either direction, depending on economic conditions, exchange rates, and interest rates.

World Demand for Platinum

Demand for platinum in automobile catalysts, particularly 3-way catalysts that use platinum and rhodium, was expected to be strong over the next 5 years.

In the United States, the number of cars and trucks outfitted with catalytic converters has remained between 10 million vehicles and 11 million vehicles from 1987 through 1989. While production of cars and trucks was expected to remain flat, overall consumption of platinum was expected to rise because of the greater amounts of platinum expected to be used in each catalytic converter. As mentioned earlier, the proposed Clean Air Bill called for reducing hydrocarbon and nitrogen oxide emissions. Another proposal being debated was extending the certification period for catalytic converters from 50,000 miles to 100,000 miles. All these measures, if enacted, would require about one-third more platinum per converter than currently used.

The decision of the Economic Community (EC) in 1989 to adopt emissions limits for cars with engines smaller than 1.4 liters will result in a large

TABLE 9

U.S. EXPORTS OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

(Kilograms)

Year and country	Platinum	Palladium	Rhodium	Iridium, osmium, ruthenium	Waste and scrap	Total	
						Quantity	Value (thousands)
1989:							
Australia	73	42	—	19	—	134	$1,477
Austria	2	116	—	—	—	118	624
Belgium	85	543	—	11	2,808	3,447	20,109
Brazil	143	22	35	1	—	201	5,803
Canada	1,902	644	197	17	443	3,203	45,814
China	150	907	36	28	—	1,121	7,919
France	128	62	—	1	100	291	3,829
Germany, Federal Republic of	140	499	250	143	2,703	3,735	41,639
Hong Kong	27	16	1	—	3	47	622
Italy	55	313	1	—	902	1,271	12,698
Japan	3,652	4,027	387	25	292	8,383	100,962
Korea, Republic of	348	40	70	1	1	460	8,364
Netherlands	—	1,497	—	—	—	1,497	9,941
Singapore	6	182	—	8	—	196	1,608
Sweden	—	22	—	79	144	245	2,057
Switzerland	615	216	16	—	125	972	13,629
Taiwan	359	393	3	8	—	763	6,579
U.S.S.R.	—	1,565	—	92	—	1,657	8,704
United Kingdom	645	1,647	159	24	7,514	9,989	103,237
Other	84	252	1	50	11	398	2,494
Total	8,414	13,005	1,156	507	15,046	38,128	398,109

Source: Bureau of the Census.

TABLE 10

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:										
Australia	5	—	—	—	—	—	3	—	8	$160
Belgium	1,326	6,410	337	—	—	—	249	1	8,323	61,207
Canada	1,198	1,094	—	—	—	—	562	8	2,862	36,389
Dominican Republic	1	34	—	—	—	—	—	—	35	552
France	10	817	—	—	—	—	—	—	827	3,838
Germany, Federal Republic of	1,976	263	194	54	101	4	—	—	2,592	40,541
Hong Kong	—	1	—	1	—	—	551	—	553	8,402
Italy	—	1	19	—	—	—	24	—	44	1,189
Japan	286	2,241	1	—	1	—	2	—	2,531	9,649
Mexico	1	—	—	—	—	—	45	—	46	371
Netherlands	94	289	14	7	4	—	—	—	408	3,990
Norway	179	411	26	—	—	—	—	—	616	5,138
South Africa, Republic of	34,109	17,270	2,580	2,027	502	54	—	—	56,542	755,638
Switzerland	2,123	1,016	438	1	—	—	17	—	3,595	63,307
Taiwan	90	973	—	—	—	—	1	—	1,064	6,794
U.S.S.R.	792	11,327	2,169	—	—	—	21	—	14,309	159,658
United Kingdom	6,928	8,920	1,256	793	80	—	432	—	18,409	217,841
Other	120	68	71	—	—	—	252	3	514	7,029
Total	49,238	51,135	7,105	2,883	688	58	2,159	12	113,278	1,381,693

Source: Bureau of the Census.

increase in demand for platinum. By 1994, demand for platinum used in autocatalyts in the EC is expected to double from about 9,300 kilograms in 1989 to 18,000 kilograms.

Autocatalysts are currently required in Australia, Canada, Japan, South Korea, the United States and most of Western Europe. Other countries, such as Brazil, Mexico, and Taiwan were expected to begin requiring autocatalysts in the early 1990's. World demand for platinum in autocatalysts could increase from about 40,000 kilograms in 1989 to 56,000 kilograms in 1994.

BACKGROUND

Products for Trade and Industry

The basic commercial forms of PGM were 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.

Industry Structure

In North America, PGM are recovered by a small number of scrap refiners, as shown in table 14. 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 or treated on toll by refiners. For example, in addition to its refining operations, Mulit-Metco, Anniston, AL, produces a 90% PGM concentrate 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 consumer a fee to have scrap toll refined, but ownership of the scrapped catalyst remains with the consumer. A refiner replaces a wornout catalyst with a fresh catalyst and charges the consumer for the refining and fabrication costs. In some cases, refiners simply refine scrap and sell it to other companies to fabricate catalysts.

Geology—Resources

PGM deposits are associated with magmatic intrusions of mafic and ultramafic rocks. They also occur to a lesser extent in 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,

TABLE 11

SUPPLY AND DEMAND FOR PLATINUM, PALLADIUM, AND RHODIUM IN THE MARKET ECONOMY COUNTRIES IN 1989

(Kilograms)

	Platinum	Palladium	Rhodium
SUPPLY			
Mine production:			
South Africa, Republic of[e]	82,838	35,308	4,070
Canada	4,461	4,669	415
United States[1]	1,430	4,850	—
Other	2,167	1,521	—
Total	90,896	46,348	4,485
Secondary from old scrap:			
Japan	1,700	620	280
United States	1,149	2,670	94
Total	2,849	3,290	374
Soviet sales to market economy countries	13,680	53,650	3,580
Total	107,425	103,288	8,439
DEMAND			
Industrial:			
Japan	48,680	47,120	3,000
United States	33,698	39,273	3,113
Western Europe	17,260	18,660	2,000
Other	8,090	5,910	160
Total	[2]107,728	110,963	8,273

[e]Estimated by the Bureau of Mines.
[1]Estimates from public sources.
[2]Excludes approximately 5,130 kilograms of investment demand.

Sources: Principally Johnson Matthey PLC, and CPM Group Ltd.

TABLE 12

PLATINUM ANNUAL MINE CAPACITY OF MAJOR PRODUCING COMPANIES, AS OF DECEMBER 31, 1989

(Kilograms)

	Capacity
North America:	
Inco Ltd.	3,800
Falconbridge Ltd.	1,300
Stillwater Mining Co.[1]	1,430
Total	6,530
Africa:	
Rustenburg Platinum Mines Ltd.[2]	44,000
Impala Platinum Holdings (Pty.) Ltd.[3]	34,000
Western Platinum Ltd.	7,800
Barplats Mines	1,000
Total	86,800
World total (rounded)	93,300

[1]Jointly owned by Chevron Corp. and Manville Corp.
[2]Owns Lebowa Platinum Ltd.
[3]Owns the Karee Mine and Messina Mine.

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.[8]

In 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 nearly 100% of revenues.[9]

World reserves of PGM are about 56 million kilograms, with 89% contained in the Bushveld Complex, Republic of South Africa, and most of the remaining 11% located in the U.S.S.R., Canada, and the United States.

Technology

Assaying.—Fire assay techniques have long been used to determine the presence of precious metals. The use of lead as a collector for fire assays is suitable for gold and silver, but not for the PGM. For the PGM, nickel sulfide or copper sulfide is the preferred collector. In addition to fire assays, PGM can be determined by chemical methods and instrumental methods such as X-ray fluorescence and spectrochemical methods.[10]

A list of independent PGM assayers is shown in table 15. The list is meant to be a sampling rather than a complete list of assayers.

Primary Processing.—The processing of PGM entails four general steps: mining, concentrating, smelting, and refining. After mining, platinum ore is crushed, ground, and concentrated by froth flotation. The concentrates are dried, roasted, and smelted to form 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.—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. Johnson Matthey estimated that 4,510 kilograms of platinum and 2,333 kilograms of palladium were recovered from scrapped catalytic converters in North America in 1989. Small quantities of rhodium were also recovered.

Major collectors and refiners of autocatalysts are shown in table 16. In the United States, only Multi-Metco, the successor of Texas Gulf Corp., refined any substantial quantities of 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.

Economic Factors

Prices.—A time series of historical prices for each of the six PGM and a brief discussion of factors influencing prices is given in a Bureau of Mines publication entitled "Nonferrous Metal Prices in the United States Through 1988."[11]

TABLE 13

PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Australia, metal content, from domestic nickel ore:[3]					
Palladium	476	428	[e]490	[e]410	400
Platinum	95	115	[e]130	[e]105	100
Canada: Platinum-group metals from nickel ore	10,485	12,190	10,930	12,541	10,375
Colombia: Placer platinum	362	447	638	810	[4]964
Ethiopia: Placer platinum[5]	[r e]2	2	1	1	2
Finland:					
Palladium	35	96	89	106	100
Platinum	35	120	120	54	60
Japan, metal recovered from nickel-copper ores:[6]					
Palladium	1,359	1,453	1,417	1,170	846
Platinum	691	663	753	647	999
South Africa, Republic of: Platinum-group metals from platinum ore[e 7]	115,100	123,200	131,300	133,300	135,800
U.S.S.R.: Placer platinum and platinum-group metals recovered from nickel-copper ores[e]	118,200	[r]121,300	[r]124,400	[r]127,500	127,500
United States: Platinum-group metals from palladium ores and gold-copper ores:[e 8]					
Palladium	W	W	2,330	3,730	4,850
Platinum	W	W	780	1,240	1,430
Yugoslavia:					
Palladium	95	85	132	142	140
Platinum	3	33	24	23	22
Zimbabwe:					
Palladium	30	35	29	46	35
Platinum	19	26	18	28	20
Total[9]	[r]246,988	[r]260,192	273,582	281,854	283,643

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] Table includes data available through Apr. 25, 1990. 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.

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

In the first quarter of 1990, the price of rhodium exceeded $2,000 per ounce, a record high for this metal. In 1989, the average price of rhodium was only $1,300. The immediate cause of the price rise was attributed to technical production difficulties at a newly commissioned refinery in the Republic of South Africa.

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.[12] Futures contracts help 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 speculators expect prices to rise or fall.

Platinum and palladium futures contracts, specifying 99.9% metal content, were traded on the NYMEX in units of 50 and 100 troy ounces, respectively. Table 8 shows the number of contracts traded, yearend, for 1986 through 1989.

Trading of platinum futures contracts on the TOCOM began in 1984. The contract unit was 500 grams, the quality specifications were 99.9%, and prices were quoted in Japanese yen per gram.

In London, physical prices of plati-

TABLE 14

SELECTED NORTH AMERICAN PLATINUM-GROUP METALS REFINERS AND FABRICATORS

Company	Type	Plant location	Specialty
AT&T/Nassau Metals	Refiner	Gaston, SC	Electronics
	do.	Staten Island, NY	Do.
Degussa/Metz	Refiner, fabricator	South Plainfield, NJ	All
	Fabricator	Burlington, Ontario	Autocatalysts
Dupont Corp.	do.	Wilmington, DE	Electronics
Engelhard Corp.	Refiner, fabricator	Carteret, NJ	All
	Fabricator	Seneca, SC	Catalysts
Gemini Industries	Refiner	Santa Ana, CA	Do.
Handy & Harman	Refiner, fabricator	South Windsor, CT	Electronics
	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 15

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 & Company	Teaneck, NJ
Umpire & Control Services Inc.	West Babylon, NY

TABLE 16

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	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

num and palladium bullion are set each day in the morning and afternoon for the wholesale professional market. The eight companies participating in establishing prices were members of the London-Zurich Good Delivery Agreement that sets standards for platinum and palladium trading in Europe. London and Zurich are the two most important European trading centers for platinum and palladium.

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Metals Week.

POTASH

By James P. Searls

Mr. Searls, a physical scientist, has been the commodity specialist for potash for 10 years. Domestic survey data were prepared by Carleen Militello, mineral data assistant; and international data were prepared by Giovanni P. Jacarepaqua, international data assistant.

U.S. potash production in terms of potassium oxide (K_2O) equivalent increased 5% relative to that of 1988, and apparent consumption declined 15%. Sales by U.S. producers increased 8% for the year. Average prices increased 5% over that of 1988 on the basis of K_2O equivalent, but there was a decline in the last 2 weeks of the year. Yearend stocks increased 24% from 1988 due to the increased production. U.S. net import reliance as a percentage of apparent consumption was 65%. Canada provided an amount equal to 69% of domestic apparent consumption. U.S. exports increased 17%, with exports to Brazil, Japan, and Mexico showing the greatest improvement.

DOMESTIC DATA COVERAGE

The 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.

STRATEGIC CONSIDERATIONS

Strategic considerations concerning potash for the United States are relatively minor problems. Although the capacities of U.S. potash mines have not expanded to meet the expanding

TABLE 1

SALIENT POTASH[1] STATISTICS

(Thousand metric tons and thousand dollars, unless otherwise specified)

		1985	1986	1987	1988	1989
United States:						
Production		2,569	2,381	2,464	2,999	3,132
K_2O equivalent		1,296	1,202	1,262	1,521	1,595
Sales by producers		2,505	2,291	2,904	2,802	3,008
K_2O equivalent		1,266	1,147	1,485	1,427	1,536
Value[2]		$178,400	$144,900	e$197,700	$240,300	$271,500
Average value per ton of product	dollars	$71.22	$63.24	$67.98	$85.75	$90.28
Average value per ton of K_2O equivalent	do.	$140.89	$126.28	$131.73	$168.37	$176.74
Exports[3]		973	1,025	926	783	945
K_2O equivalent		513	547	470	380	446
Value[4]		NA	NA	NA	NA	NA
Imports for consumption[3 5]		7,571	6,934	6,706	6,964	5,618
K_2O equivalent		4,593	4,212	4,073	4,217	3,410
Customs value		$499,100	$385,100	$433,000	$623,000	$501,300
Consumption, apparent[6]		9,103	8,200	8,683	8,983	7,680
K_2O equivalent		5,346	4,843	5,088	5,264	4,500
Yearend producers' stocks, K_2O equivalent		[7]336	[8]378	155	248	307
World: Production, marketable K_2O equivalent		29,151	r28,788	30,526	p32,108	e29,789

e Estimated. p Preliminary. NA Not available.

[1] Includes muriate and sulfate of potash, potassium magnesium sulfate, glaserite, 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 6,000 tons.

[8] Inventory adjustment of minus 12,900 tons.

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[1]		Gross weight		K_2O equivalent	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
January–June:														
Muriate of potash, 60% K_2O minimum:														
Standard	347	r342	212	r209	327	r387	199	r236	e23,800	e30,600	99	118	60	72
Coarse	116	130	71	79	112	130	68	79	e9,400	e11,300	11	33	7	20
Granular	497	513	300	310	506	504	306	305	e41,800	e45,400	89	106	54	64
Chemical	6	5	4	3	6	6	4	4	W	W	1	2	1	1
Potassium sulfate	110	172	56	88	119	142	61	73	e20,000	e24,500	21	76	11	38
Other potassium salts[2]	425	405	112	104	431	446	114	115	W	W	106	143	23	34
Total[3]	1,501	r1,569	755	r793	1,502	r1,616	752	r812	e127,300	e r147,200	327	478	156	229
July–December:														
Muriate of potash, 60% K_2O minimum:														
Standard	407	371	249	227	342	348	209	212	e25,500	e26,200	164	142	100	86
Coarse	124	114	76	69	103	113	63	69	e8,400	e9,700	32	33	20	20
Granular	459	551	278	334	452	478	273	290	38,300	40,100	96	178	58	108
Chemical	9	8	6	5	7	8	5	5	W	W	3	2	2	1
Potassium sulfate	119	153	61	78	94	146	48	74	16,800	28,800	46	83	23	42
Other potassium salts[2]	381	366	97	89	303	299	77	74	W	W	184	211	45	49
Total[3]	1,498	1,563	766	802	1,300	1,392	675	724	e113,000	e124,300	525	649	248	307
Grand total[3]	2,999	3,132	1,521	1,595	2,802	3,008	1,427	1,536	e240,300	e271,500	XX	XX	XXX	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.

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[2]
1988:							
January–June	5,965	899	1,352	668	1,373	678	114,300
July–December	6,543	954	1,371	690	1,162	593	99,500
Total[3]	12,508	1,853	2,722	1,359	2,535	1,271	213,800
1989:							
January–June	7,029	987	1,401	700	1,476	730	e133,200
July–December	7,138	985	1,434	729	1,235	635	e109,400
Total	14,167	1,972	2,835	1,429	2,711	1,365	e242,600

e Estimated.

[1] Sylvinite and langbeinite.

[2] F.o.b. mine.

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

TABLE 4

SALIENT U.S. SULFATE OF POTASH[1] STATISTICS

(Thousand metric tons of K_2O equivalent and thousand dollars)

	1986	1987	1988	1989
Production	88	100	117	166
Sales by producers	97	109	109	147
Value[2]	$30,483	$33,059	$36,854	$47,355
Exports[3 4]	79	118	91	78
Value[5]	NA	NA	NA	NA
Imports[3]	27	26	46	10
Value[6]	$9,900	$10,500	$19,300	$11,700
Consumption, apparent[4 7]	45	16	65	79
Yearend producers' stocks	25	16	23	42

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.

U.S. demand for potash, large amounts of high-grade potash ore reserves are across the Canadian border in the Province of Saskatchewan. The United States has a long history of cooperation and friendship, even mutual investments, with Canada as indicated by the recent Free Trade Agreement between Canada and the United States. There is little to worry about concerning 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 expectation of sales to the U.S. market, especially in the Corn Belt. A cessation of trade with the United States would close at least 60% of the Canadian capacity until the offshore market for potash grew.

ISSUES

The Reilly-Wendover potash operation on the western end of the Bonneville Salt Flats came under question concerning the environmental impact of mining under the salt flats. The Carlsbad, NM, producers mine areas that oil and gas producers would like to drill on an exploratory basis. The potash producers are deeply concerned that the oil and gas wells may leak natural gas into the potash mines. This would cause the potash mines to be declared "gassy" and would require major new investments in special equipment for gassy mines. This additional financial burden may cause potash producers to go out of business before the potash deposits are completely recovered. This would be a loss to the United States and would increase dependence on imported potash. The Carlsbad area would be severely impacted economically by the shutdowns and consequent loss of jobs.

PRODUCTION

Domestic potash production, in K_2O equivalents, increased 5% in 1989 compared with that of 1988. Of the total production for the year, 77% was standard, coarse, and granular muriate of potash, also known as potassium chloride, and 10% 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" refer to the particle sizes of the finished product. "Standard," "coarse," and "granular" muriate of potash comprise the "three muriates," a term that ignores the soluble and chemical grades of muriate of potash. "Sulfates" is a term for the addition of sulfate of potash data to sulfate of potash-magnesia data. "Manure salts" used to refer to high-grade "run-of-mine" ore; 25% K_2O ore is nearly 40% KCl which can be used on sugar beets. It now refers to a mixture of white muriate of potash and common table salt for industrial uses. The New Mexico potash producers accounted for 90% of the total marketable potash salts production. Production of crude salts in New Mexico was 14.2 million tons[1] with an average K_2O content of 13.9%. The producers were AMAX Potash Corp. of AMAX Inc., Eddy Potash Inc. of Trans-Resources Inc., International Minerals & Chemical Corp. of IMC Fertilizers Inc. (IMCF), Mississippi Chemical Corp., New Mexico Potash Corp. of Trans-Resources Inc., and Western Ag-Minerals Co. of Rayrock Resources Ltd. of Canada. All of the New Mexico producers, except Western Ag-Minerals, mined sylvinite ore and beneficiated the ore into muriate of potash. Several beneficiation processes 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 types of ore and reacted fractions of each potash product to produce sulfate of potash.

One plant in Texas and one plant in Utah manufactured sulfate of potash. AMAX Potash operated the plant in Dumas, TX, and that production was reported in both the Bureau of Mines sulfate of potash mine production totals and the potash production totals shown in the tables. The Permian Chemical Corp. sulfate of potash plant in Odessa, TX, was closed for the year. The Climax Chemical Co. plant in Utah produced about 23,000 tons. This company's production was not included in either the Bureau of Mines sulfate of potash mine production totals or the total mine production of all types and grades of potash.

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 converted some of Moab Salt's potassium chloride to potassium sulfate for sale by Texasgulf. Great Salt Lake Minerals & Chemicals Corp. began production of sulfate of potash by solar evaporation and conversion from kainite. 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.

In California, Kerr-McGee Chemical Corp. continued to produce both muriate and sulfate of potash along with other products by selective crystallization from the underground brines of Searles Lake.

Near Hersey, MI, Kalium Chemical Ltd. of Sullivan and Proops Inc. commenced potash production by solution mining of an ore body, which was about 2,400 meters deep. Only minor amounts of muriate of potash were produced on a pilot plant scale.

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. Contractors Sand & Gravel Co. near Middletown, DE, ceased production of greensand at the end of 1988. Production and sales information are withheld to avoid disclosing company proprietary data. Processed greensand continued to be 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 source of slowly released potash, with a K_2O equivalent between 5% and 10%, to the organic farmers of North America.

CONSUMPTION AND USES

Apparent domestic consumption of all forms of potash in 1989 decreased 15% compared with that of 1988. This is an extremely difficult decrease to understand when compared to the Potash & Phosphate Institute's (PPI) report of a slight increase in potash consumption. The problem appears to be with the Bureau of Census' import data, which show a 19% decrease while PPI import data concerning Canada shows a 1% increase. Part of the answer may be in the amount of potash in warehouses not owned by potash producers over the winter of 1988–89. There may have been a problem with importers not listing the imported potash under the new Harmonized Code categories. If the Potash & Phosphate Institute aggregate imports figures were used, the apparent consumption of the United States would be 5.27 million metric tons or essentially level with last year.

According to the Potash & Phosphate Institute, the consumption of agricultural potash from Canadian and United States potash producers rose 3% from 1988 to 1989. The major States for consumption of agricultural potash from Canadian and United States potash producers, in decreasing order, were Illinois, Iowa, Ohio, Minnesota, Indiana, Missouri, and Wisconsin. These seven States consumed 59% of the total from Canadian and United States producers. Domestic producers provided 10% of Illinois' potash consumption, 8% of Iowa's consumption, 4% of Ohio's consumption, 2% of Minnesota's consumption, 9% of Indiana's consumption, 59% of Missouri's consumption, and 1% of Wisconsin's consumption. The major agricultural consumers of domestically produced potash, in decreasing order, were Missouri, Texas, California, Illinois, Florida, and Arkansas. These six States accounted for 59% of the total. The major consumers of the domestically produced sulfates of potash, in decreasing order, were Florida, California, Georgia, Texas, North Carolina, Ohio, and Kentucky. These six States accounted for 65% of the total.

STOCKS

Yearend producers' stocks of potash increased 24% from that of 1988. Yearend stocks represented 19% of annual production or 10 weeks of average production.

PRICES

The average annual price, f.o.b. mine, of U.S. potash sales of all types and grades was up 5% compared with that of 1988 to $176.74 per ton. The average price was $181.36 per ton for the first one-half of the year and $171.56 per ton for the second one-half of the year. The average annual price of

FIGURE 1

THE REAL PRICE OF POTASH, ALL TYPES AND GRADES

(GNP price deflator)

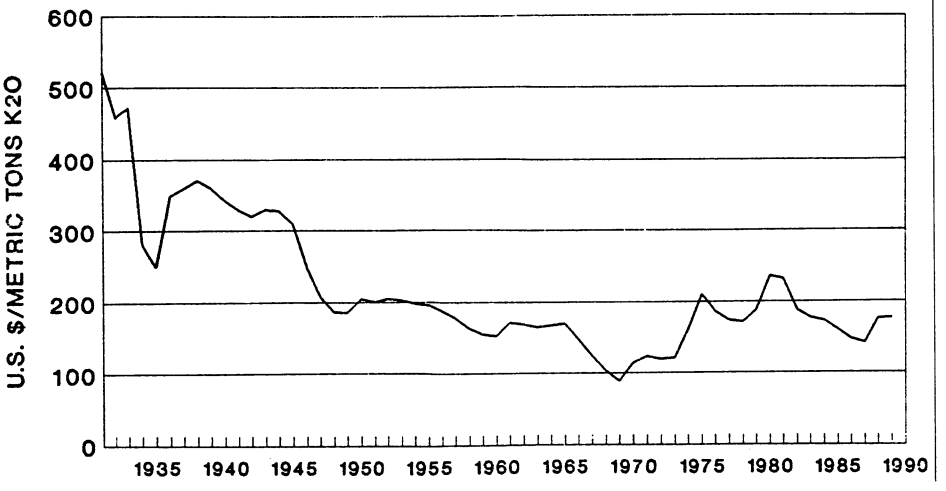


TABLE 5

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1988	1989	1988	1989
Alabama	63,278	57,895	106,001	111,870
Alaska	274	1,574	—	—
Arizona	1,742	2,807	1,789	1,749
Arkansas	48,203	57,467	560	103
California	70,826	71,063	8,052	6,839
Colorado	7,871	9,902	2,278	1,065
Connecticut	3,650	6,084	69	114
Delaware	17,509	16,995	41,603	39,945
Florida	95,976	154,752	823	749
Georgia	110,228	116,795	2,249	2,216
Hawaii	9,093	8,475	1,141	
Idaho	22,778	23,787	32	883
Illinois	604,351	593,744	1,791	1,932
Indiana	301,184	333,268	854	1,630
Iowa	450,110	478,596	1,725	2,165
Kansas	46,553	46,676	2,840	1,526
Kentucky	110,383	114,280	322	584
Louisiana	143,318	131,146	3,598	3,021
Maine	5,967	3,519	556	549
Maryland	28,533	28,077	158	375
Massachusetts	3,861	2,502	718	679
Michigan	174,549	209,779	5,392	5,994
Minnesota	318,475	341,110	2,023	4,920
Mississippi	27,466	32,773	41,670	40,591
Missouri	241,883	273,227	2,870	3,270
Montana	9,773	11,492	210	215
Nebraska	29,643	32,613	1,047	1,073
Nevada	66	18	80	104
New Hampshire	2,325	780	59	24
New Jersey	6,153	5,270	2,022	2,500
New Mexico	16,344	9,074	16,319	21,008
New York	64,900	48,138	19,565	23,250
North Carolina	87,801	72,107	727	689
North Dakota	19,450	27,539	15	15
Ohio	421,591	362,297	55,260	47,116
Oklahoma	22,170	23,027	3,486	3,617
Oregon	22,065	26,454	1,593	2,181
Pennsylvania	51,387	53,886	3,238	3,101
Rhode Island	2,455	1,962	45	22
South Carolina	73,328	64,003	73	96
South Dakota	15,007	15,678	—	122
Tennessee	86,152	81,193	1,004	2,134
Texas	131,720	131,011	33,347	27,671
Utah	7,390	15,912	7,516	9,804
Vermont	1,893	3,635	—	—
Virginia	79,845	75,454	117	201
Washington	34,765	40,201	806	2,855
West Virginia	1,793	9,857	841	544

the three grades of muriate increased to $137.05 per ton. Standard-grade muriate of potash averaged $126.66 per ton, coarse-grade averaged $141.91 per ton, and granular-grade averaged $143.67 per ton. The average annual price for all grades of sulfate of potash averaged $321.90 per ton.

The effect of the price agreement between the U.S. Department of Commerce and the Canadian potash producers in January 1988, can be seen in perspective in figure 1.

FOREIGN TRADE

Total U.S. potash exports as reported by the Bureau of the Census increased 17%, by ton K_2O. The major destinations of potash exports were to Latin America, which received 67%, by product tonnage, of the total exports. The individual countries were, in decreasing order, Brazil, Mexico, Colombia, Costa Rica, Dominican Republic, Peru, and Chile: These seven countries accounted for 89% of the exports to Latin America. Three countries represented 89% of the non-Latin American market: In decreasing order, these were Japan, China, and Canada. Exports of sulfate of potash declined 14% from that of 1988 and represented 18% of U.S. potash exports. For the nearly 13,000 tons decrease in sulfate of potash exports there was an increase of more than 20,000 tons (45%) of sulfate of potash-magnesia exports.

Potash imports for consumption as reported by the Bureau of the Census declined 19% by ton product. Muriate of potash imports declined 19%, and only Jordan showed an increase from those of 1988. Canada provided 91% of all potash imports by K_2O content but declined 18% from those of 1988. Canada provided 92% of all muriate of potash imports. Israel was the second largest source of imports with 5% of muriate of potash imports and 5%, by K_2O content, of total potash imports. Imports of potash from the U.S.S.R. declined 68% from those of 1988.

The PPI reported decrease of imports from offshore sources of 44%. Canada increased exports of potash to the United States by 1% for an aggregate decrease of 4% of potash imports.

TABLE 5—Continued

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1988	1989	1988	1989
Wisconsin	253,702	267,447	16,267	24,345
Wyoming	1,681	2,012	383	21,153
Total	4,351,460	4,497,353	393,134	426,609

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	1986	1987	1988	1989
Agricultural:				
Standard	319	328	259	310
Coarse	1,882	2,078	2,095	2,036
Granular	1,683	1,866	1,530	1,658
Soluble	336	360	339	342
Total	4,220	4,632	4,223	4,346
Nonagricultural:				
Soluble	98	88	104	116
Other	225	269	283	305
Total	323	357	387	421
Grand total	4,543	4,989	4,610	4,767

Source: Potash & Phosphate Institute.

TABLE 7

PRICES[1] OF U.S. POTASH, BY TYPE AND GRADE

(Dollars per metric ton of K_2O equivalent)

Type and grade	1987		1988		1989	
	January–June	July–December	January–June	July–December	January–June	July–December
Muriate, 60% K_2O minimum:						
Standard	84.28	103.28	119.73	122.29	129.54	123.45
Coarse	86.35	113.05	137.28	133.95	142.77	140.92
Granular	76.11	106.21	136.62	140.12	149.01	138.05
All muriate[2]	80.24	106.06	130.84	132.65	140.80	132.98
Sulfate, 50% K_2O minimum	331.06	295.65	326.98	335.76	336.48	306.96

[1] Average prices, f.o.b. mine, based on sales.
[2] Excluding soluble and chemical muriates.

WORLD REVIEW

World production decreased 7% below that of 1988. World prices, as exemplified by the per-ton price of standard muriate of potash, f.o.b. Vancouver, Canada, rose from approximately $152 (about $91 per ton product) in October 1988, to approximately $165 (about $99 per ton product) in January 1989, and stayed at that level until August. The price declined to approximately $162 (about $97 per ton product) by October. These prices were reported by British Sulphur Corp. Ltd. These prices reflect, in the first one-half of the year, the rising of the international price to meet the domestic price. After August, the less-than-expected spring and fall sales in the United States and the continued production by all of the North American producers lifted North American stocks to a level high enough to permit international market prices to decline. In the last 2 weeks of December, there was price cutting in the domestic market but this did not affect the international price.

Industry Structure

The two largest potash producing countries in the world are the U.S.S.R. and Canada with 10.5 million tons and 7.458 million tons of production, respectively. These two countries produce about 62% of the world total. The potash produced in the Soviet Union was delivered primarily to their domestic farms and eastern European neighbors leaving approximately 3.5 million tons for export. The Canadians sold only 315,000 tons domestically and sold about 6.8 million on the world market. As a result, Canada is the world leader and price setter in potash. Canada is also the swing producer, responsible for keeping stocks of finished product below a level that would lead to the lowering of potash price. The world price benchmark is set between Canada and a combination of China, India, and Japan. World prices are typically quoted in reference to standard product, f.o.b. Vancouver, British Columbia, the port from which most of Canada's potash is exported. The U.S.S.R. has sometimes sold potash at prices that are lower than the Canadian prices because the U.S.S.R. product quality has not always been up

TABLE 8

AVERAGE ANNUAL U.S. PRODUCER PRICE

(Dollars per metric ton, K_2O equivalent)

Year	Nominal prices						Based on constant 1988 dollars, 1982 = 100					
	All types and grades	Muriate			Sulfate	Other	All types and grades	Muriate			Sulfate	Other
		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	24.7	25.61	—	52.37	88.43	63.85	75.53	78.31	—	160.14
1970	39.64	29.52	35.47	37.9	—	60.87	114.86	85.54	102.78	109.82	—	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	41.8	42.78	91.14	71.64	117.25	93.77	102.77	105.18	224.08	176.13
1974	68.7	58.04	58.83	56.52	122.12	100.42	154.83	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	127.2	139.36	138.63	261.79	227.88	226.69	180.63	197.90	196.86	371.76	323.61
1981	172.4	136.55	141.61	136.86	349.23	262.78	223.20	176.79	183.34	177.19	452.14	340.22
1982	148.87	106.36	115.9	109.53	352.35	248.56	181.17	129.44	141.05	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	132.49	80.99	87.49	81.17	312.82	298.40	141.32	86.38	93.32	86.58	333.65	318.27
1987	132.90	93.68	99.80	93.55	303.43	271.73	137.65	97.03	103.37	96.89	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

[1] GNP implicit Price Deflator used.
[2] Includes chemical and soluble muriates, manure salts, potassium magnesium sulfate, and before 1971, potassium sulfate.
[3] Prior to 1971, potassium sulfate was included with "Other."

to international standards. The U.S.S.R. is the world's largest potash-consuming area. Outside of the U.S.S.R., the largest potash-consuming area is the corn-soybean belt in the Middle West. Illinois, Indiana, and Iowa consumed more potash than China in 1989.

Brazil

Petrobras Mineração S.A. expressed optimism concerning the ultimate viability of the Tarquari-Vassouras Mine by purchasing four continuous miners.[2] There is a report that the Rosario Mine has started trial production.[3]

Canada

Potash Corporation of Saskatchewan commenced a program to take the sales arm of the company private, with stock and bonds to be sold on the open market. Potash Company of America's new operation reopened in May. The new methodology involves solution mining and cold crystallization of potash in a pond from September to May. The Dead Sea Works of Israel entered into negotiations to purchase the 40% portion of Allan Mine in Saskatchewan. This portion is presently owned by Saskterra Fertilizer Ltd. of Canterra Energy.

Chile

Sociedad Chilena de Litio Ltda. commenced production of muriate of potash in its Salar de Atacama ponds in 1988.[4] Because this product was sold to Sociedad Química y Minera de Chile (SOQUIMICH) for inclusion into SOQUIMICH's KNO_3, product, it is not clear whether there was double counting in Chile's total production figures.

China

The 120,000-ton-per-year First Phase of the Qinghai Fertilizer Factory commenced operation in the middle of the year.

Egypt

The BHP-Utah International Inc. firm signed an agreement with the Egyptian Geological Survey and Mining Authority to investigate a potash occurrence in Egypt.[5]

France

The potash workers held a strike for assurance of employment until the year 2004, the expected year of potash ore depletion for the Alsatian potash mines. Late in the year, the Government commenced public dialogue concerning rationalization of the French chemical industry, including the fertilizer industry. Enterprise Miniere et Chimique, the sole potash producer in France, may be folded into Société Nationale Elf Aquataine.

German Democratic Republic

During late winter, a mine collapse in the Ernst Thaelmann Mine of the Kalibetrieb Werra halted production at

TABLE 9

U.S. EXPORTS OF POTASH, BY COUNTRY[1]

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades[2]		Total[3]	
	1988	1989	1988	1989	1988	1989
Algeria	—	1,200	—	—	—	1,200
Argentina	330	7,200	4,150	1	4,480	7,200
Australia	190	830	14,390	9,280	14,580	10,110
Bahamas	—	—	380	640	380	640
Belgium-Luxembourg	38,570	—	—	—	38,570	—
Belize	1,950	2,790	—	430	1,950	3,220
Bolivia	280	530	—	580	280	1,110
Brazil	172,460	229,820	24,050	21,470	196,510	251,290
Canada	1,220	1,710	69,920	54,310	71,140	56,020
Chile	8,000	6,800	28,080	20,270	36,080	27,070
China	—	—	22,000	73,940	22,000	73,940
Colombia	25,490	53,870	51,470	25,020	76,960	78,890
Costa Rica	13,520	26,550	14,700	23,110	28,220	49,660
Dominican Republic	25,260	35,820	6,590	3,930	31,850	39,750
Ecuador	11,030	6,130	3,178	13,020	14,208	19,150
Egypt	—	130	—	—	—	130
El Salvador	20,750	4,080	2,160	500	22,910	4,580
France	170	7	110	—	280	7
Greece	230	—	—	—	230	—
Guatemala	—	5,200	—	3,700	—	8,900
Guyana	2,000	—	700	400	2,700	400
Honduras	4,000	1,900	340	6,990	4,340	8,890
Ireland	11,910	—	—	—	11,910	—
Italy	30	800	160	—	190	800
Japan	28,720	16,520	62,540	116,300	91,260	132,820
Korea, Republic of	1,130	11,430	90	80	1,220	11,510
Malaysia	—	—	16,630	—	16,630	—
Mexico	8,090	61,330	13,470	37,140	21,560	98,470
New Zealand	2,880	120	90	460	2,970	580
Panama	2,040	2,140	50	860	2,090	3,000
Peru	50	12,140	12,070	21,070	12,120	33,210
Philippines	—	9	300	—	300	9
Saudi Arabia	20	—	5,780	—	5,800	—
Singapore	—	—	110	—	110	—
South Africa, Republic of	30	—	2,200	—	2,230	—
Spain	9,300	—	40	—	9,340	—
Sweden	800	950	—	—	800	950
Taiwan	—	—	260	350	260	350
Thailand	—	—	5,250	4,000	5,250	4,000
Trinidad	—	2,610	—	490	—	3,100
United Kingdom	—	3,530	—	2	—	3,532
Venezuela	9,880	42	20,050	10,500	29,930	10,542
Other	500	390	720	36	1,220	426
Total[3]	400,831	496,575	382,027	448,880	782,858	945,455

[1] The Bureau of the Census ceased publication of value data in 1985.
[2] Includes potassium magnesium sulfate.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF 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.	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
Belgium-Luxembourg	5,000	21	2,700	5,800	—	—	—	—	7,700	5,800	$900	$1,100	$1,100	$1,200
Canada	6,009,100	5,089,800	200	900	4,500	—	800		6,014,600	5,090,700	523,200	440,100	559,500	509,200
Chile	—	—	—	—	7,600	19,000	32,900	11,500	40,500	30,500	6,100	5,100	7,000	6,000
Dominican Republic	12,900	—	—	—	—	—	—	—	12,900	—	1,200	—	1,300	—
France	—	—	4,100	10,200	—	—	—	—	4,100	10,200	1,000	1,800	1,100	2,200
German Democratic Republic	154,300	56,300	—	—	—	—	—	—	154,300	56,300	13,300	5,000	15,200	5,700
Germany, Federal Republic of	29,100	400	79,200	45,600	—	—	—	—	108,300	46,000	18,300	7,200	20,600	8,100
Israel	288,500	248,200	—	—	23,400	14,700	—	—	311,900	262,900	31,300	30,400	36,700	34,300
Italy	28	—	60	400	—	—	—	—	88	400	30	40	30	40
Japan	38	40	—	—	—	6	—	100	38	150	20	90	20	100
Jordan	—	22,000	—	—	—	—	—	—	—	22,000	—	2,000	—	2,400
Netherlands	8,800	3,000	1,000	73	—	—	—	—	9,800	3,100	1,200	343	1,300	400
Poland	—	—	—	—	—	36	—	—	—	36	—	20	—	20
U.S.S.R.	276,600	87,200	—	—	—	—	—	—	276,600	87,200	24,100	7,900	28,400	9,600
United Kingdom	23,000	3,000	—	—	—	—	—	—	23,000	3,000	2,200	180	2,500	220
Total[1]	6,807,400	5,510,000	87,300	63,000	35,500	33,700	33,700	11,600	6,963,900	5,618,300	662,900	501,300	674,700	579,500

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

Source: Bureau of the Census, as adjusted by the Bureau of Mines.

that site.[6] The shock waves also caused damage at the nearby Wilhelm Pieck Mine.

Israel

Dead Sea Works Ltd. (DSW) officials announced the discovery of a solid potash ore body, called Har Sdom, which was being investigated for underground mining.[7] In the middle of the year, the Government of Israel announced plans to sell over 50% of the stock of the DSW. At the end of the year, the Knessett expressed hesitancy about losing control of the DSW.

Jordan

Modifications over the past 6 years to the Arab Potash Co. solar ponds and refinery have raised the capacity of the operation to 810,000 tons per year.[8]

Thailand

The Association of Southeast Asian Nations (ASEAN) Committee on Industry, Minerals and Energy accepted the development of the Bamnet Narong resource as a project.[9] The project cost was placed at $300 million, but the finished product capacity has not been set. The Government of Thailand will finance 20% and the ASEAN organization will finance 40% of the project. The last 40% will be open to regional private industry. Kali und Salz AG of the Federal Republic of Germany will provide engineering.

U.S.S.R.

An agreement in principal has been reached with Minerals and Metals Trading Corp. of India whereby India would develop the Port of Muriupol on the Azov Sea,[10] which connects to the Black Sea. The U.S.S.R. will ship 600,000 tons of potash per year for an unannounced period of time to pay for this development. This would be 60% of India's 1988 imports of potash.

OUTLOOK

United States Demand

The Bureau of Mines funded a study of the fertilizer market by The Wharton Econometric Forecasting Associates (WEFA) Group in 1988. Their model forecasted an increase in grain exports that resulted in a 2.6% increase in potash consumption out to 1995, at which time, the consumption would be 5.7 million tons K_2O.

For this Minerals Yearbook, the Bureau of Mines funded a macroeconomic forecast by DRI Inc. of some general macroeconomic series. By regressing the Bureau of Mines potash apparent consumption time series on several of these general macroeconomic series, a simple model was found with an $R^2 = .74$. The three series used were "food exports," "grain mill production," and "textile mill production." Using forecasts for 1995 of these three

series, a very optimistic forecast for 1995 was derived, however, it is not likely to be achieved. Historical data do not strongly support growth. Figure 2 shows the historical data since 1962, including the cusp in 1980.

World Demand

The WEFA Group model forecasts a growth rate of 2% out to 1995 reaching a consumption rate of 30 million tons per year. The data in figure 3 portray a production history that was constant in growth up to 1975 and started to waiver, although the trend has continued upwards. The problem of the relationship between production and consumption is appreciated, but these are the best data available. Production may vary a year behind consumption as producers watch their stockpiles of finished product enlarge or contract, but only if producers make production rate changes no more than once a year.

FIGURE 2

APPARENT CONSUMPTION, 1962–89

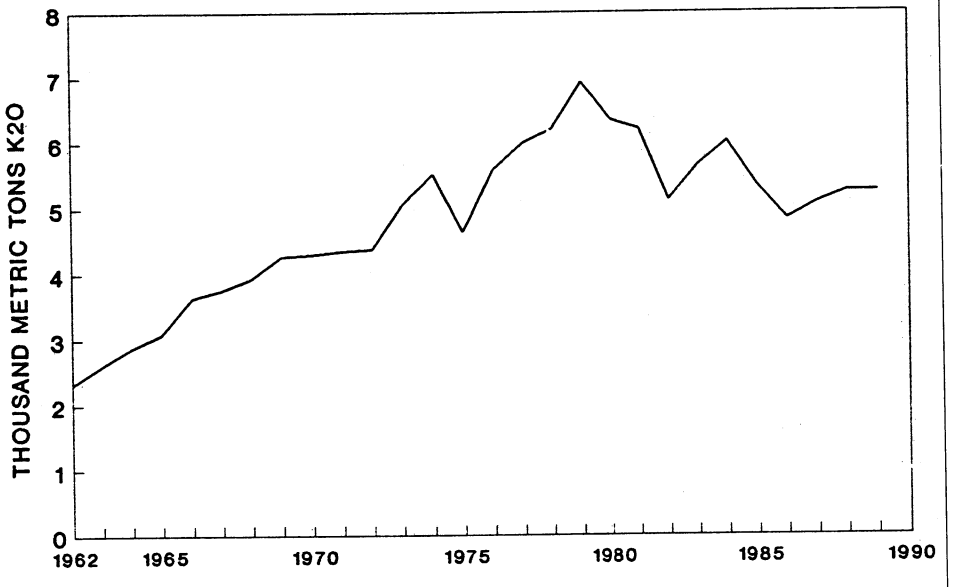


FIGURE 3

WORLD PRODUCTION

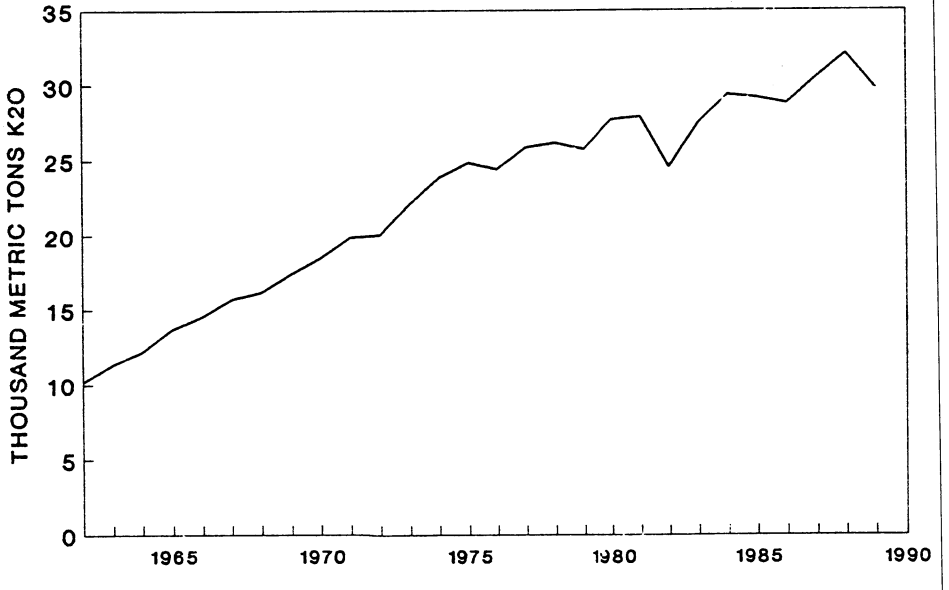


TABLE 11

WORLD POTASH ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY[1]

(Thousand metric tons of K_2O equivalent)

	Rated capacity
North America:	
Canada	11,520
Mexico	NA
United States	1,920
Total	13,440
South America:	
Brazil	150
Chile	45
Total	195
Eastern Europe:	
German Democratic Republic	3,500
U.S.S.R.	13,700
Total	17,200
Western Europe:	
France	1,680
Germany, Federal Republic of	2,700
Italy	400
Spain	750
United Kingdom	490
Total	6,020
Asia:	
China	120
Israel	1,260
Jordan	810
Total	2,190
World total[2]	39,050

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.

BACKGROUND

Technology

The technologies used in potash mining encompass those involved in exploration, development of access to the ore, mining, beneficiation, and physical processing.

Exploration.—Potash minerals do

TABLE 12

WORLD POTASH RESERVES AND RESERVE BASE

(Million metric tons, K_2O equivalent)

	Reserves	Reserve base[1 2]
North American:		
United States	88	360
Canada	4,400	9,700
Mexico	NA	NA
Total[3]	4,500	10,000
South America:		
Brazil	60	400
Chile	10	50
Total[3]	70	450
Europe:		
France[2]	23	45
German Democratic Republic	800	1,000
Germany, Federal Republic	500	600
Italy[2]	20	40
Spain[2]	30	50
U.S.S.R.[4]	3,000	22,600
United Kingdom[2]	25	30
Total	4,400	24,400
Africa:		
Congo	—	20
Ethiopia	NA	NA
Tunisia	NA	NA
Total	—	20
Asia:		
China	200	NA
Israel	55	150
Jordan	55	150
Laos	NA	20
Thailand	NA	100
Total	310	400
World total	9,300	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 Bureau of Mines Division of Minerals Availability.

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

[4] 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 13

SALIENT CANADIAN POTASH STATISTICS

(Thousand metric tons of K_2O equivalent)

	1986	1987	1988	1989
Production[1]	6,697	7,267	8,327	7,360
Domestic sales by domestic producers[1]	327	499	416	315
Exports:				
United States[1]	4,091	4,223	4,248	3,886
Overseas[1]	2,612	3,133	3,792	2,924
Imports for consumption[2]	10	19	11	16
Domestic consumption[3]	337	518	427	331
Yearend producers' stocks[1]	1,537	1,135	1,356	1,596

[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 14

MARKETABLE POTASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of K_2O equivalent)

Country	1985	1986	1987	1988[p]	1989[e]
Brazil	—	18	62	56	60
Canada[2]	6,661	[r]6,753	7,668	8,311	[3]7,458
Chile[4]	21	20	23	25	25
China[e]	40	40	40	40	40
France	1,750	1,617	1,539	1,502	1,200
German Democratic Republic	3,465	3,485	3,510	3,510	3,200
Germany, Federal Republic of	2,583	2,161	2,199	2,390	2,240
Israel	1,200	1,255	1,253	1,244	[3]1,271
Italy	205	158	178	197	200
Jordan	561	660	734	785	790
Spain	659	[r]795	741	766	745
U.S.S.R.	10,367	10,228	10,888	11,301	10,500
United Kingdom	343	396	429	460	465
United States	1,296	1,202	1,262	1,521	[3]1,595
Total	29,151	[r]28,788	30,526	32,108	29,789

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 18,1990.

[2] Official Government figures. Potash & Phosphate Institute production data are given in table 13.

[3] Reported figure.

[4] Data represent officially reported output of potassium nitrate product (gross weight basis) converted assuming 14% K_2O equivalent.

not typically show on the earth's surface, where they could be found in routine surveys. Present potash minerals are water soluble and would have washed away in the weather many centuries ago. They are normally found during the search for another mineral in sedimentary-type areas. The original Stassfurt, German Democratic Republic, mines were discovered while digging a shaft for salt. The mines in New Brunswick, Canada, and Solikamsk, U.S.S.R., were found during searches for salt. The mines of the United States, Saskatchewan, Canada, and France were discovered during searches for oil wells. Potash has been found as a mineral outcropping only in the Ciscarpathian area of the Western Ukraine.

Access.—Shaft sinking to allow worker-access to the ore zone is a relatively highly developed procedure that is done by specialists. The Canadian Elk Point Basin potash ore zone lies under a high-pressure aquifer that endangered any attempt to penetrate to the potash zone below. To successfully

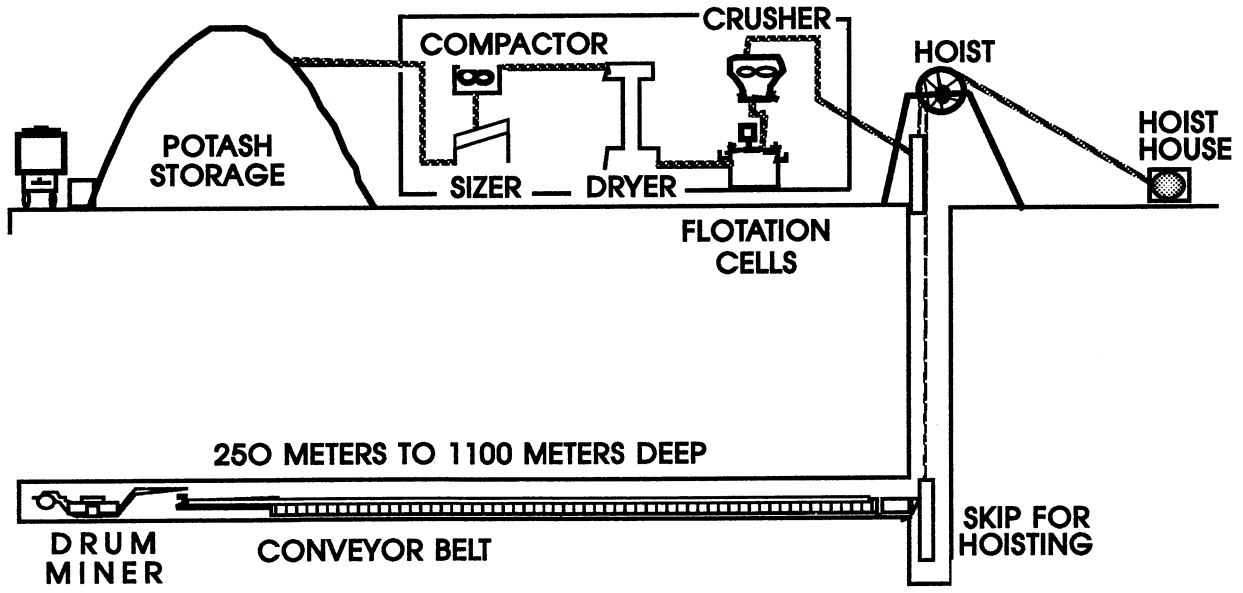
sink a shaft in this area the water zone was frozen from above, and the shaft was dug through the frozen section. The shaft sinkers installed large cast-iron sections that bolted together to form a water-tight cylinder extending from above to below the frozen water zone. The top and bottom of this cylinder were sealed to the non-water-bearing country rock by driving wooden wedges between the cast-iron sections and the rock. These cast-iron sections are so precise that a constant temperature must be maintained in the shaft to prevent expansion and contraction, which might allow leaks to start. Shaft sinking through the Blairmore Aquifer in Canada is so expensive that only two shafts are sunk per mine. In most other potash mine shafts, the water problems were solved with grouting.

Carlsbad, NM, mine owners have had to add shafts to their mines because the mining faces have advanced miles away from the original shafts. The cost of moving workers to the mining face and back to the original shaft during an 8-hour shift becomes too high. It saves wages and produces more tons of ore per worker-shift to sink a shaft near the working face and quickly bring the miners to the face. The potash ore in these mines continues to travel to the original hoist shaft to be available to the refinery or mill. Mines may have as much as 20 miles of conveyor belts underground in both permanent (main line) and temporary (panel) placements. The Bergmanssegen-Hugo Mine in the Federal Republic of Germany uses a large spiral incline for personnel and equipment access by motor vehicle.

Mining.—Underground potash mining in the Carlsbad, NM, region and in Saskatchewan, Canada, is relatively clean and straightforward. The evaporite beds are regular, tabular, and essentially untilted. The Carlsbad beds are typically no deeper than 300 meters and are mined using classic room-and-pillar techniques. The room-and-pillar method of mining has been used extensively in the United States and the U.S.S.R. This method can be imagined by "looking down" on the ore zone from above and dividing the area to be mined into a checkerboard. Then, imagine mining out a large L-shaped portion of each square, leaving a square pillar at the same (for example, lower left-hand) corner of each square. The size of the square imagined for any ore and the relative size ratio of the pillar to the original square are determined by

FIGURE 4

NORMAL POTASH MINING, UNDERGROUND MINING WITH FLOTATION



the ore zone depth and rock mechanics, especially the mechanical strength and integrity of the layer just above the ore zone. The relatively shallow depth of Carlsbad potash means that the lithostatic pressure allows safe mining with a recovery rate of about 75%. Continuous miners are commonly used, sometimes connected directly to the conveyor belt and sometimes loading to a pair of shuttle cars that transport the ore to the conveyor belt. The Carlsbad mines that produce potassium magnesium sulfate have to use blasting agents to loosen the ore because the ore is too hard for mining machines. The potash mines in Saskatchewan, Canada, are much deeper, operating at between 975 and 1,040 meters. Lithostatic pressure on a potash ore zone is critical at this depth. Underground recovery is reduced to 35% to 45%, and, in some mines, the miners have to cut panels that collapse to protect the miners in other panels. One technique is to mine five parallel, 18-foot-wide panels each separated by about 20 feet of pillar. The outside panels collapse taking the stress off the inner three panels. The inner three panels are then used for conveying potash ore away from the face, access for workers and equipment, and bringing fresh air to and from the workings. Several of the mines that use multiple panels have collapsible, wheeled conveyor belts connecting between the boring machines and the head of the semipermanent conveyor belt leading to the hoist. The parallel panels are laterally connected by angled cuts that resemble "turkey tracks." These groups of parallel panels, called faces, are about 45 meters wide and leave a pillar that is about 45 meters between each face. The Boulby Mine in England is of the same depth and has adopted this five-panel entry pattern to permit mining at such depth. Miners in Saskatchewan, working at a location that is not quite as deep, found that they could mine panels that were 40 feet wide with safety. This mine has an extremely thick cover (back) of salt that provides more structural integrity at this panel width. Mine practice is a single panel that may extend a mile at 90° to the main passageway. Recovery is about 45% under these conditions.

The northern (Lower Saxony) potash beds of the Federal Republic of Germany are extremely folded, even vertical, because the deposits have been deformed by tectonics and the upflow of the underlying salt formations into salt domes. Open sublevel stoping is the mining technology in large rooms. A stope panel is 200 meters high and several hundred meters long and wide. Funnel-shaped draw holes are excavated at the bottom of the panel for loading railcars below. Then blocks of ore are broken by blasting agents from the bottom of the stope to the top. The broken ore falls to the funnels and into cars for haulage to the skip. One of the benefits of this mining system is that mill tailings are returned to the mine instead of going to surface tailings piles. The French mines dip from west to east up to 25° and become hotter, approaching 135° F, at their eastern edge.[11] For this extreme heat, the owner has installed 700 kilowatts of air-conditioning capacity underground. The mining depth varies between about 460 meters and 1,070 meters. The French mines have converted to longwall mining for the highest recovery factor underground. They have driven roadways out to the extreme edges of their ore zones, installed continuous mining equipment, and are retreating to the shafts. The longwall miners are connected by several flexible chain conveyors to the mine's main conveyor belts, which lead to the ore shaft.

An important consideration in potash mines is the gassiness of the ore zone. The Boulby Mine in England and both mines in France are considered gassy mines. None of the mines in Carlsbad, NM, are considered gassy, according to 45 years of sampling records; nor are any of the mines in Canada. However, the Cane Creek Mine near Moab, UT, was abandoned as an underground mine due to a methane gas explosion.

Other technologies used in North America involve beneficiating naturally occurring brines or solution mining. Each site has its slight variations. The oldest potash-from-the-ground site in the United States is the Searles Lake site in southern California. Near-surface brines are pumped into a plant for mechanical crystallizing of potassium chloride, potassium sulfate, and boron. At Wendover, UT, near-surface brines are gathered in shallow trenches and pumped to solar ponds for crystallization by evaporation. One pond at a time is dewatered, and crystals of the resulting sylvinite are scraped from the pond floor and taken to a flotation plant for beneficiation to potassium chloride. The site on the north arm of Great Salt Lake takes brine solely from the north arm of the lake and runs the brine through many solar ponds. The potash ore kainite is crystallized by solar energy in these ponds. One pond at a time is dewatered, and kainite is scraped from the floor of the pond and transported to the plant which converts the kainite to potassium sulfate. The potash mine outside of Moab, UT, was once an underground mine but proved too gassy and undulating. The mine was converted to a solution mine by sealing the shafts and drilling wells to both uphill and downhill locations on the side of a syncline. Fresh water is pumped underground updip of the lowest point mined. Brine pumped from the lowest point of the mine is passed to solar ponds for crystallization by solar evaporation. One pond at a time is dewatered, and the sylvinite is scraped out of the pond and transferred to the original flotation plant for beneficiation to potassium chloride. The solution mine near Belle Plaine, Saskatchewan, mines ore which is about 5,000 feet deep. Concentric pipes move brine down a single well to a cavity in the ore and return a saturated brine to the plant for crystallization using natural gas. The process is repeated in the many wells in this operation. This plant is able to separate the halite from the sylvite in the evaporators and does not have to use flotation to beneficiate the potassium chloride. The two firms using the waters from the Dead Sea in the Middle East use solar evaporation to crystallize the potash ore out of the brine. The water chemistry is such that a combination of carnallite and halite are harvested by the floating dredges.

A new process is rumored to have started in northern Mexico. The Cerro Prieto geothermal generating plant uses hot brines from geothermal wells to generate electricity. As the brines lose their heat to the power process, salts crystallize out. The process was designed to crystallize potassium chloride to a reasonably pure product. No information is available on the annual production at this time.

The newest process in North America is used in the recently flooded PCA Mine and the Kalium Mine in Saskatchewan, Canada. The ore zone is solution mined, but instead of using solar evap-

oration or heat-driven evaporators and crystallizers as other solution and brine operations do, potash is produced during the fall, winter, and spring from a large, outdoor pond by cooling the brine to near freezing temperatures. After the pure sylvite crystallizes at the bottom of the pond, it is collected by dredging. The mill is used only to dry and compact the crystals to several commercial sizes. This technology is also proposed in the Karlyuk Mine site in Turkmen S.S.R. where the first pilot plant of this process was operated in the mid-1980's.

Beneficiation.—Most sylvinite ores in the United States and elsewhere are beneficiated by froth flotation, after comminution to release the sylvite and halite particles from their agglomeration. The sylvite is floated from the halite in an aqueous solution that is saturated with both sodium and potassium chloride. Pulp densities are 20% to 35% solids. Common collectors are hydrochloride and acetate salts of aliphatic amines with a carbon chain length of 12 to 24. Frothers such as cresylic acid, pine oil, or alcohols are added before the slurry enters the flotation cell. The central point to this technology is to add a chemical to the slurry (pulp) of sylvite and halite that selectively attaches to both sylvite and air. By bubbling air through the slurry the chemical attaches to the rising air bubble and pulls the particle of sylvite to the surface. The froth of air bubbles containing potash on the surface is swept off the cell and passed on to the rest of the plant while the halite is drawn off the bottom of the cell. All the plants in Canada use froth flotation except for the two solution mines. Froth flotation is used exclusively in England and Spain. Plants in the U.S.S.R. using froth flotation are Beloruskaliy's Soligorsk 1, 2, and 3, and the Uralkaliy's Berezniki 2 and 3. Froth flotation is used in less than one-half of the plants of the Federal Republic of Germany. Froth flotation is used in one plant, Theodore, in France and in the newest plant, Zielitz, in the German Democratic Republic.

The other technologies used in beneficiation are heavy media separation, electrostatic separation, leaching, and dissolution-recrystallization. Heavy media separation is used exclusively by one company that operates potash mines in Carlsbad, NM, and Esterhazy, Saskatchewan. This technology uses a taconite solution to separate the sylvite, langbeinite, and halite by slight differences in density. Electrostatic separation is used in over one-half of the mills in the Federal Republic of Germany to separate the complex salts that are recovered from some of their mines. These ores contain sylvite, halite, carnallite, and kainite and are not well suited to aqueous separation. Leaching is used in Israel and Jordan to remove the magnesium chloride of the carnallite from the sylvite. There are hot leach and cold leach processes. The Israeli plant uses froth flotation, hot leach, and cold leach processes. Dissolution-recrystallization is much like solution mining except that the ore is conventionally mined and is brought to the surface as a solid. On entering the mill, the ore is dissolved in a hot NaCl saturated brine, which preferably dissolves potash and leaves the insolubles and the halite behind in the ore. Sylvite solubility in water doubles between 20° C and 80° C while halite solubility decreases slightly. As the water cools, only potassium chloride tends to crystallize out. Both French mills use this technology. Beneficiation by this technique is used in the Uralkaliy Combine in Soligorsk 1 and Berezniki 1. It is used in one Carlsbad, NM, mill because the ore has 7% clay, and is also the method used by the PCA plant in Saskatchewan, Canada.

Physical Processing.—Once the sylvite is reasonably pure (95% or higher) the producer turns his attention to the final particle size. Many countries in the world have the tradition of hand-casting the potash onto the fields. They are happy with the particle size that emerges from the flotation cells. The United States, Canada, much of Europe, and other countries have developed technologies of spreading the potash over great acreages that could not be covered by one person walking and spreading the fertilizer by hand. These technologies require that the particles of potash be larger than is normally recovered from the ore. Part of the requirement is that the potash particle match the particle size of diammonium phosphate (DAP) or mono-ammonium phosphate (MAP) granules. Potash and DAP are often mixed together to make a complete fertilizer application. If the two products were not the same size (and were mixed together in a fertilizer spreader), the smaller sized material would be segregated at the bottom of the spreader. During spreading, the material at the bottom of the spreader (the small sized material) would be applied primarily to the first part of the field and the larger material would be applied to the latter part of the field. Neither part of the field would receive a balanced application. The solution to this problem is to "compact" the fine potash between two rollers under high pressure to form a board of potash. This board is broken up with larger particles of potash coming out of the process. These larger particles are the desirable sizes, coarse and granular, that match the DAP and MAP particle sizes.

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[1] All tonnages are reported in metric tons, K_2O equivalent, unless otherwise noted.

[2] Mining Magazine (London), v. 160, No. 12, Dec. 1989, p. 490.

[3] O'Driscoll, M. Brazil's Industrial Minerals: Seeking Success Against All Odds. Ind. Miner. (London), Nov. 1989, p. 63.

[4] Telephone conversation with Cyprus Foote Mineral Co. executive.

[5] Fertilizer International (London), No. 279, Nov. 1989, p. 12.

[6] Mining Magazine (London), v. 160, No. 5, May 1989, p. 353.

[7] Fertilizer International. No. 276, Aug. 1989, p. 11.

[8] ——. No. 269, Jan. 1989, p. 11.

[9] Phosphorus & Potassium (London), No. 162, July-Aug., 1989, p. 15.

[10] Fertilizer Focus. Aug. 1989, p. 30.

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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 and pumicite since September 1989. Domestic survey data were prepared by Blanche S. Hughes, mineral data assistant, and the international production table was prepared by Virginia Woodson, international minerals data assistant.

Domestic production of pumice and pumicite sold or used increased about 20% compared with that of 1988. Apparent consumption increased about 8%. Greece was the principal source of pumice imports with 71% of total imports compared to 86% in 1988.

DOMESTIC DATA COVERAGE

Domestic production data for pumice and pumicite were developed by the Bureau of Mines from one voluntary survey of U.S. operations. All 19 operations that received a survey form responded. Fourteen active operations contributed 100% of the quantity and value of sold and used pumice and pumicite as shown in table 1.

Large changes in production, unit value, and markets for pumice and pumicite were attributed to improved data collection rather than an indication of drastic changes in value or markets for this commodity.

PRODUCTION

Production of pumice and pumicite sold or used increased to 424,000 metric tons with a value of $8.2 million. The States of Oregon, California, New Mexico, and Idaho, in order of decreasing production, accounted for nearly all of the pumice sold or used in the United States.

Principal domestic producers were Glass Mountain Pumice Inc., Siskiyou Co., CA; Hess Pumice Products, Malad City, ID; Producers Pumice, Meridan, ID; Copar Pumice Co. Inc., Santa Fe, NM; General Pumice Corp., Santa Fe, NM; Utility Block Co., Albuquerque, NM; Cascade Pumice Co., Bend, OR; and Central Oregon Pumice Co., Bend, OR. These eight companies accounted for 94% of U.S. pumice and pumicite production.

CONSUMPTION AND USES

The most important market for pumice was building block, consuming 73% of the total. Compared to the marketing pattern in 1988, abrasive uses increased 12%, while landscaping uses of pumice decreased 68%. Other and unspecified uses of pumice and pumicite increased to over 60,000 tons.

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TABLE 1

SALIENT PUMICE AND PUMICITE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1985	1986	1987	1988	1989
United States: Sold and used by producers:					
Pumice and pumicite	461	503	356	353	424
Value (f.o.b. mine and/or mill)	$4,553	$5,756	$4,493	$4,129	$8,213
Average value per ton	$9.88	$11.44	$12.62	$11.70	$19.38
Exports[e]	1	1	1	1	7
Imports for consumption	220	349	247	306	293
Apparent consumption[1]	680	851	602	658	710
World: Production, pumice and related volcanic materials	r10,930	r10,893	11,907	p12,636	e12,312

[e]Estimated. [p]Preliminary. [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	1988		1989	
	Quantity	Value	Quantity	Value
Arizona	1	7	—	—
California	32	1,245	79	4,612
New Mexico	76	852	77	795
Other[1]	243	2,025	268	2,806
Total	[2]353	4,129	424	8,213

[1]Includes Hawaii, Idaho, Kansas, and Oregon.
[2]Data do not add to total shown because of independent rounding.

TABLE 3

PUMICE AND PUMICITE SOLD AND USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Abrasives[1]	33	846	37	2,953
Concrete admixture and aggregate	131	739	9	28
Decorative building block	148	1,507	311	3,345
Landscaping	19	491	6	807
Other[2]	22	546	61	1,080
Total	353	4,129	424	8,213

[1]Includes cleaning and scouring compounds and stone washing.
[2]Includes pesticide carriers, 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		For use in the manufacture of concrete masonry products		Manufactured, n.s.p.f.
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Value (thousands)
1988:							
Ecuador	—	—	—	—	4,898	$255	—
Greece	4,017	$630	58	$14	259,886	2,370	—
Guatemala	2,215	454	503	124	50	1	$7
Italy	151	54	1,262	444	—	—	31
Mexico	17,464	2,495	—	—	50	8	3
Spain	930	93	—	—	—	—	72
Turkey	2,811	587	20	2	10,924	967	2
Other[1]	282	73	44	47	—	—	589
Total	27,871	4,386	1,887	631	275,808	3,601	704
1989:							
Australia	3,952	228	145	6	NA	NA	NA
Ecuador	17,197	1,775	14,410	1,416	NA	NA	NA
Greece	[2]210,017	4,499	347	58	NA	NA	NA
Guatemala	3,909	586	433	40	NA	NA	NA
Indonesia	5,583	665	383	27	NA	NA	NA
Italy	259	115	1,208	509	NA	NA	NA
Mexico	20,432	3,011	([3])	1	NA	NA	NA
Turkey	11,722	1,539	6,068	929	NA	NA	NA
Other[4]	393	65	697	663	NA	NA	NA
Total	273,464	12,483	23,691	3,649	NA	NA	NA

NA Not available.

[1]Includes Australia, Austria, Canada, China, France, the Federal Republic of Germany, Iceland, Indonesia, Japan, the Republic of Korea, Norway, Sweden, Taiwan, Thailand, the United Kingdom, and Venezuela.

[2]The Journal of Commerce Port Import/Export Reporting Service data.

[3]Less than 1/2 unit.

[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]	1985	1986	1987	1988[p]	1989[e]
Argentina[3]	44,350	22,957	99,093	160,100	100,000
Austria: Trass	6,981	5,808	6,922	7,359	7,000
Cameroon: Pozzolan	105,634	168,425	[e]170,000	130,490	130,000
Cape Verde Islands: Pozzolan[e]	10,000	10,000	10,000	10,000	10,000
Chile: Pozzolan	206,333	222,080	242,453	277,179	250,000
Costa Rica	[e]1,500	[e]1,500	6,000	6,000	6,000
Dominica: Pumice and volcanic ash[e]	110,000	110,000	100,000	100,000	100,000
Ethiopia	15,000	35,481	26,042	143,442	90,000
France: Pozzolan and lapilli	496,100	409,600	[e]450,000	[e]450,000	450,000
Germany, Federal Republic of: Pumice (marketable)	207,000	215,000	205,000	[r e]185,000	140,000
Greece:					
Pumice	620,328	[r]860,047	779,885	750,000	700,000
Pozzolan	938,181	[r]1,005,000	814,000	900,000	900,000
Guadeloupe: Pumice	215,340	221,157	[e]220,000	[e]220,000	220,000
Guatemala: Pumice	16,038	11,442	15,191	[e]15,000	15,000
Iceland	56,000	52,500	58,792	65,444	65,000
Italy:[e]					
Pumice and pumiceous lapilli	750,000	700,000	725,000	[r]730,000	700,000
Pozzolan	5,000,000	4,500,000	5,000,000	5,000,000	4,500,000
Martinique: Pumice[e]	150,000	140,000	130,000	130,000	130,000
New Zealand[e]	20,000	20,000	15,000	[4]25,003	25,000
Spain[5]	849,440	968,116	1,053,914	[e]950,000	950,000
Turkey[e]	[r]200,000	[r]325,000	[r]1,000,000	[r]1,620,000	2,000,000
United States (sold and used by producers)	460,800	502,600	355,600	352,900	423,800
Yugoslavia: Volcanic tuff	[r]450,610	385,844	423,917	407,988	400,000
Total	[r]10,929,635	[r]10,892,557	11,906,809	12,635,905	12,311,800

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through May 8, 1990.

[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 12 years industry and Bureau of Mines experience, has been the commodity specialist for quartz crystal since 1986. Domestic survey data were prepared by Maureen Nash, mineral data assistant.

Cultured quartz crystal production and consumption increased in 1989 for the third consecutive year, and consumption of domestic lascas as feedstock for cultured quartz crystal increased also. The single domestic producer of lascas, the raw material from which cultured quartz crystal is produced, operated its mine to supply material to consumers. Demand for specimen-quality natural quartz continued; quartz crystal for this application is discussed in the Gem Stones chapter.

Electronic-grade quartz crystal is single-crystal silica that is free from all visible defects and has piezoelectric properties that permit its use in electronic circuits for accurate frequency control, timing, and filtration. These uses generate practically all the demand for electronic-grade quartz crystal.

Natural electronic-grade quartz crystal was the leading form of quartz until 1971 when cultured quartz crystal took the lead. Cultured (synthetic) quartz has replaced natural crystal in practically all applications. In 1989, synthetic quartz crystal producers consumed about 570,000 kilograms of lascas in their production and less than 500 kilograms of natural quartz crystal found application in electronic devices.

DOMESTIC DATA COVERAGE

The Bureau of Mines collected domestic production and consumption data for quartz crystal through a voluntary survey of U.S. operations. Seven companies responded to the canvass for the production of cultured quartz crystal, and the six 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 1989. These companies represented nearly 100% of total consumption, also shown in table 1. Consumption for the nonrespondents was estimated using reported prior-year consumption levels.

The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on quartz crystal that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

LEGISLATION AND GOVERNMENT PROGRAMS

The National Defense Stockpile contained about 764,000 kilograms of natural quartz crystal, valued at $10 million. This quantity represented an excess of about 492,000 kilograms

TABLE 1

SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS

(Thousand kilograms and thousand dollars)

	1985	1986	1987	1988	1989
Production:					
Mine[e 1]	454	544	—	272	454
Cultured	258	238	381	389	464
Exports:					
Natural:[2]					
Quantity	27	34	63	43	NA
Value	$290	$411	$708	$431	NA
Cultured:[2]					
Quantity	84	147	203	189	57
Value	$3,723	$5,686	$6,954	$7,162	$2,600
Lascas:					
Quantity	[e]363	—	—	—	—
Imports of lascas:[3]					
Quantity	78	24	66	98	NA
Value	$99	$51	$157	$180	NA
Consumption:					
Natural (electronic- and optical-grade)	3	1	(4)	2	(4)
Cultured (lumbered)	20	20	25	28	17
Cultured (as grown)	102	194	250	293	344
Total	125	215	275	323	361

[e] Estimated. NA Not available.
[1] Excludes lascas produced for specimen and jewelry material uses.
[2] Bureau of the Census as adjusted by the Bureau of Mines.
[3] Bureau of the Census.
[4] Less than 1/2 unit.

above the goal set for the stockpile. During the year, quartz crystal stockpile sales amounted to about 74,800 kilograms at $368,000 to support the ferroalloys upgrading project. These were the first sales since 1985. The stockpile material, which primarily consists of large natural crystals, could be absorbed by the specimen and gem material industry. Very little, if any, of the material would be consumed in the same applications as synthetic quartz crystal.

STRATEGIC CONSIDERATIONS

Natural electronic-grade quartz crystal was initially designated after World War II as a strategic and critical material. At the time of U.S. stockpile acquisition, cultured quartz crystal was not commercially available. 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] Near yearend 1989, the President received authorization from Congress to further reduce the stockpile goal from about 272,000 kilograms to about 110,000 kilograms of quartz crystal.[2]

The National Defense Stockpile contains natural quartz in several weight classes and grades, including about 13,000 kilograms of material consisting of individual crystals weighing more than 10,000 grams each. Some of the individual quartz pieces in this weight class are suitable for generating mother seeds for cultured quartz crystal production. These large pieces were acquired from Brazil because similar materials were not available from a domestic source.[3]

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. Coleman mined only during the summer months, but processed lascas yearround. Lascas was mined, crushed, and sized. Crushed and sized material was transported to the processing plant where operators rinsed it in oxalic acid and then in deionized water to remove external contaminants. Finally, hand sorting, drying, and examination on a light table completed the necessary processing. The material was then shipped to cultured quartz crystal producers in 45-kilogram (100-pound) bags.

Production of cultured quartz crystal increased nearly 20% in 1989. Six 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, sold the quartz-crystal-growing portion of their 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°C to 400°C; the temperature of the top portion is maintained at 10°C to 50°C less. At these temperatures, the solution expands and creates an internal pressure in the vessel between 10,000 and 30,000 psi. Under these conditions the lascas dissolves to create a solution saturated with silica.

Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed crystals in the top half of the autoclave. The process continues until the growing crystals reach their desired size. The process may take 30 to 60 days, and sometimes even longer.

The processing of quartz crystals into various end uses is the same whether natural or cultured crystal is used. Before cutting, crystals are examined for physical defects. 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; the electrodes are attached; and 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 six domestic quartz crystal producers increased about 27%, from 451,000 kilograms in 1988 to 572,000 kilograms in 1989. The 25 active device-fabricating companies in 9 States consumed 12% more quartz crystal in 1989 than in 1988. 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 and the wafer then vibrates mechanically throughout the bulk of the material at a characteristic natural resonance frequency. The quartz resonators are uniquely suitable for military-aerospace and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate sta-

bility, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators were used for many less demanding applications such as providing timing signals for watches, clocks, and microprocessors in industrial, automotive, and consumer products.

For very high frequencies (above 100 megahertz), the quartz wafer becomes too thin for practical use. At these higher frequencies, quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than wafer thickness, have become more important. 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.

Sand and lascas were raw materials used by the majority of manufacturers in the silica glass industry. High-quality domestic silica sands were suitable for most uses, although lascas may be used as a feedstock material for manufacturing special large lenses, mirrors, and windows.

Historically, quartz crystal has been a material of strategic importance. During World War II, quartz was used principally in analog communications (e.g., in telephone multiplexing and in mobile military radios). Today, because of military emphasis on command, control, and communications (C^3) surveillance and the growth of more sophisticated electronic systems, the importance of use of quartz crystal devices has grown. Many of the military applications are at the leading edge of technology. It has been U.S. Department of Defense policy to require that all military systems be hardened to nuclear radiation. To meet this special requirement, cultured quartz crystal must be radiation hardened by sweeping, a technique to remove certain impurities from the quartz.

Because of cost advantages, cultured quartz was used almost exclusively by the crystal device industry. 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 in the past have discontinued use of natural quartz. 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 56,000 kilograms at the beginning of 1989. At yearend, these stocks had increased to 73,000 kilograms.

PRICES

The average value of as-grown cultured quartz, based on reported sales of about 340,000 kilograms, was $30.67 per kilogram ($13.91 per pound), an increase of 59% compared with that of 1988. Sales volume increased 22%. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, increased 17% to $140.97 per kilogram ($63.94 per pound), based on reported sales of 40,000 kilograms. Sales volume decreased 37%.

FOREIGN TRADE

The Bureau of the Census began using the Harmonized Tariff Schedule in 1989 to identify material passing through U.S. customs. This system makes classification codes for imports and exports consistent internationally. With the adoption of the new codes, imports and export codes for quartz crystal changed, and some formerly listed details are no longer available. The import code for Brazilian crude pebble, which represented nearly all lascas imports recorded, was eliminated. Although this material probably continued to enter the United States, the new code system aggregated several categories making information about specific materials unavailable. Likewise, the export data for natural electronic-grade quartz crystal were no longer available.

Because of these changes, foreign trade information for quartz crystal is limited. While information remained concerning exports of synthetic quartz crystal, comparison between the figures for 1988 and 1989 indicated that exports decreased nearly 70%. Reports for domestic producers indicated that these data may not be accurate. Reports indicated that exports were higher than those reported by Census.

OUTLOOK

Domestic production of cultured quartz crystal has grown steadily since 1986. Increased demand for crystal devices for electronic consumer products along with similar increases for all microprocessor controlled devices, indicated that 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 will 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] U.S. Senate. Title XXXIII—National Defense Stockpile, Sec. 3301. Authorized Changes in Material Quantities. Congr. Rec., v. 135, No. 110, Aug. 15, 1989, pp. 10507-10508.

[3] Work cited in footnote 1.

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RARE-EARTH MINERALS AND METALS

By James B. Hedrick and David A. Templeton

Messrs. Hedrick and Templeton are physical scientists with the Branch of Nonferrous Metals. Mr. Hedrick has covered rare earths for 9 years. Mr. Templeton has shared coverage of the commodity for 2 years. Domestic survey data were prepared by Ms. Imogene P. Bynum, Nonferrous Metals Data Section. International data were prepared by Mr. Harold Willis, International Data Section.

Domestic consumption of the rare earths was almost double the quantity used in 1988, mine production increased sharply, and the industry performed well amid increased international competition. Traditional markets of the rare earths, such as petroleum catalysts and metallurgical additives, continued a downward trend while new and emerging markets, such as neodymium-iron-boron permanent magnets, advanced ceramics, and automotive catalysts, showed strong growth. The television and lamp phosphors market was unchanged, and glass polishing applications increased markedly. Demand for rare earths consumed in high-temperature superconductors was small; however, technologic breakthroughs in 1989 increased the prospects for commercial development of rare-earth superconductors.

TABLE 1

SALIENT U.S. RARE-EARTH STATISTICS

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1985	1986	1987	1988	1989
Production of rare-earth concentrates[1]	13,428	11,094	16,710	11,533	20,787
Exports:[e 2]					
Cerium compounds	NA	NA	NA	NA	1,433
Rare-earth metals, scandium, and yttrium	NA	NA	NA	NA	510
Ore and concentrate	4,419	r3,911	r3,041	r4,415	NA
Ferrocerium and pyrophoric alloys	23	29	r72	r32	e31
Imports for consumption:[e 2]					
Monazite	3,132	1,628	617	1,058	426
Metals, alloys, oxides, compounds	1,124	r751	r724	r912	6,125
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent[e]	12,100	r10,900	r11,100	r16,800	27,770
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	2.14	2.14	2.31	2.43	2.65
Monazite concentrate, REO basis	1.09	1.06	.90	1.15	1.19
Mischmetal, metal basis	12.35	12.35	12.35	12.35	12.35
Employment, mine and mill[e 3]	330	283	r301	320	381
Net import reliance[e 4] as a percent of apparent consumption	(5)	(6)	(6)	r29.00	23.49

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1]Comprises only the rare earths derived from bastnasite, as reported in Unocal Corp. annual reports.
[2]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import and export categories for 1989 are not necessarily comparable with those of previous years.
[3]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.
[4]Imports minus exports plus adjustments for Government and industry stock changes.
[5]Increase in industry stocks exceeded net imports.
[6]Net exporter.

PRODUCTION

Bastnasite, a rare-earth fluocarbonate mineral, was mined by Molycorp, Inc. at its Mountain Pass, CA, open pit mine. Although mine output increased, Molycorp's sales of rare earths reportedly decreased slightly, mainly as a result of weak foreign demand and increased international competition. Molycorp completed an expansion of its separation facilities to produce additional quantities of dysprosium and neodymium oxides for the permanent magnet industry. The company also began production of erbium, an element used in glass coloration (pink), lasers that emit light in the blue wavelengths, and as a burnable poison in nuclear reactors. Monazite, a rare-earth phosphate mineral, was produced as a byproduct of titanium and zirconium minerals production by Associated Minerals (USA) Inc., a subsidiary of the Australian company Renison Goldfields Consolidated Ltd. (RGC). Associated Minerals operated its placer dredging operation at Green Cove Springs, FL. The addition of a spud barge to the Florida operation has reportedly increased ore mining capability significantly and offset falling heavy-mineral sand grades. The barge addition allowed the floating concentrator to operate at design capacity. Monazite from all of RGC's mineral sands operations, including Green Cove Springs, was fully sold under long-term contracts.[1]

Imperial Mining Co. produced minor amounts of a mixed monazite-xenotime-zircon concentrate at a gold and industrial sand and gravel mine in North Carolina. To improve byproduct heavy-mineral sands recovery and delineate ore, Imperial was seeking a joint-venture partner to provide capital and expertise.

Scandium concentrate, produced in prior years in Utah, was processed by Sausville Chemical Co., Garfield, NJ, and Boulder Scientific Co., Mead, CO, into high-purity scandium oxide. Facilities to purify scandium compounds were operated by Research Chemicals Div. of Rhône-Poulenc Inc., Phoenix, AZ, and the Materials Preparation Center, Ames, IA.

Principal domestic producers of neodymium-iron-boron magnet alloys were Molycorp, Neomet Corp., and Research Chemicals. Leading U.S. producers of rare-earth magnets were the Delco Remy Div. of General Motors Corp., Hitachi Magnetics, Crucible Magnetic Materials, and IG Technologies.

In New Mexico, Molycorp and the Mescalero Apache Tribe announced a joint-venture agreement to develop a zirconium and yttrium-bearing deposit on the tribe's reservation. The deposit, identified by Molycorp in 1985, contains eudialyte, an yttrium-bearing zirconium silicate mineral. Reported reserves were 2.4 million tons grading 1.2% zirconium oxide and 0.18% yttrium oxide. Initial metallurgical tests by Molycorp indicate that the ore could be economically processed with conventional heap-leach technology.

In the southeastern United States, Associated Minerals and its parent company, RGC, announced completion of the exploration phase of the Old Hickory heavy-mineral sands deposit located southwest of Richmond, VA. The deposit reportedly contains 7.3 million metric tons of heavy minerals with minor amounts of monazite. Mining of the Old Hickory deposit could begin in 3 to 5 years.

CONSUMPTION AND USES

Domestic rare-earth processors consumed 72% more rare earths in 1989 than they consumed in 1988. Bastnasite consumption was 73% higher than in 1988, but monazite consumption was 42% lower. Shipments of rare-earth products from domestic processors of ore, concentrates, and intermediate concentrates was equivalent to 12,975 tons of rare earth oxide (REO), up 31% from the 9,867 tons shipped in 1988.

Consumption of mixed rare-earth compounds decreased 49% from the 1988 level, while consumption of purified compounds increased 98%. Higher consumption of purified compounds was the result of continued strong demand for neodymium, dysprosium, and certain other rare earths used in high-strength permanent magnets, cerium used in automotive catalytic converter materials and glass, and for yttrium used in a variety of ceramic and refractory applications.

The producers of mischmetal, rare-earth silicide, and other rare-earth alloys consumed 30% more rare earths in 1989 than in 1988, while shipments of these goods fell 2% during the same period. Shipments of high-purity rare-earth metals increased 22% during the year.

The approximate distribution of rare earths by use, based on information supplied by primary processors and some consumers, was as follows: catalysts in petroleum, chemical, and pollution control applications, 42%; metallurgical uses as iron and steel additives, alloys, and mischmetal, 14%; ceramics and in glass polishing compounds and as glass additives, 43%; and miscellaneous uses in phosphors, electronics, permanent magnets, and in lighting and research applications, 1%.

The glass industry's principal use of rare earths, mainly cerium concentrate or cerium oxide, was as polishing compounds for lenses, mirrors, 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, and decolorizers, as 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, avionic and data displays, X-ray intensifying screens, low- and high-pressure mercury vapor lights, electronic thermometers, and trichromatic fluorescent lamps.

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, and as principal constituents and stabilizers in high-temperature refractories, such as yttria-stabilized zirconia, and in glasses and paints.

Rare-earth compounds had applications in petroleum fluid cracking catalysts, noncracking catalysts, oxygen-sensing electrolytes, computer bubble domain memories, dyes and softeners for textiles, electronic components, nuclear fuel reprocessing, microwave applications, incandescent gas mantles, laser crystals, fiber optics, carbon arc lighting, synthetic gem stones, and superconductors.

Rare-earth permanent magnets were used in electric motors; alternators; generators; line printers; computer disk-drive actuators; proton linear accelerators; synchronous torque couples; eddy current brakes; microwave transmission focusing; magnetrons; klystrons; medical and dental applications, including nuclear magnetic resonance imaging; traveling wave tubes, metallic separators; aerospace applications, including 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, hydrogen storage alloys used in heat exchangers and fuel cells, lighter flints, armaments, permanent magnets, neutron converter foils, special lead fuses, target materials for sealed-tube neutron generators, and high-voltage transmission cable.

STOCKS

Stocks of rare-earth ores and concentrates held by 19 producing, processing, and consuming companies decreased 54%. Bastnasite concentrate stocks held by the principal producer and six other processors decreased 59% from the 1988 level. Yearend stocks of monazite increased 35%, while stocks of yttrium concentrate decreased 10%.

Stocks of other rare-earth concentrates fell 43%. Stocks of mixed rare-earths compounds increased 12%, as stocks of purified compounds decreased 55%. Yearend stocks of mischmetal, rare-earth silicide, and other alloys containing rare earths gained 37%, as inventories of high-purity rare-earth metals were off 78%.

PRICES

Published prices for the rare earths were generally nominal and subject to change without notice. Increased foreign competition resulted in competitive pricing policies in the United States in 1989 with prices for most rare-earth products quoted on a daily basis.

Prices quoted by Molycorp for unleached, leached, and calcined bastnasite in standard quantities, containing 60%, 70%, and 85% REO, were $1.15, $1.20, and $1.40 per pound of contained REO, respectively, at yearend 1989. These prices were respectively $0.10 per pound more than at yearend 1988.

The price range of Australian monazite (minimum 55% rare-earth oxide, including thoria, f.o.b./f.i.d.),[2] as quoted in Australian dollars (A$),[3] increased from A$700-A$780 per ton at yearend 1988, to A$780-A$880 per ton by yearend 1989. The U.S. price range, converted from Australian dollars, increased from US$598-US$666[4] in 1988 to US$616-US$695[5] in 1989. The average declared value of imported monazite increased in 1989 to $685 per ton, up $85 from the 1988 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.

The price of cerium concentrate quoted by American Metal Market was $1.55 per pound of contained cerium oxide at yearend 1989, an increase of $0.15 from the previous year. The yearend price of lanthanum concentrate remained unchanged from the 1988 level at $1.40 per pound of REO contained.

Mischmetal (99.8%, lots over 100 pounds, f.o.b. shipping point) prices for 1989, quoted by Reactive Metals and Alloys Co., were $5.00 per pound.

The price for neodymium-iron-boron alloy, compiled by the Bureau of Mines, averaged $15 per pound, 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 October 1, 1988, and throughout 1989, as follows:

Product (oxide)	Percent[1] purity	Quantity (pounds)	Price per pound
Cerium	99.0	200.0	$8.75
Europium	99.99	25.0	745.00
Gadolinium	99.99	55.0	65.00
Lanthanum	99.99	300.0	8.75
Neodymium	96.0	300.0	6.75
Do.	99.9	50.0	40.00
Praseodymium	96.0	300.0	16.80
Samarium	96.0	55.0	65.00
Terbium	99.9	44.1	375.00
Yttrium	99.99	50.0	52.50

[1]Purity expressed as percent of total REO.

Molycorp also quoted prices for lanthanide (rare earth) compounds, net 30 days, f.o.b. York, PA, or Louviers, CO, effective November 15, 1989, as follows:

Product (compound)	Percent[1] purity	Quantity (pounds)	Price[2] per pound
Cerium carbonate	99.0	150	$5.10
Cerium fluoride	Tech grade	250	3.00
Cerium nitrate	96.0	250	2.35
Lanthanide chloride	46.0	525	1.00
Lanthanum carbonate	99.9	175	5.90
Lanthanum-lanthanide chloride	46.0	525	.95
Lanthanum-lanthanide carbonate	60.0	200	2.45
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.

Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, as follows:

Product (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	99.5	20	$25.75
Dysprosium	95.0	20	132.00
Erbium	96.0	20	190.00
Europium	99.99	10	1,960.00
Gadolinium	99.99	50	136.50
Holmium	99.9	5	510.00
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	7,000.00
Neodymium	95.0	20	20.00
Praseodymium	96.0	20	38.85
Samarium	96.0	25	175.00
Terbium	99.9	5	880.00
Thulium	99.9	5	3,600.00
Ytterbium	99.0	10	230.00
Yttrium	99.99	50	115.50

Nominal prices for various rare-earth oxides and metals were quoted by Research Chemicals, per kilogram, net 30 days, f.o.b. Phoenix, AZ, for yearend 1989 as follows:

Element	Oxide[1] price per kilogram
Cerium	$80.00
Dysprosium	230.00
Erbium	570.00
Europium	1,900.00
Gadolinium	180.00
Holmium	610.00
Lanthanum	55.00
Lutetium	9,000.00
Neodymium	130.00
Praseodymium	160.00
Samarium	380.00
Terbium	2,250.00
Thulium	7,200.00
Ytterbium	675.00
Yttrium	115.50

[1]Minimum 99.9%-pure, 1- to 20-kilogram quantities.

No published prices for scandium oxide were available. Yearend nominal prices for scandium oxide per kilogram, compiled by the Bureau of Mines from information from several suppliers, were as follows: 99% purity, $5,000; 99.9% purity, $9,000; 99.99% purity, $9,500; 99.999% purity, $10,000. Scandium metal prices, as listed by the Johnson Matthey Aesar Group, were as follows: 99.99% purity, lump, sublimed dendritic, $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 2 grams.

FOREIGN TRADE

Rare-earth imports increased dramatically in 1989 from the previous year. Brazil, China, France, and India dominated the import market as shown in figure 1. Japan and Korea were the principal destinations of U.S. exports as shown in figure 2.

WORLD REVIEW

Bastnasite was the world's principal source of rare earths. It was mined as a primary product in the United States and as a byproduct of iron ore mining in China. Monazite was the second leading source of rare earths and was produced largely as a byproduct of processing minerals sands for titanium and zirconium minerals or tin minerals. The leading monazite producers were Australia, Brazil, China, India, Malaysia, the Republic of South Africa, Taiwan, and the United States. Xenotime

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

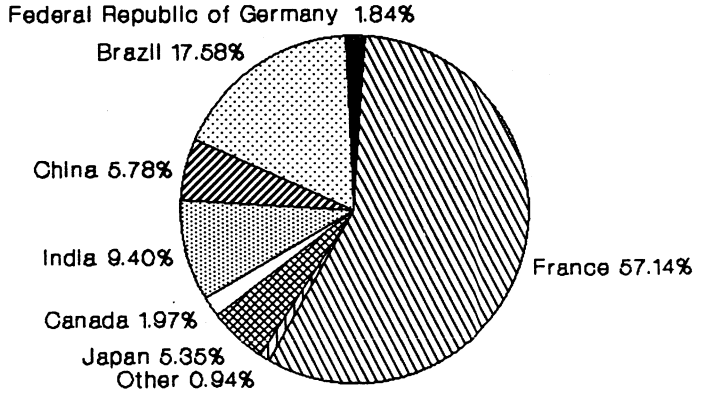
Country	1985		1986		1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	5,694	$1,984	2,660	$978	—	—	382	$237	180	$117
India	—	—	300	128	—	—	—	—	—	—
Indonesia	—	—	—	—	—	—	1,144	687	794	557
Malaysia	—	—	—	—	527	$298	197	125	—	—
Thailand	—	—	—	—	594	329	201	105	—	—
Total	5,694	1,984	2,960	1,106	1,121	627	1,924	1,154	974	674
REO content[e]	3,132	XX	1,628	XX	617	XX	1,058	XX	536	XX

[e]Estimated. XX Not applicable.

Source: Bureau of the Census. REO content estimated by the Bureau of Mines.

FIGURE 1

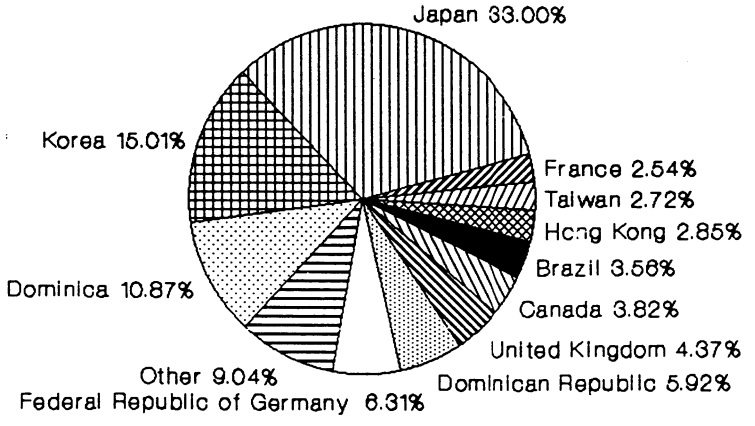
U.S. IMPORTS OF RARE EARTHS



Source: Bureau of the Census.

FIGURE 2

U.S. EXPORTS OF RARE EARTHS



Source: Bureau of the Census.

was the major source for yttrium and a minor source for the lanthanides. Xenotime was recovered primarily as a byproduct of processing for tin minerals in Indonesia, Malaysia, and Thailand, but was also produced as a byproduct of processing titanium and zirconium minerals in Australia and China. Increasing supplies of rare earths, including yttrium, were produced from rare-earth minerals in clay in China and from spent uranium leach solutions in Canada. Scandium was recovered as a byproduct of processing tungsten, tin, iron, and beryllium ores in China and was produced as a byproduct of uranium processing in the United States up to February 1989.

Capacity

Capacity to produce rare-earth minerals increased significantly in the 1980's. China and India installed the largest share of capacity during the decade.

Reserves

World reserves of rare earths were estimated by the Bureau of Mines at 45 million tons of contained REO, of which 23% is in market economy countries.[6] China had the largest share of world reserves at 76%.

Australia

Newmont Australia Ltd. and Western Rare Earths NL (previously Golden Cue NL) entered a 60-40 venture, respectively, to assess the Yangibana rare-earth deposit in Western Australia. Located about 400 kilometers northeast of Carnavon, Western Australia, the deposit reportedly contained 3.1 million tons of ore averaging 1.7% rare-earth oxide.[7]

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Country	1987		1988		1989	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds:						
Austria	—	—	—	—	591	$4,606
France	80	$1,068	77,387	$38,592	221,019	964,289
Germany, Federal Republic of	370	34,223	523	42,731	3,669	154,565
Italy	—	—	—	—	173	42,413
Japan	—	—	105	1,434	25,353	770,381
Norway	—	—	—	—	1	4,000
Switzerland	2	2,863	—	—	—	—
United Kingdom	—	—	1	1,530	—	—
Total	452	38,154	78,016	84,287	250,806	1,940,254
Other mixtures of rare-earth oxides or rare-earth chlorides:						
Canada	—	—	—	—	3,628	$504,186
China	—	—	—	—	90,485	2,336,173
France	—	—	—	—	6,827,238	18,806,732
Germany, Federal Republic of	—	—	—	—	252,066	2,141,690
Hungary	—	—	—	—	2,519	9,260
Japan	—	—	—	—	132,180	1,949,341
Netherlands	—	—	—	—	4,000	4,720
Norway	—	—	—	—	11,619	1,089,092
South Africa, Republic of	—	—	—	—	106	1,067,415
Switzerland	—	—	—	—	985	19,396
U.S.S.R.	—	—	—	—	24,864	2,157,938
United Kingdom	—	—	—	—	40,905	598,972
Other	—	—	—	—	94	24,333
Total	NA	NA	NA	NA	7,390,689	30,709,248
Rare-earth oxide, excluding cerium oxide:						
Brazil	—	—	—	—	15,061	23,645
Canada	430	54,197	—	—	—	—
Chile	100	8,334	—	—	—	—
China	9,319	1,015,770	5,470	377,200	2,108	156,719
France	216,869	13,995,531	52,197	4,597,098	168,978	3,638,954
Germany, Federal Republic of	10,848	263,889	334	38,893	1,050	232,266
Hong Kong	20	29,188	—	—	200	12,084
India	—	—	—	—	290,800	460,000
Japan	5,595	611,937	2,343	318,210	11,358	1,051,525
Malaysia	5,980	119,364	—	—	—	—
Netherlands	3,815	915,912	754	135,174	—	—
Norway	3,073	426,143	1,460	152,624	1,313	125,261
South Africa, Republic of	3	38,594	—	—	—	—
Sweden	—	—	1,000	84,721	—	—
Taiwan	—	—	—	—	78	5,339
U.S.S.R.	26,516	1,663,127	7,764	484,079	4,019	381,893
United Kingdom	744	328,392	11,567	1,052,925	6,933	898,581
Total	283,312	19,470,378	82,889	7,240,924	501,898	6,986,267

See footnotes at end of table.

TABLE 3—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY[1]

Country	1987		1988		1989	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth metals, including scandium and yttrium:						
Austria	1,284	$35,487	—	—	4,031	$43,785
Brazil	—	—	—	—	139,896	728,099
Canada	—	—	3,147	$27,692	7,191	228,706
China	6,619	392,069	12,677	392,468	110,860	754,063
Germany, Federal Republic of	1,541	114,011	—	—	1,906	28,619
Hong Kong	5	12,738	1,000	62,018	—	—
Japan	1,724	181,385	125	18,432	7,338	259,851
Kiribati	—	—	100	4,900	—	—
Norway	—	—	—	—	222	19,450
Sweden	—	—	—	—	980	182,139
U.S.S.R.	500	32,469	403	59,765	150	23,250
United Kingdom	1,817	581,821	2,635	341,608	21,632	1,908,627
Other	—	—	—	—	30	4,232
Total	13,490	1,349,980	20,087	906,883	294,236	4,180,821
Other rare-earth metals:[2]						
Australia	—	—	752	22,282	—	—
Austria	3,733	97,314	4,108	201,193	—	—
Brazil	—	—	—	—	837,746	1,250,378
China	—	—	1,818	24,500	35,590	297,734
France	17,971	593,959	23,853	666,018	—	—
Germany, Federal Republic of	469	13,211	946	20,577	38	3,998
India	—	—	—	—	302,000	575,000
Japan	72	5,872	1,011	30,196	221,379	5,409,189
Norway	—	—	—	—	1,686	181,197
United Kingdom	(3)	1,272	—	—	3,990	364,140
Other	—	—	—	—	19	4,319
Total	22,245	711,628	32,488	964,766	1,402,448	8,085,955
Ferrocerium and other pyrophoric alloys:						
Austria	—	—	3,258	81,084	4,083	103,494
Brazil	35,890	475,256	39,075	516,944	37,031	482,609
Canada	10,142	75,057	—	—	97,490	209,155
China	—	—	—	—	1,425	1,376
Finland	—	—	—	—	1,140	3,778
France	43,701	656,671	43,714	702,545	42,541	633,583
Germany, Federal Republic of	890	24,633	—	—	5,333	42,039
Hong Kong	—	—	—	—	1,840	13,104
Italy	—	—	12,600	29,610	—	—
Japan	202	5,203	—	—	30	2,890
Korea, Republic of	—	—	—	—	18,890	109,877
Netherlands	3,280	43,434	—	—	2,100	1,785
Sweden	—	—	—	—	189	10,725
Switzerland	—	—	—	—	12,591	56,133
Taiwan	319	1,273	—	—	1,055	4,973
Thailand	257	2,329	—	—	—	—
United Kingdom	148	10,301	2,015	18,270	18,533	14,211
Total	94,829	1,294,157	100,662	1,348,453	244,271	1,689,732

NA Not available.

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable with those of previous years.

[2]Listed as "Other compounds of rare-earth metal, including scandium and yttrium" under the Harmonized Tariff System.

[3]Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 4

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Country	1989	
	Quantity (kilograms)	Value
Thorium ore and concentrates:		
Austria	180	$117,045
France	2	29,780
Indonesia	594	413,249
Total	776	560,074
Cerium compounds:		
Argentina	1,440	12,280
Australia	34,063	292,140
Brazil	67,103	222,198
Canada	20,246	130,596
Chile	558	3,465
Colombia	2,124	15,175
France	47,754	296,549
Germany, Federal Republic of	107,816	777,276
Greece	1,926	10,120
Hong Kong	53,681	304,077
India	1,440	7,382
Ireland	1,920	8,258
Israel	2,860	14,627
Italy	10,353	62,109
Japan	599,253	2,684,774
Korea, Republic of	282,524	1,092,363
Malaysia	963	274,334
Mexico	13,563	99,636
Portugal	960	3,907
Singapore	5,047	30,923
Spain	14,609	90,884
Thailand	47,140	176,249
Taiwan	33,150	182,975
Trinadad and Tobago	8,628	105,000
United Kingdom	71,800	85,779
Uruguay	960	4,214
Other	791	38,884
Total	1,432,672	7,026,174
Rare-earth metals, including scandium and yttrium:		
Australia	2,313	22,646
Canada	43,036	356,612
China	300	95,400
Dominica	170,697	87,664
Dominican Republic	92,896	20,000
France	670	17,907
Germany, Federal Republic of	9,243	200,203
Italy	3,364	94,888
Japan	22,252	2,597,590
Korea, Republic of	213	15,686
Netherlands	268	25,580
Norway	11,442	523,043
Panama	3,938	6,902

See footnote at end of table.

Carr Boyd Minerals Ltd., owner of the Mount Weld rare-earth carbonatite deposit near Laverton, Western Australia, reportedly upgraded its measured reserves at a 20%-REO cutoff to 1.35 million tons of ore averaging 23.6% REO, including yttrium. At a 10%-REO cutoff grade, the reserves were 6.31 million tons at a grade of 16.2% REO.[8]

Rhône-Poulenc SA of France continued its quest to gain approval for a rare-earth separation plant at Pinjarra, Western Australia. Environmental concerns related to the disposal of naturally radioactive thorium have delayed the project. Rhône-Poulenc proposed a new plan to dispose of the thorium by injecting it into deep wells drilled into a saline aquifer.[9]

The Nissho Iwai Corp. of Japan purchased RZ Mines (Newcastle) Ltd. and Cable Sands Pty. Ltd. for A$240 million from Pioneer International Ltd. Nissho had been importing rutile and zircon produced by RZ Mines for 20 years before the purchase. Nissho's purchase was reportedly in response to anticipated growth in demand for zircon resulting from Japan's increase in steel production and from expanding European markets for fine ceramics. Combined, Cable and RZ Mines produced about 1,200 tons of monazite per year.[10]

Cable Sands continued development of the Jangardup heavy-mineral deposit in southwestern Western Australia. The company expected to begin mining in 1990 or 1991.[11]

An appeal to the Land and Environment Court concerning environmental issues delayed the startup of Australmin Holdings Ltd.'s mine at Newrybar, New South Wales. However, the appeal was not upheld, and the company expected production to begin in early 1990. Annual production of 30,000 tons of heavy- mineral concentrate was expected to yield 12,000 tons of rutile, 10,000 tons of zircon, and smaller quantities of monazite. Reserves at Newrybar were 22.3 million tons of ore averaging 1.1% heavy minerals.[12]

Renison Consolidated Goldfields subsidiary, Associated Minerals Consolidated, began development of the Eneabba West deposit in Western Australia. Initial mining was expected to start in 1990 or 1991. The deposit reportedly contained 230 million tons of sand with a heavy-mineral grade of 3.1%. Approximate annual production of monazite was expected to reach 2,500 tons.[13]

BHP-Utah Minerals International investigated the Beenup heavy-mineral sands

TABLE 4—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Country	1989	
	Quantity (kilograms)	Value
Poland	388	75,264
Singapore	781	53,475
Switzerland	1,163	171,519
Taiwan	20,010	49,973
United Kingdom	31,156	174,788
Venezuela	10,433	160,000
Other	274	51,483
Total	424,837	4,800,623

[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, exports are not necessarily comparable with those of previous years.

Source: Bureau of the Census.

TABLE 5

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Australia	18,735	14,822	12,813	11,872	13,500
Brazil	[r]3,953	[r]3,618	4,332	[r e]4,500	4,500
India[e]	4,000	4,000	4,000	4,000	4,000
Malaysia	5,808	5,959	2,908	2,920	3,100
Mozambique[e]	4	[r]3	([3])	([3])	—
South Africa, Republic of[e]	1,000	1,000	1,200	1,200	1,250
Sri Lanka[e]	200	200	200	200	200
Thailand	663	1,609	458	590	600
United States	W	W	W	W	W
Zaire	—	7	97	168	[4]175
Total	[r]34,363	[r]31,218	26,008	25,450	27,325

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Table includes data available through June 27, 1990.

[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.

[3]Revised to zero.

[4]Reported figure.

deposit in the Scott River area of Western Australia. Initial studies indicated that the Beenup deposit could support dredging operations of up to 500,000 tons of heavy-mineral-bearing ore per year. Encouraging concentrations of heavy-mineral sands were reportedly found on Scott River area leases held by joint-venture partners Golden Plateau NL, Kingsgate Consolidated Ltd., and Wynarde Pty. Ltd.[14]

North Broken Hill Peko Ltd. was evaluating the feasibility of the Naracoopa mineral sands project on King Island, situated midway between Victoria and Tasmania in the Bass Strait. Reserves were estimated to contain 25 million tons of ore grading 5.2% heavy minerals.[15]

Mineral Deposits Ltd. (MDL), a subsidiary of the Australian company Broken Hill Pty. Ltd., announced the development of a mineral sands deposit near Agnes Water, Queensland. Startup of the mine was scheduled for 1991.[16]

Minproc Chemicals Pty. Ltd. and KMCC Western Australia Pty. Ltd., a subsidiary of the U.S.-based Kerr-McGee Corp., planned to start mining the Cooljarloo heavy-mineral sand deposit near Cataby, Western Australia, in the first half of 1990. Reserves of 569 million tons of ore containing 18.3 million tons of heavy minerals, including monazite, were reported.[17]

Brazil

Production of monazite concentrates in 1987 was 4,332 tons, with 177 tons from the State of Espírito Santo, a decrease from the 197 tons produced in 1986; 3,271 tons from the State of Rio de Janerio, a decrease from the 1986 production of 3,421 tons; and 884 tons from the State of Bahia, which produced no monazite in 1986.

Measured reserves of monazite in 1987 were 36,806 tons. Estimated rare-earth oxide content based on these reserves was 18,376 tons. Monazite reserves were located in the States of Bahia, Espírito Santo, Minas Gerais, and Rio de Janeiro.[18]

Production of rare-earth compounds, as reported by the Government in 1987, was 22,500 kilograms of rare-earth carbonate, 2,422,000 kilograms of rare-earth chloride, and 66,000 kilograms of rare-earth oxides.[19]

Companhia Vale do Rio Doce (CVRD) planned to construct a rare-earth separation plant at Araxa, Minas Gerais, utilizing separation technology from Japan's Mitsubishi Corp. The company reportedly will be able to produce 3,000 tons of REO per year as byproducts from its titanium operation at Tapira.[20]

Canada

Yttrium concentrate production in 1989 from uranium ores at the Elliot Lake Mine in Ontario, on an yttrium oxide content basis, increased from 50 tons to 100 tons. The yttrium operations were a joint venture of Unocal Canada Ltd., SM Yttrium Ltd., and Denison Mines Ltd.[21]

Joint-venture partners Hecla Mining Co. and Highwood Resources Ltd. decided not to develop the Thor Lake beryllium-niobium-rare-earth deposit in the Northwest Territories because of poor market outlook. The deposit reportedly contained 8,600 tons of yttrium oxide along with other rare earths.

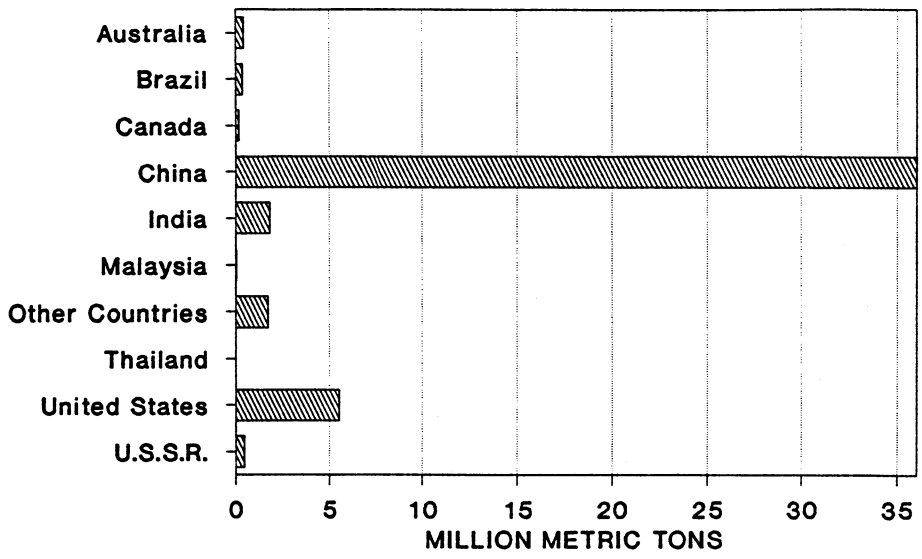
China

China remained the world's leading producer of rare earths despite reduced output from southern mines.[22] Decreased production was reportedly caused by a drop in domestic and foreign demand during the second half of 1989. Production of various mixed and separated rare-earth products reportedly reached 19,670 tons of equivalent

FIGURE 3

WORLD RESERVES OF RARE EARTHS

(REO CONTENT)



REO, an increase of 5.4% from 1988's level. Growth sectors for the rare earths in China were petroleum cracking catalysts, agricultural fertilizers, permanent magnets, and phosphors.

Scandium was produced at five locations in China and refined at four locations as follows:[23]

Scandium mine locations
1. Jiangxi Province, tungsten mines
2. Guangxi Province, tin mines
3. Guangdong Province, tin mines
4. Fujian Province, iron (magnetite) mines
5. Zhejian Province, tungsten and beryllium mines

Scandium processor locations	Principal product
1. Jiangxi Province Guizhou Cobalt Smelter	Tungsten
2. Guangxi Province, Pingkwa	NA
3. Hunan Province, Taujian, Rare-Earth Metal Smelter	NA
4. Hunan Province, Hunan Rare-Earth Metal Research Institute	Tin

NA Not available.

Denmark

Morstral Minerals investigated a heavy-mineral sands deposit near Hanstholm, northern Jutland. The deposit, covering 100 square kilometers, contains the minerals ilmenite, rutile, zircon, and monazite.[24]

Greenland

Hecla Mining Co. (47%), Nuna Oil (50%), and Gewerkschaft Wilhelm Bergbaugesellschaft (3%) formed a consortium, named Sarfartoq, to explore for rare earths and niobium in southeastern Greenland.[25]

Others, including A/S Carl Nielsen of Denmark and a Canadian triventure composed of Platinova Resources Ltd. (40%), Highwood Resources Ltd. (30%), and Aber Resources Ltd. (30%), explored a banded nepheline syenite (kakortokite) in the Ilimaussaq intrusive complex that contains the rare-earth and zirconium-bearing mineral eudialyte.[26]

Guyana

An estimated 450 river-based diamond and gold dredges were reportedly processing heavy-mineral-containing resources. Other heavy minerals identified as potential byproducts of the dredging operations were ilmenite, rutile, zircon, and, in some deposits, monazite.[27]

Japan

Japanese demand for scandium was primarily for metal halide lamps, consuming about 50%. An estimated 30% is consumed in gadolinium-scandium-gallium garnets (GSGG) and the balance consumed in the electron guns of CRT's, automotive catalysts, and other uses.[28]

Madagascar

QIT-Fer et Titane Inc. (QIT), a subsidiary of RTZ Corp. PLC (RTZ), announced that its joint-venture heavy-mineral sands project would be delayed at least until 1995, a result of problems encountered in negotiations with the Government.

Malawi

The French group, BRMG, investigated the well-known Kangankunde Hill rare-earth carbonatite in 1988, and was reportedly preparing a prefeasibility report.[29] Monazite in the carbonatite was environmentally acceptable because of its low thorium oxide content, 0.08%.

New Zealand

Fletcher Titanium Products Ltd. started production of heavy minerals at a pilot plant located on the west coast of South Island at yearend. Production of 400 tons per year of rutile, zircon, and monazite was planned.[30]

South Africa, Republic of

General Mining Corp. Ltd. continued to produce byproduct monazite from its Naboomspruit fluorspar operations in the Transvaal. Monazite reportedly was separated during processing of the fluorspar by wet high-intensity magnetic separators.[31]

The Anglo American Corp. of South Africa Ltd. studied the feasibility of developing heavy-mineral sand deposits in Namaqualand. The deposits were on lands owned by De Beers Consolidated Mines near the west Cape coast, 30 miles north of the Olifants River. A wet concentration pilot plant was operated during the year. If a decision is made to proceed with the project, production was planned to commence in 1992, with an expected monazite output of 1,000 tons per year. Rutile and zircon production were expected to be

25,000 and 100,000 tons per year, respectively.[32]

Severin Mining and Development Co. (Pty.) Ltd. conducted pilot plant tests on samples of a deposit 30 miles south of Richards Bay at Mitunzini. The deposit resembled the Richards Bay deposit and was reported to have a 10% heavy-mineral grade. A decision was expected in early 1990, following completion and analysis of pilot plant tests.[33]

Richards Bay Minerals reportedly delayed exploration and development work on its project at Lake St. Lucia in the Natal Province because of environmental concerns.[34]

Rio Tinto Minerals Development Ltd., a subsidiary of RTZ, acquired total ownership of QIT from BP Minerals Development Ltd., a subsidiary of British Petroleum. QIT holds a 50% interest in Richards Bay Minerals in the Republic of South Africa.[35]

Taiwan

Pacific Ocean Rare Earth Industry Co. (POR), continued production of heavy minerals, including monazite, on the west coast. Monazite reserves in Yuanlin and Chiai Counties were 50,000 tons. Ore from the area was shipped to Hsinchu for processing and separation of the rare earths from monazite. The POR rare-earth plant at Hsinchu was capable of processing 1,000 tons of monazite per year with annual separation capacity as follows: lanthanum oxide, 100 tons; cerium oxide, 240 tons; didymium oxide (Pr-Nd), 100 tons; samarium oxide, 12 tons; europium oxide, 2 tons; mixed gadolinium-terbium-dysprosium oxide, 20 tons; and yttrium oxide, 4 tons.[36]

Thailand

The Office of Atomic Energy for Peace of Thailand was building a rare-earth separation plant to process 300 tons of monazite per year. The plant was scheduled for completion in late 1990.[37]

CURRENT RESEARCH

Carr Boyd Minerals Ltd. reported a breakthrough in beneficiation of the rare earths. Company-funded research at the University of Western Australia discovered that mixed rare earths could be mechanically separated from the ore using high-energy ball mills instead of conventional chemical treatment. Rare earths produced from the new process can reportedly be reduced directly to mischmetal or alloyed simultaneously without prior melting or heating.[38]

Magnesium Elektron announced the development of a new rare-earth-magnesium alloy as a replacement for certain magnesium-thorium alloys. The new alloy, WE43, contains 3.75% to 4.05% yttrium, 2% to 2.5% neodymium, 0.75% to 1.25% heavy rare earths, a minimum 0.3% zirconium, and the balance magnesium. The alloy can reportedly substitute for the magnesium-thorium alloys presently used in several aerospace applications.[39]

Researchers at the Aluminum Company of America created a high-temperature aluminum alloy using a rare earth. The rapidly cooled cerium-iron-aluminum alloy had an extremely fine-grained microstructure, in the 5 to 40 micron range. Designated Cu78, the new alloy reportedly has improved strength and fracture toughness up to 349° C. Cu78 was expected to be used in airframe structural parts and other aerospace components.[40]

TABLE 6

RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY

(Metric tons of REO equivalent)

Country	1987	1988[p]	1989[e]
Australia	7,047	6,530	7,400
Brazil	2,383	2,475	2,475
Canada[e]	100	100	100
China	15,100	29,640	[1]25,220
India[e]	2,200	2,200	2,200
Malaysia	1,618	1,630	1,730
Mozambique[e]	[2]	[2]	—
Sri Lanka[e]	110	110	110
Thailand	267	375	[1]365
United States[3]	16,710	11,533	[1]20,787
Zaire	53	92	[1]96
Total	45,588	54,685	60,483

[e]Estimated. [p]Preliminary.
[1]Reported figure.
[2]Revised to zero.
[3]Comprises only the rare earths derived from bastnasite as reported in Unocal Corp. annual report, 1989.

OUTLOOK

The outlook for rare earths was promising. Exhibiting a wide range of chemical and physical properties, the rare earths have found increased use in an expanding number of applications. The demand pattern was expected to continue to favor separated high-purity products. Although a few traditional markets have been in decline (petroleum cracking catalysts and mixed metallurgical additives), increased rare earth use is expected in the near-term in permanent magnets, automotive catalytic convertors, glass additives, and industrial, medical, and communications lasers. Recent advancements in high-temperature superconductor technology indicate a large potential for long-term growth.

World supplies of rare earths are expected to be adequate to meet demand, in part because increased demand for titanium and zirconium minerals has initiated expansions in both the mining and processing sectors. Australia, China, and the United States should continue as the principal sources of supply.

Economic projections forecast only a modest advance in the economy in 1990, followed by a resurgence of consumer demand in 1991.[41] Rare-earth demand is predicted to outperform the domestic economy in 1990, especially in the nontraditional markets. Continued diversification in rare-earth markets is expected to provide increased stability to the industry.

BACKGROUND

Definition, Grades, and Specifications

The rare earths are a group of 17 elements comprised of scandium, yttrium, and the lanthanides.

TABLE 7

WORLD ANNUAL RARE-EARTH MINERAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Metric tons of rare-earth oxides)

	Rated capacity
North America:	
Canada:[e]	
Monazite,[1] brannerite[2]	1,000
United States:	
Bastnasite	26,000
Monazite[1]	W
South America:[e]	
Brazil:	
Monazite[1]	2,200
Europe:	
U.S.S.R.:[e]	
Monazite[3]	500
Other[4]	1,000
Africa:[e]	
Mozambique:	
Monazite[5]	2
South Africa, Republic of:	
Monazite[1]	NA
Monazite[4]	NA
Zaire:	
Monazite[4]	55
Asia:	
China:[e]	
Bastnasite[6]	20,000
Monazite[1]	10,000
Xenotime[1]	50
Other[7]	1,000
India:[e]	
Monazite[1]	2,200
Malaysia:[e]	
Monazite[5]	3,300
Xenotime[5]	600
Sri Lanka:[e]	
Monazite[1]	110
Thailand:[e]	
Monazite[5]	1,100
Xenotime[5]	75
Oceania:	
Australia:	
Monazite[1]	11,000
Xenotime[1]	20
World total (rounded)	91,000

[e]Estimated. NA Not available. W Withheld to avoid disclosing proprietary data.
[1]Byproduct of processing for titanium and zirconium minerals.
[2]Byproduct of processing for uranium, recovered as yttrium concentrate.
[3]Byproduct of processing for gold.
[4]Byproduct of processing for phosphate rock.
[5]Byproduct of processing for tin minerals.
[6]Byproduct of processing for iron minerals.
[7]Residual weathering product in clay.

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 it occurs in greater quantities in crustal rocks than lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities as a result of its aversion to combine with the common ore-forming anions.

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 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.

Largely because of 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, respectively). Yttrium is classed with the heavy subgroup because of its occurrence, ionic radius, and other similar properties.

Bastnasite can theoretically contain 74.81% REO.[42] 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 theoretically can 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.

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. Ferrocerium is a pyrophoric alloy of mischmetal and iron. Rare-earth silicide is an alloy containing about one-third mischmetal, one-third iron, and one-third silicon. The rare-earth content in master alloys ranges from tenths of a percent in nodularizing alloys for ductile iron to 10% or more in inoculants for gray cast iron. Alloys containing nearly 100% rare-earth metals, such as mischmetal, are additives to certain steels.

The purity of separated rare-earth elements, produced primarily by solvent extraction or ion exchange, usually grade 96% or higher in purity. High-purity rare-earth compounds and metals are produced up to 99.9999% 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 marketed. Analyses of the rare-earth contents of selected ores are shown in table 8.

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 companies that mine rare earths sell their concentrates to processors that separate the rare earths by chemical processing, primarily solvent extraction or ion exchange. Processors producing separated rare-earth products are often partially integrated, manufacturing fabricated and semifabricated products that are sold directly to manufacturers or end users. The distribution of the global mining industry is illustrated in figure 7.

TABLE 8

RARE-EARTH CONTENTS OF MAJOR SOURCE MINERALS

(Percent of total rare-earth oxide)[1]

Rare earth	Bastnasite Mountain Pass, California, USA[2]	Bastnasite Nei Monggol, China[3]	Monazite Capel, Western Australia[4]	Monazite North Stradbroke Island, Queensland, Australia[5]	Monazite Green Cove Springs, Florida, USA[6]	Monazite Nangang, Guangdong, China[7]
Lanthanum	33.2000	23.000	23.8938	21.5000	17.5000	23.0000
Cerium	49.1000	50.0000	46.0177	45.8000	43.7000	42.7000
Praseodymium	4.3400	6.2000	5.0442	5.3000	5.0000	4.1000
Neodymium	12.0000	18.5000	17.3805	18.6000	17.5000	17.0000
Samarium	.7890	.8000	2.5310	3.1000	4.9000	3.0000
Europium	.1180	.2000	.0531	.8000	.1600	.1000
Gadolinium	.1660	.7000	1.4867	1.8000	6.6000	2.0000
Terbium	.0159	.1000	.0354	.2900	.2600	.7000
Dysprosium	.0312	.1000	.6903	.6400	.9000	.8000
Holmium	.0051	trace	.0531	.1200	.1100	.1200
Erbium	.0035	trace	.2124	.1800	trace	.3000
Thulium	.0009	trace	.0177	.0300	trace	trace
Ytterbium	.0006	trace	.1239	.1100	.2100	2.4000
Lutetium	.0001	trace	.0354	.0100	trace	.1400
Yttrium	.0913	.5000	2.4071	2.5000	3.2000	2.4000
Total	99.8615	100.1000	99.9823	100.7800	100.0400	98.7600

	Monazite Southwest Coast Taiwan[8]	Xenotime Lahat, Perak, Malaysia[2]	Xenotime Southeast Guangdong, China[9]	RE minerals in clay Xunwu, Jiangxi Province[10]	RE minerals in clay Longnan, Jiangxi Province[10]	RE in uranium residues Elliot Lake, Ontario, Canada[11]
Lanthanum	20.0000	1.2400	1.2000	43.3700	1.8200	.8000
Cerium	46.0000	3.1300	3.0000	2.3800	.3700	3.7000
Praseodymium	5.0000	.4930	.6000	9.0200	.7400	1.0000
Neodymium	20.0000	1.5900	3.5000	31.6500	3.0000	4.1000
Samarium	3.7000	1.1400	2.2000	3.9000	2.8200	4.5000
Europium	.5800	.0120	.2000	.5000	.1200	.2000
Gadolinium	2.0000	3.4700	5.0000	3.0000	6.8500	8.5000
Terbium	.3000	.9060	1.2000	trace	1.2900	1.2000
Dysprosium	.4500	8.3200	9.1000	trace	6.6700	11.2000
Holmium	.0900	1.9800	2.6000	trace	1.6400	2.6000
Erbium	—	6.4300	5.6000	trace	4.8500	5.5000
Thulium	.9800	1.1200	1.3000	trace	.7000	.9000
Ytterbium	—	6.7700	6.0000	.2600	2.4600	4.0000
Lutetium	—	.9880	1.8000	.1000	.3600	.4000
Yttrium	.9000	61.0000	59.3000	8.0000	65.0000	51.4000
Total	100.0000	98.5890	102.6000	102.1800	98.6900	100.0000

[1]Some analyses previously adjusted to 100%.

[2]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.

[3]Zang, Z., et al. Rare-Earth Industry in China. Hydrometallugy, v. 9, No. 2, 1982, pp. 205-210.

[4]Westralian Sands Ltd. Company Brochure. Product Specifications.

[5]Analysis from Consolidated Rutile Ltd.

[6]Analysis from Associated Minerals, Green Cove Springs, FL.

[7]Xi, Zhang. The Present Status of Nd-Fe-B Magnets in China. Paper presented at The Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producers Conf. Gorham International Inc., Clearwater, FL, Mar. 2-4, 1986, 5 pp.

[8]Lu, Daluh, Horng, J., and C. Tung. The Separation of Europium from Taiwan Black Monazite. In the Proceedings of the ClChE-AlChE Symposium on Modern Chem. Eng. Tech., Taipei, Taiwan, Sept. 16-19, 1986, pp. 57-59.

[9]Nakamura, Shigeo. 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).

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FIGURE 4

BASTNASITE
(PERCENT REO)

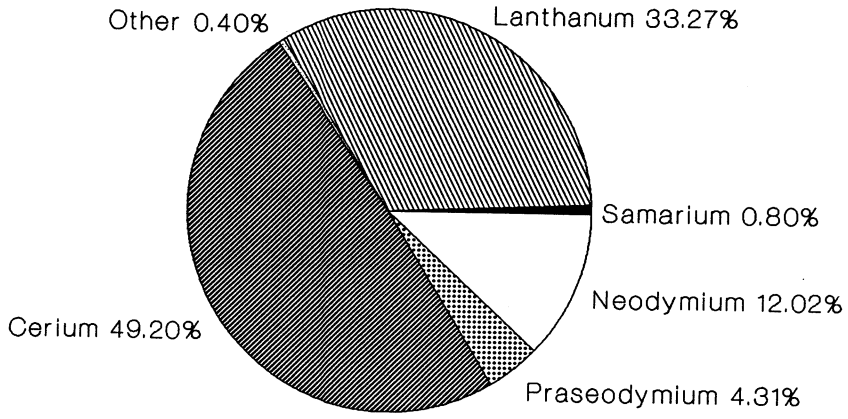
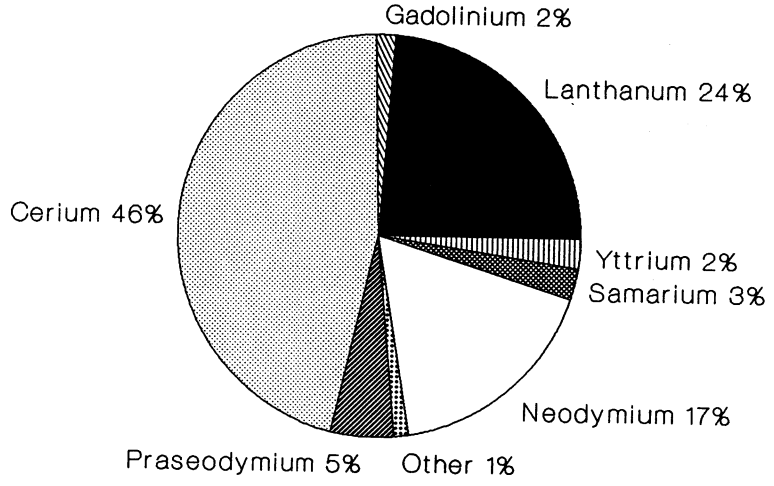
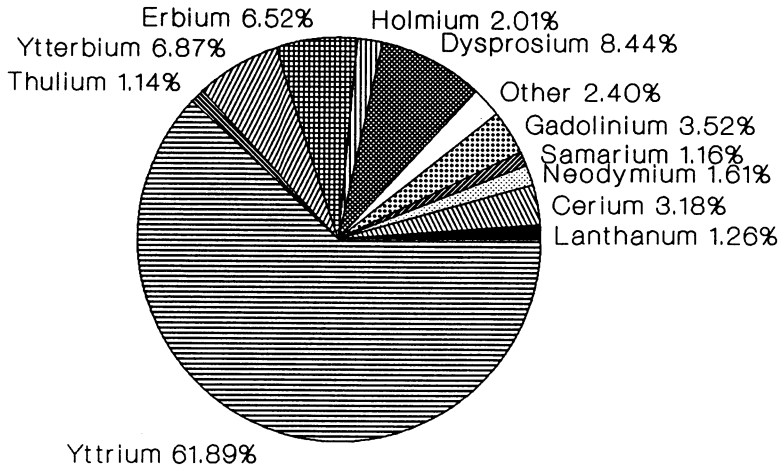


FIGURE 5

MONAZITE
(PERCENT REO)



XENOTIME
(PERCENT REO)



Geology-Resources

Although the rare-earth elements are essential constituents in more than 100 minerals, only bastnasite, monazite, xenotime, and rare earth-bearing clay occur in concentrations high enough to be considered economic ore deposits. Other rare-earth-bearing minerals such as eudialyte, an yttrium-bearing zirconium silicate, may be considered an economic resource at some time in the future.

Monazite and xenotime originate as primary accessory minerals in many crustal rocks. Erosion of the crust breaks down the crust-forming rocks releasing monazite, xenotime, and other minerals. Eroded alluvial material then undergoes natural separation and sorting by rain and wind and dissolution of the soluble minerals. Further separation and concentration of heavy minerals, especially by specific gravity, is accomplished primarily by river and sea currents. Only the more chemically and physically stable minerals, including monazite and xenotime, survive transport to become concentrated in an economic heavy-mineral deposit.

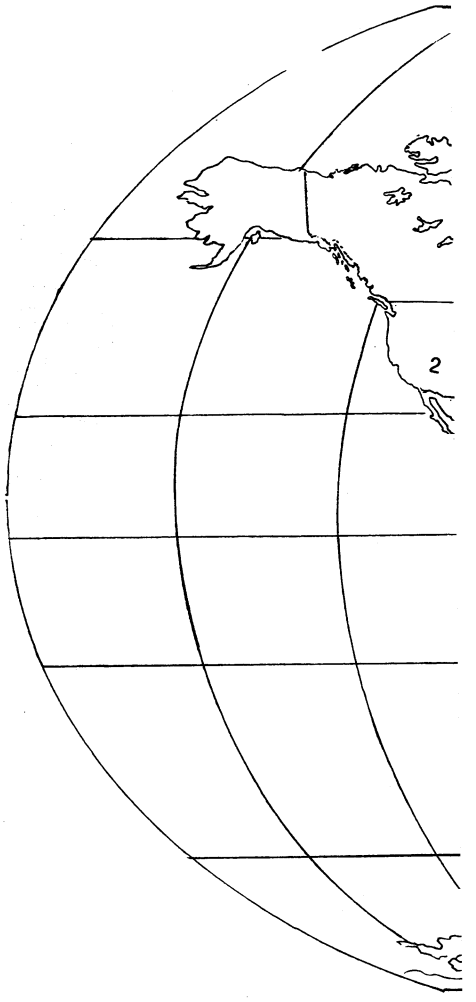
Bastnasite occurs in greater abundance in crustal rocks than do monazite or xenotime. It is most frequently associated with rocks termed carbonatites. This name is derived from the high number of carbonate (e.g., calcite) minerals that make up the composition of the rock. Unlike sea shells, which form calcite from calcium and carbon dioxide taken from seawater, these carbonate minerals arise from molten magma originating from beneath the crust. The magma intrudes the crust at points of weakness and begins to crystallize as it ascends because of decreases in pressure and temperature. As crystallization (i.e., rock forming) progresses, the once-molten magma becomes increasingly more viscous, and the rise toward the surface is halted. If the carbonatite occurs at or near the surface at a sufficient grade it may be economic.

Technology

Exploration and Development.—The Mountain Pass deposit was discovered during exploration for radioactive minerals, a property typical of most rare-earth minerals or those associated with them. Exploration techniques employed to locate the rare earths include surface and airborne reconnaissance with magnetometric and radiometric equipment. It should be noted,

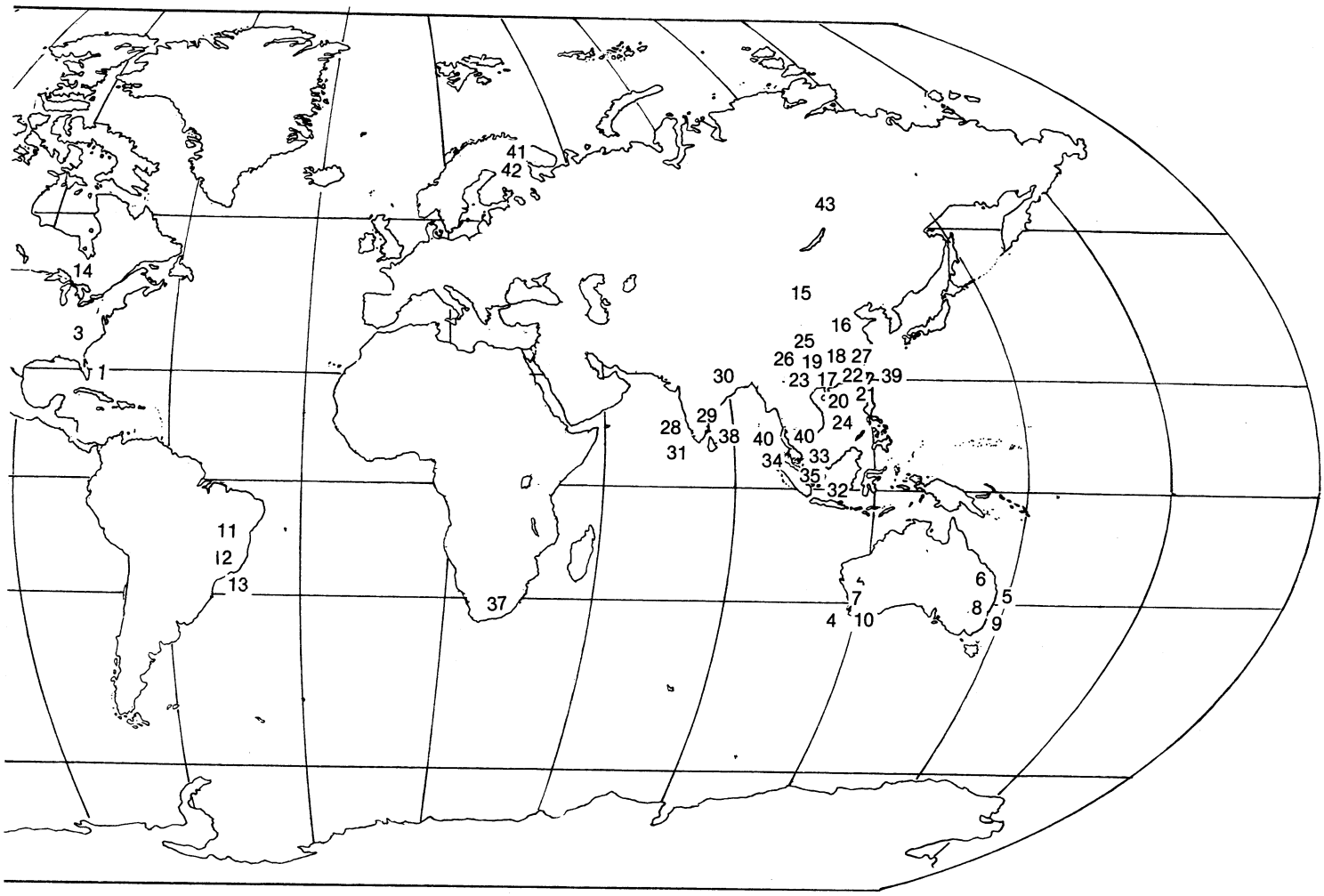
PRINCIPAL WORLD RARE-EA

COMPANY	LOCATION	RARE-EARTH MINERALS	PRIMARY MINERALS
UNITED STATES			
1. Associated Minerals (USA) Inc.	Green Cove Springs, Florida	Monazite	Titanium minerals and zircon
2. Molycorp, Inc.	Mountain Pass, California	Bastnasite	Bastnasite
3. Imperial Mining Co.	Marion, North Carolina	Monazite, xenotime	Gold and industrial sand and gravel
AUSTRALIA			
4. Associated Minerals Consolidated Ltd.	Capel and Eneabba, Western Australia	Monazite	Titanium minerals and zircon
5. Consolidated Rutile Ltd.	Amity, Bayside, Gordon, Dunwich, and Pinkenba, Queensland	Monazite	Titanium minerals and zircon
6. Currumbin Minerals Pty. Ltd.	Kirra, Kingscliff, Gympie, Gold Coast, Rainbow Beach, Cudgen, and Currumbin, Queensland	Monazite	Titanium minerals and zircon
7. Cable Sands (WA) Pty. Ltd.	North Capel, Waroona, and Bunbury, Western Australia	Monazite, xenotime	Titanium minerals and zircon
8. Mineral Deposits Ltd.	Stockton and Durness (Tea Gardens), New South Wales	Monazite	Titanium minerals and zircon
9. RZ Mines (Newcastle) Pty. Ltd.	Tomago and Nabiac, New South Wales	Monazite	Titanium minerals and zircon
10. Westralian Sands Ltd.	Yoganup (Yoganup Extended), Boyanup (Yoganup North), and Capel (North Capel), Western Australia	Monazite	Titanium minerals and zircon
BRAZIL			
11. Nuclebras de Monazita e Associados Ltda. (NUCLEMON)	Alcobaca, Porto Seguro, and Prado, Bahia	Monazite	Titanium minerals and zircon
12. Nuclebras de Monazita Associados Ltda. (NUCLEMON)	Aracruz, Guarapari, and Itapemirim Espirito Santo	Monazite	Titanium minerals and zircon
13. Nuclebras de Monazita e Associados Ltda. (NUCLEMON)	Sao Joao da Barra, Rio de Janeiro	Monazite	Titanium minerals and zircon
CANADA			
14. Denison Mines Ltd.	Elliot Lake, Ontario	Monazite, brannerite	Uraninite, brannerite
CHINA			
15. State-owned	Baiyunebo, Inner Mongolia Autonomous Region	Bastnasite, monazite	Magnetite, specularite and hematite
16. State-owned	Weishan, Shandong Province	Bastnasite	Unknown
17. State-owned	Longnan, Xunwu, and Dingnan, Jiangxi Province	RE minerals in clay	RE minerals in clay
19. State-owned	Xihuashan, Jiangxi Province	RE minerals	Wolframite, scheelite
20. State-owned	Yangjiang (Nanshanhai), Xitou, Dianbai, Zhanjiang, and Haikang, Guangdong Province	Monazite, xenotime	Titanium minerals and zircon
21. State-owned	Nangang, Guangdong Province	Monazite, xenotime	Titanium minerals and zircon
22. State-owned	Pingyuan, Qingyuan, Longchuan Heping, and Ruyuan, Guangdong Province	RE minerals in clay	RE minerals in clay
23. State-owned	Qinzhou and Beihai, Guangxi Province	Monazite	Titanium minerals and zircon
24. State-owned	Sai-Lao, Wuzhaung, and Xinglong, Hainan Island	Monazite	Titanium minerals and zircon
25. State-owned	Yueyang, Hunan Province	Monazite	NA
26. State-owned	Tongsalin, Hunan Province	RE minerals in clay	RE minerals in clay
27. State-owned	Fujian Province	RE minerals in clay	RE minerals in clay



COMPANY	LOCATION
INDIA	
28. Indian Rare Earths Ltd.	Chavara, Alwaye
29. Indian Rare Earths Ltd.	Manavalakurichi
30. Indian Rare Earths Ltd.	Chatrapur, Oriss
31. Kerala Minerals & Metals Ltd.	Chavara, Kerala
INDONESIA	
32. PT Tambary Timah	Belitung, Bangka kep, Sumatra
MALAYSIA	
33. Malaysian Mining Corp. Berhad	Various locations and Selangor St
34. Beh Minerals Sendirian Berhad	Lahat, Perak
35. Others	Various locations
SOUTH AFRICA	
36. General Mining Corp. Ltd.	Naboomspruit, T
37. Richards Bay Minerals	Richards Bay, N

TH MINERAL PRODUCERS



	RARE-EARTH MINERALS	PRIMARY MINERALS
rala	Monazite	Titanium minerals and zircon
nil Nadu	Monazite	Titanium minerals and zircon
	Monazite	Titanium minerals and zircon
	Monazite	Titanium minerals and zircon
l Sing-	Monazite, xenotime	Cassiterite
Perak	Monazite, xenotime	Cassiterite
	Monazite, xenotime	Cassiterite
	Monazite, xenotime	Cassiterite
vaal	Monazite	Fluorite
	Monazite	Titanium minerals and zircon

COMPANY	LOCATION	RARE-EARTH MINERALS	PRIMARY MINERALS
SRI LANKA			
38. Ceylon Mineral Sands Corp.	Pulmoddai	Monazite	Titanium minerals and zircon
TAIWAN			
39. Pacific Ocean Rare Earth Industry Co.	Yuanlin and Chiai Counties	Monazite	Ilmenite and zircon
THAILAND			
40. Various companies	Prachuap Khiri Khan, Chumphon, Phuket, and Takua Pa	Monazite	Cassiterite
U.S.S.R			
41. State owned	Lovozero complex, Kola Peninsula	Loparite	Apatite
42. State-owned	Khibiny complex, Kola Peninsula	Apatite	Apatite
43. State-owned	Synnyr, Khrebet	Bastnasite	NA

however, that very little exploration is conducted specifically for rare earths. Two world-class bastnasite deposits are developed and dozens of heavy mineral sand deposits are being worked for their combined mineral suite. Most of the mineral sand deposits were found during exploration conducted for ilmenite or other titanium minerals.

Mining.—Mountain Pass bastnasite is mined as a primary product from carbonatite, an intrusive igneous rock associated with alkaline intrusive igneous rocks. The hard rock is mined via benchcut, open pit methods. Blasted ore is trucked to the mill where it is crushed, screened, and heated to improve flotation. Bastnasite recovered from the flotation circuit is thickened, filtered, and dried to produce a 60% REO concentrate. The concentrate can be upgraded to 70% REO by leaching with 10% hydrochloric acid to consume any remaining calcite. Subsequent roasting can further increase the REO content to 85% by liberating carbon dioxide from the carbonate portion of the mineral.

Heavy-mineral sands are the sources of most monazite and xenotime mined in the world. Almost all mining of these sands is done by floating dredges that concentrate the heavy minerals onboard and discharge the unwanted tailings back into the previously mined areas. Dredging is particularly well-suited for the mining of unconsolidated sands. Dredged ore is mined with either cutter-head suction dredges or bucketwheel excavators. The onboard wet mill separates the economic heavy minerals ("heavies") from the gangue through a series of equipment that may include hydrocyclones, screens, spirals, and cones. Indurated sand deposits that are too difficult to extricate by dredging are mined with typical earth-moving equipment (e.g., dozers, loaders, and/or scrapers).

Processing.—Bastnasite is processed by leaching 85% REO roasted calcine with hydrochloric acid to yield soluble chlorides. Cerium, oxidized during roasting to a higher valence, is insoluble and passes through a countercurrent decantation and thickening circuit. The thickened material is then filtered to collect the precipitate, containing about 70% REO, 90% of which is ceric oxide, which is dried and sold as cerium concentrate. The leach solution overflowing the thickener circuit contains the remaining rare earths in the form of chlorides and is put through a solvent extraction process to separate the rare earths into two concentrates. One contains lanthanum, praseodymium, and neodymium and the other samarium, gadolinium, and europium. Each of these concentrates is then put through other solvent extraction circuits, and proprietary processes are used to separate the individual rare earths from each other.

Monazite and xenotime concentrates can be processed by dissolution in either sodium hydroxide or sulfuric acid. The first process is preferred because of its effectiveness in removing phosphate. In either method, thorium and certain other elements are separated, and the rare earths are subsequently recovered as mixed or individual compounds.

In the alkaline process, the concentrate is finely ground and reacted with a hot (140° to 150° C) solution of sodium hydroxide for several hours. The rare earths and thorium form insoluble hydroxides, and trisodium phosphate is dissolved. Water is added for thinning purposes, and after settling, the hydroxide precipitates are recovered by filtration, sodium hydroxide is recycled, and trisodium phosphate is recovered by crystallization.

The next processing step is to separate the rare earths and thorium. Two common methods exploit solubility differences for the separation. One way is to dissolve the mixed hydroxides in nitric or hydrochloric acid. Thorium can then be selectively precipitated by partially neutralizing the solution with the addition of sodium hydroxide or ammonium hydroxide. The solution is filtered to remove the thorium precipitate. Another method selectively dissolves the rare-earth hydroxides in hydrochloric acid. Rare-earth chlorides are dissolved, and thorium hydroxide is precipitated and separated by filtration. Solvent extraction also may be employed to separate the two materials. Tri-butyl phosphate or certain amine nonaqueous solvents can be used, but amine extractants are reported to perform best in sulfate solutions and form a high-purity thorium complex.

In the acid digestion process, monazite is finely ground and reacted with concentrated sulfuric acid at about 200° C. Temperature and acid concentration are controlled during digestion, and both rare-earth and thorium sulfates are formed. The sulfates are then dissolved in water and separated from the insoluble impurities by filtration. Thorium is then separated by precipitating with ammonia.

Byproduct Scandium.—There is no domestic exploration or mining conducted solely for scandium. This is because it occurs only in trace amounts ranging from about one part per million in uranium ores to between 500 and 800 part per million in tungsten concentrates. Scandium has recently been recovered as a secondary byproduct of copper mining at the Bingham Canyon Mine in Utah. It was recovered there from barren copper leach solutions that were processed by ion exchange and solvent extraction to produce uranium concentrates. Because of low uranium prices, recovery operations for this commodity and, hence, the byproduct scandium were placed on standby status in February 1989.

The leach solution, after completing its course through the copper recovery circuits, was obtained and processed by Energy Fuels Nuclear Corp. using an ion-exchange method to recover uranium. In this method, metal cations contained in the solution were adsorbed on resins in the ion exchange columns. Upon successive passes through this circuit, the solution was depleted of uranium, scandium, and other impurities. The resins were then stripped of their adsorbed materials via solvent extraction. Uranium products became entrained in the solvent and a sludge developed. Scandium was contained in the sludge in concentrations ranging from 5% to 10%. The sludge was then processed at a refinery to recover scandium oxide or other specific compound products.

Economic Factors

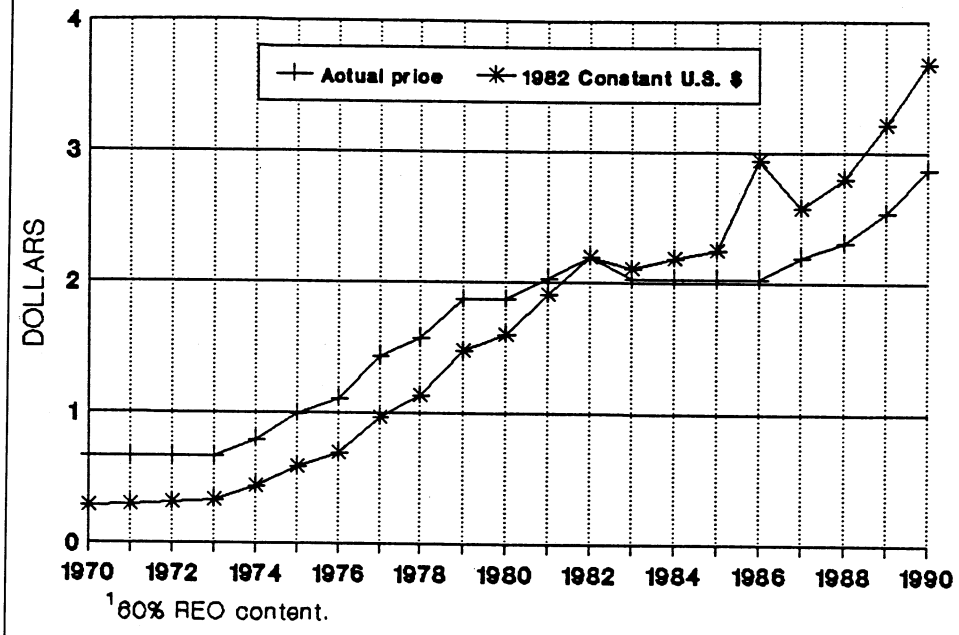
Prices.—Trends for bastnasite and monazite concentrate prices are shown in figures 8 and 9. Both concentrates exhibited a fairly steady growth in prices except for a few years following the 1979-81 economic recession. Time-price relationships, based on 1982 constant dollars, are shown in table 9.

Tariffs.—In 1989, the classification of imports to the United States was revised under the Harmonized Tariff Schedule of the United States. The new system of classification was enacted to facilitate trade between the United States and the rest of the world. The tariffs on imported rare-earth materials are shown in table 10.

Depletion Provisions.—The U.S. Government's tax depletion allowance on domestically produced monazite was 22% on the thorium content and 14% on the

FIGURE 8

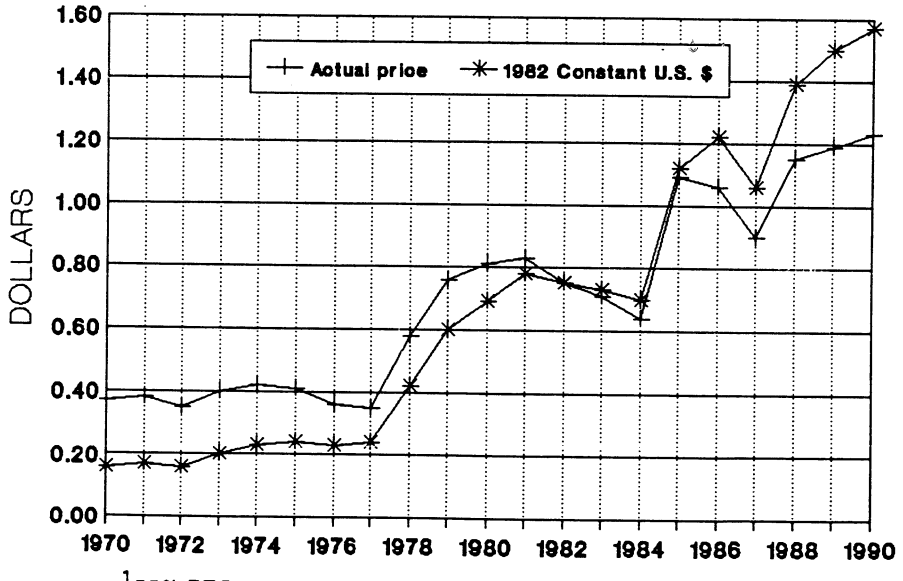
BASTNASITE CONCENTRATE[1] PRICES



[1]60% REO content.

FIGURE 9

MONAZITE CONCENTRATE[1] PRICES



[1]55% REO content.

rare-earth content. Monazite produced in foreign countries was permitted a 14% depletion allowance. The domestic depletion allowance for U.S. and foreign produced bastnasite and xenotime was 14%.

Operating Factors

Environmental Requirements.—Domestic mines and processing plants were required to meet Federal and State environmental guidelines for air, water, and soil quality. Reclamation of land currently mined for materials other than coal, including rare earths, was controlled by State authority. Requirements differed by State jurisdiction, with most requiring the mined land be returned to its original use or transformed into recreational and agricultural areas.

Naturally radioactive thorium-bearing rare-earth minerals and their byproducts were controlled by Federal and State regulatory agencies. State requirements differed by jurisdiction, but typically controlled the handling, shipping, and storage of materials containing thorium. Thorium-bearing residues were required to be disposed of only in Federally licensed fee-for-burial sites. The domestic rare-earth industry has incurred substantial costs to properly store and dispose of radioactive waste products.

Toxicity.—The rare-earth elements are considered only slightly toxic.[42] 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 males are less susceptible than females to the toxic effects of the 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, based on the quarterly average number of workers, is shown in figure 10. Data were furnished by the U.S. Department of Labor and compiled by the Bureau of Mines.

Productivity Trends.—The 11-year trend for U.S. rare-earth mine productivity, based on capacity utilization, shows a slight increase for monazite and a slight decrease for bastnasite. However, gains were made during the period as improved mining plans and recovery methods were initiated at the rare-earth mines in California and Florida.

[1]Renison Goldfields Consolidated Limited. Annual Report, 1989, p. 12.

[2]Free on board/free into container depot.

[3]Metal Bulletin (London). Non-Ferrous Ores in Europe. Dec. 30, 1988, p. 36.

[4]Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.1710-US$1.00 based on yearend 1988 foreign exchange rates reported by the Wall Street Journal.

[5]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 by the Wall Street Journal.

[6]Hedrick, James B. Availability of Rare Earths. Am. Cer. Soc. Bull., v. 67, No. 5, May 1987, pp. 858-861.

[7]Industrial Minerals (London). New J-V to Evaluate Yangibana Rare Earths. No. 261, June 1989, p. 8.

[8]———. Rare Earths Refining Development. No. 267, Dec. 1989, p. 8.

[9]———. Rhone Poulenc RE Interest. No. 267, Dec. 1989, p. 68.

[10]American Metal Market. Nissho-Iwai Buys RZM, Cable Units. Dec. 27, 1989, p. 2.

[11]Mining Annual Review. Pacific and Australasia. p. A71.

[12]Industrial Minerals. Australmin Minsands Production. No. 268, Jan. 1990, p. 8.

[13]Mining Magazine. Eneabba Sands Go-Ahead. Aug. 1989, p. 99.

[14]Industrial Minerals (London). Australia-Scott River Mineral Sands Interests. No. 265, Oct. 1989, p. 12.

[15]Mining Journal (London). North Broken Hill Rings New Changes. V. 313, No. 8044, Nov. 3, 1989, pp. 376-377.

[16]Work cited in footnote 11.

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[20]Mining Magazine. Rare Earths from Brazil. V. 160, No. 7, July 1989, p. 19.

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[22]China Rare Earth Information. China Rare Earth 1989. No. 17, May 1990, pp. 1-2.

[23]Chori Co. Ltd., High-Tec Division. Scandium (translated from Japanese). China and Rare Metals. No. 94, May 1988, p. 29.

[24]Industrial Minerals (London). Danish Minsands Evaluated. No. 267, Dec. 1989, p. 9.

[25]Jones, Grayden. Hecla Seeking Rare Minerals in Greenland, (Article in the Spokane Spokesman newspaper), Aug. 9, 1989.

[26]Bondam, Jan. Greenland. Min. Annu. Rev., p. A184.

[27]Russell, A. Guyana's Industrial Minerals. Ind. Miner. No. 260, May 1989, pp. 61-67.

[28]Roskill's Letter from Japan. Demand for Scandium in Japan: 50% goes to Metal Halide Lamps. No. 154, Feb. 1989, p. 9.

[29]Ottley, Derek. Mineral Resources Potential of Malawi. Min. Mag. Feb. 1989, p. 129.

[30]Industrial Minerals (London). Fletcher Ilmenite Progress. No. 257, Feb. 1989, p. 13.

[31]Griffiths, Joyce. South Africa's Minerals: Diversity in Adversity. Ind. Miner. No. 263, Aug. 1989, p. 30.

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[33]Metal Bulletin (London). QIT Unit Puts Off South African Titanium Exploration. No. 7419, Sept. 25, 1989, p. 15.

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[36]Nakamura, Shigeo. Taiwan Rare Earths (translated from Japanese). China and Rare Metals. No. 94, May 1988, p. 87.

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[38]Work cited in footnote 8.

[39]Materials Edge. Magnesium Elektron-Opportunity Knocks for Yttrium-Based Castings. V. 1, No. 12, July-Aug. 1989, p. 12.

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[43]Haley, T. J. Ch. 40 in Handbook on the Physics and Chemistry of Rare Earths, v. 4: Non-Metallic Compounds II. North-Holland Publ. Co., 1979, pp. 553-585.

TABLE 9

YEAREND RARE-EARTH CONCENTRATE PRICES

(Dollars per kilogram of rare-earth oxide contained)

Year	Bastnasite concentrate, 60% REO		Monazite concentrate, 55% REO plus thoria	
	Actual	Constant	Actual	Constant
1970	$0.66	$0.28	$0.37	$0.16
1971	.66	.29	.38	.17
1972	.66	.31	.35	.16
1973	.66	.33	.40	.20
1974	.79	.43	.42	.23
1975	.99	.58	.41	.24
1976	1.10	.69	.36	.23
1977	1.43	.96	.35	.24
1978	1.57	1.13	.58	.42
1979	1.87	1.47	.76	.60
1980	1.87	1.60	.81	.69
1981	2.03	1.91	.83	.78
1982	2.20	2.20	.75	.75
1983	2.03	2.11	.71	.73
1984	2.03	2.19	.64	.70
1985	2.03	2.25	1.09	1.12
1986	2.03	2.94	1.06	1.22
1987	2.20	2.58	.90	1.06
1988	2.31	2.80	1.15	1.39
1989	2.54	3.21	1.19	1.50

TABLE 10

TARIFF RATES

		Most favored nation (MFN)		Non-MFN	
		Jan. 1, 1989	Jan. 1, 1990	Jan. 1, 1989	Jan. 1, 1990
Thorium ores and concentrates (monazite)	2612.20.0000	Free	Free	Free	Free.
Rare-earth metals, intermixed or alloyed	2805.30.0000	$0.705/kg	$0.705/kg	$4.41 kg	$4.41 kg.
Cerium coumpounds[1]	2846.10.0000	7.2% ad val.	7.2% ad val.	35% ad val.	35% ad val.
Mixtures of rare-earth oxides or rare-earth chlorides	2846.90.2000	Free	Free	25% ad val.	25% ad val.
Rare-earth oxides except cerium oxide	2846.90.2010	Free	Free	25% ad val.	25% ad val.
Other rare-earth compounds or mixtures	2846.90.2050	Free	Free	25%	25%.
Other rare-earth oxides or other rare-earth chlorides[2]	2846.90.5000	3.7% ad val.	3.7% ad val.	25% ad val.	25% ad val.
Ferrocerium and other pyrophoric alloys	3606.90.3000	$.485/kg + 2.6% ad val.	$.485/kg + 2.6% ad val.	$4.41 kg + 25% ad val.	$4.41 kg + 25% ad val.

[1]Duty of 3.7% ad val. on certain yttrium, ore material, and compounds suspended through 1993.

[2]Duty on yttrium bearing material and compounds temporarily suspended in 1989 and 1990.

FIGURE 10

U.S. RARE-EARTH MINE AND MILL EMPLOYMENT

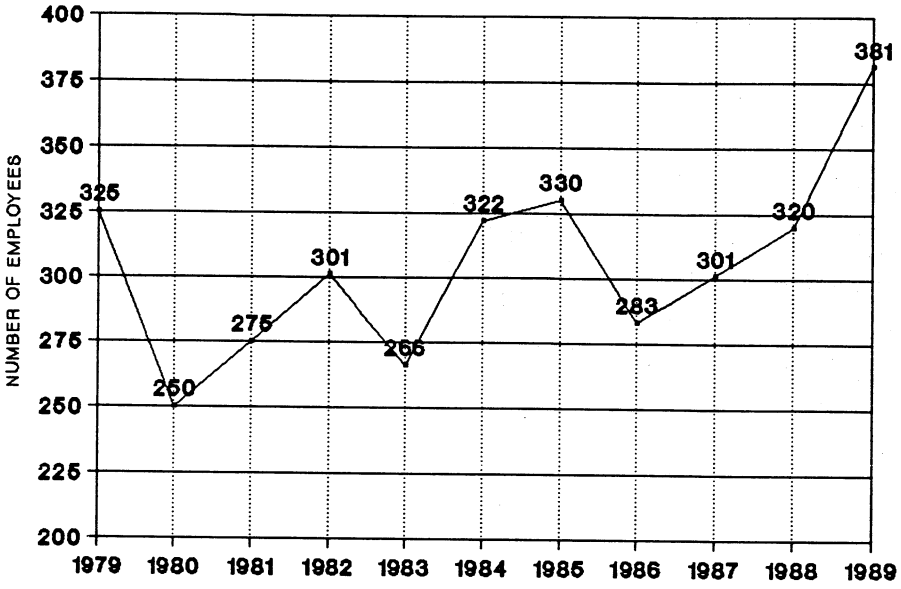


FIGURE 11

U.S. BASTNASITE CAPACITY UTILIZATION[1]

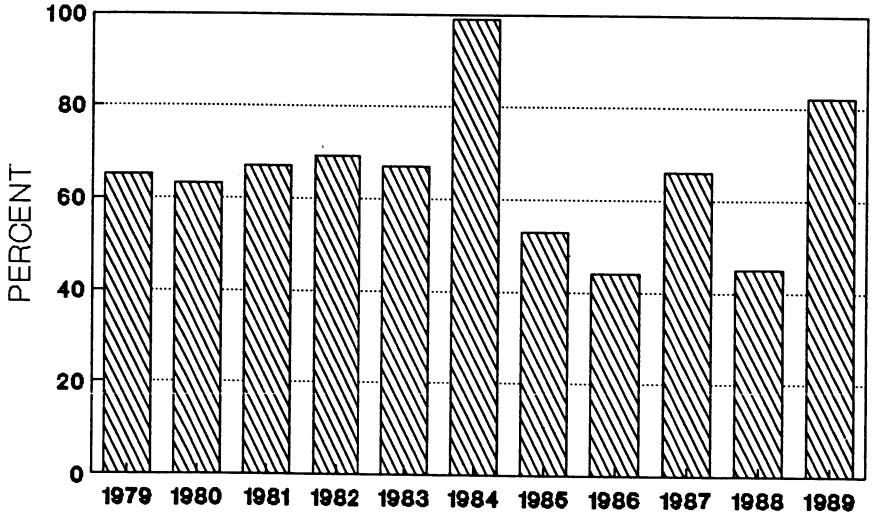
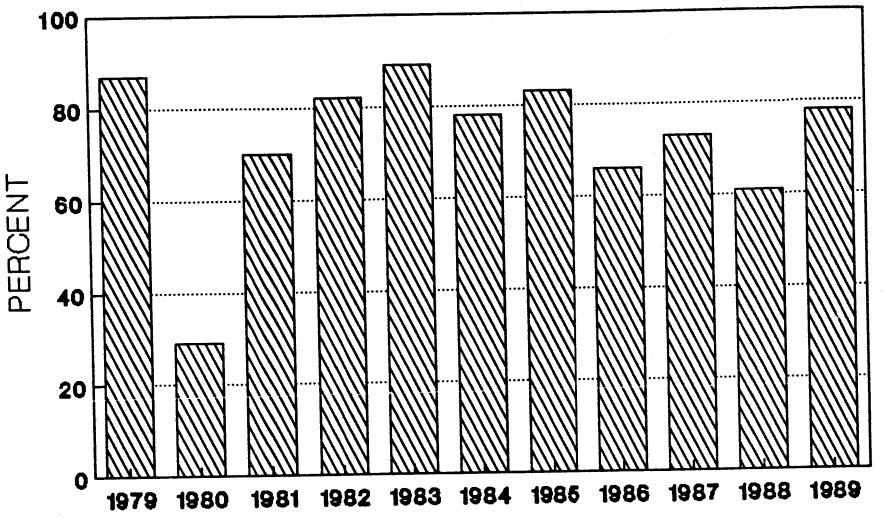


FIGURE 12

U.S. MONAZITE CAPACITY UTILIZATION



RHENIUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 42 years industry and Government experience, has been the commodity specialist for rhenium since 1983.

In 1989, domestic demand for rhenium metal and other rhenium products was met by domestic recovery, domestic stocks, and imports.

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 increased about 6% in 1989. Imports for consumption apparently decreased about 23%. Some of this apparent decrease in imports was caused by category changes under the Harmonized Tariff Schedule, which became effective January 1, 1989. The major uses during the year were bimetallic platinum-rhenium catalysts and jet engine high-temperature components. The price of rhenium metal was about $700 per pound, and the price for ammonium perrhenate about $650 per pound of contained metal.

DOMESTIC DATA COVERAGE

Domestic mine production data for rhenium are developed by the Bureau of Mines from reported molybdenum production at the seven operating porphyry copper-molybdenum-rhenium mines in the United States.

TABLE 1

SALIENT U.S. RHENIUM STATISTICS

(Pounds of contained rhenium)

	1985	1986	1987	1988	1989
Mine production[1]	21,100	21,700	21,800	26,300	38,500
Consumption[e]	13,000	13,000	15,500	17,000	18,000
Imports (metal)	4,943	5,495	7,436	6,821	8,346
Imports for consumption of ammonium perrhenate	3,325	12,189	7,225	5,979	2,089

[e]Estimated.
[1]Calculated rhenium contained in molybdenite concentrates.

CONSUMPTION AND USES

The major uses of rhenium are in petroleum-reforming catalysts and in high-temperature super alloys 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.

TABLE 2

HARMONIZED TARIFF OF THE UNITED STATES (1990) RHENIUM

Action	HTS No.	Commodity description	Unit	Duties import only	
				Most favored nation (MFN) percent ad valorem	Non-MFN percent ad valorem
Export	2811.19.0000	Other inorganic acids: Other-Rhenium, etc.	kg	—	—
Import	2811.19.5050	do.	kg	4.2	25
Export	2841.90.0000	Salts of peroxometallic acids: Other-Rhenium, etc.	kg	—	—
Import	2841.90.2000	Salts of peroxometallic acids: Other-Ammonium perrhenate	kg	3.1	25
Export	8112.91.0000	Rhenium, etc. (metals)-Unwrought; Waste and scrap; powders	kg	—	—
Import	8112.91.0500	Rhenium, etc. (metals)-Waste and scrap	kg	Free	Free
Do.	8112.91.5000	Rhenium, (metal)-Unwrought; Powders	kg	3.7	25
Export	8112.99.0000	Rhenium, etc. (metals)-Wrought; etc.	kg	—	—
Import	8112.99.0000	do.	kg	5.5	45

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY

(Rhenium content)

Country	1987		1988		1989	
	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)	Quantity (pounds)	Value (thousands)
Brazil	70	$27	—	—	—	—
Chile	4,906	1,426	3,449	$1,892	579	$151
China	4	2	—	—	—	—
Ecuador	154	61	—	—	—	—
Germany, Federal Republic of	547	176	427	278	—	—
Japan	209	89	192	125	—	—
Netherlands	—	—	761	390	—	—
Sweden	1,040	272	1,150	729	290	188
Switzerland	—	—	—	—	1,220	610
United Kingdom	295	69	—	—	—	—
Total	7,225	2,122	5,979	3,414	2,089	949

Source: Bureau of the Census

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY

Country	1987		1988		1989	
	Gross weight (pounds)	Value	Gross weight (pounds)	Value	Gross weight (pounds)	Value
Chile	5,463	$1,445,049	5,359	$2,144,211	3,710	$1,582,515
Germany, Federal Republic of	1,867	593,093	1,442	1,003,724	4,623	2,588,163
Other[1]	106	34,342	20	13,100	12	25,880
Total	7,436	2,072,484	6,821	3,161,035	8,345	4,196,558

[1]Includes France, Japan, Sweden, Switzerland, and Uruguay.

Source: Bureau of the Census

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 haveimproved 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 varied uses have represented only about 10% of total demand over the past year.

FOREIGN TRADE

Imports for consumption of ammonium perrhenate came from Chile, Sweden, and Switzerland, whereas Chile, the Federal Republic of Germany, France, Japan, Mexico and Sweden supplied rhenium metal.

World production of rhenium was estimated to be 75,000 pounds contained in molybdenum concentrates; however, the quantity of rhenium actually recovered is much lower since 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."

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 located 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 located 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 located in Europe and in sedimentary copper-cobalt deposits in Zaire, in Africa.

OUTLOOK

In the next 5 years, demand for rhenium metal could double to about 45,000 pounds annually, with propulsion component needs at 60%, petroleum-reforming catalysts

30% and the various other uses consuming 10%. This increase in demand may be met by processing a greater amount of concentrates containing rehenium, 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.

TABLE 5

WORLD RHENIUM RESERVES AND RESERVE BASE

(Pounds)

Country	Reserves	Reserve base
Canada	70,000	3,400,000
Chile	2,880,000	5,600,000
Peru	100,000	1,200,000
U.S.S.R.	1,310,000	1,700,000
United States	850,000	10,000,000
Other countries	200,000	800,000
World total	5,410,000	22,700,000

SALT

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 11 years Bureau of Mines experience, has been the commodity specialist for salt since 1980. Domestic survey data were prepared by Ms. Carleen Militello, mineral data assistant; and international data tables were prepared by Mr. Peter Roetzel, international data section.

The U.S. salt industry continued to restructure itself through consolidations, name changes, and domestic and foreign acquisitions to become a more integrated North American industry competing in the Western Hemisphere. The United States continued to be the world's largest producer of salt, accounting for about 18% of total world production. Production and trade of salt increased slightly compared with the previous year. World production of all types of salt rose about 4%. The greatest increase in production was in China, which reported a 27% increase in output, mainly for use in its expanding chemical industry. Environmental problems associated with emissions of chlorinated compounds may affect the short-term status of the domestic chloralkali industry, which is the largest single consumer of salt.

ISSUES

About one-half of the domestic production of salt is for use as feedstock by the chloralkali industry to manufacture chlorine and coproduct caustic soda. Environmental concerns regarding emissions of chlorine-base compounds, such as those used in chlorofluorocarbons (CFC's) and in paper bleaching, have reduced the demand of chlorine and caustic soda since 1988. A decrease in chlorine production because of demand changes will have a corresponding affect 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. Although dioxin investigations have been conducted since 1983, 104 bleached pulp mills were studied 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 their effect on humans is controversial and inconclusive. The issue is whether or not the quantity of dioxin that has migrated from milk carton stock into milk or from other paper products, such as paper towels, coffee filters, disposable diapers, and sanitary paper products is harmful. Some pulp mills are considering 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 is anticipated to have favorable growth, polyvinyl chloride (PVC). 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% 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, some chlorine and caustic soda manufacturers reportedly are also evaluating the possibilities of 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 Bureau of Mines survey for 1989, 31 companies operated 69 salt-producing plants in 13 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 1989, 12 companies (16 operations) produced solar-evaporated salt; 6 companies (17 operations), vacuum pan salt; 10 companies (14 operations), rock salt; and 16 companies (30 operations), salt brine.

The five leading States in terms of total salt sold or used were Louisiana, 34%; Texas, 20%; New York, 14%; Ohio, 11%; and Kansas, 5%. Although Louisiana, New York, and Ohio were major rock salt-producing States, a substantial amount of salt was produced in Alabama, Kansas, Louisiana, New York, North Dakota, Ohio, Texas, Utah, and West Virginia as brine for the chemical industry.

The U.S. salt industry continued to restructure with changes of ownership, acquisitions, and name-change announcements. Great Salt Lake Minerals and Chemical Corp. (GSL) was acquired in March for $34.5 million by D. George Harris and Associates and GSL senior management. Aside from salt, the Utah facility also produced potassium sulfate, sodium sulfate, and magnesium chloride. American Salt Co., which also is owned by Harris, markets GSL's salt. Domtar Inc.'s Sifto Salt Div. was tentatively sold at yearend, pending final approval by the U.S. Department of Justice, to Carey Salt Holdings Inc., the parent organization of American Salt Co. and Carey Salt Inc. The purchase was to include Domtar's rock salt mines in Goderich, Ontario, and Baldwin,

LA. The vacuum pan plants in Nappan, Nova Scotia; Goderich, Ontario; and Unity, Saskatchewan; were also included. The acquisition of Domtar, which was the third largest salt producer in North America, would double Carey's annual sales.

The salt division of Morton Thiokol was spunoff in July into Morton International, a separate business composed of other chemical operations. Another major U.S. salt producer, International Salt Co., was renamed to Akzo Salt Inc., as part of a worldwide name change by its parent corporation in the Netherlands. The change also affected International's solar salt subsidiary in Utah, which was renamed Akzo Salt of Utah, Inc.

CONSUMPTION AND USES

More than 43.8 million tons of domestic and imported salt was consumed in the United States in 1989, based on the annual survey of the U.S. salt producers. The reported percent distribution of salt by major end use was chemicals, 46%; ice control, 26%; distributors, 10%; food and agricultural, 6%; industrial, 5%; primary water treatment, 1%; and other combined with exports, 6%. For a more complete analysis of end-use markets, specific sectors of distribution in table 7 can be combined, such as agricultural and water conditioning with agricultural and water conditioning distribution, respectively. On an annual per capita basis, the average citizen consumes about 352 pounds, based on an estimated U.S. population of 247 million and total reported consumption data in table 7. 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 7, 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 chloralkali manufacturers now purchased brine from independent brine supply companies. In certain cases, brine is captively produced by one chemical company, and any excess brine is sold to neighboring competitors. According to a survey of domestic salt-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%.

TABLE 1

SALIENT SALT STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Production[1]	39,217	37,282	36,943	39,170	39,278
Sold or used by producers[1]	40,067	36,663	36,493	38,940	38,856
Value	$739,609	$665,400	$684,170	$699,323	$776,846
Exports	904	1,165	541	884	1,567
Value	$15,988	$16,928	$8,217	$10,858	$20,211
Imports for consumption	6,207	6,665	5,716	5,474	6,084
Value	$65,593	$79,709	$66,936	$77,357	$74,474
Consumption, apparent[2]	45,370	42,163	41,668	43,530	43,373
World: Production	r190,629	r192,755	196,852	p202,785	e209,988

eEstimated. pPreliminary. rRevised.
[1]Excludes Puerto Rico.
[2]Sold or used plus imports minus exports.

TABLE 2

SALT PRODUCTION IN THE UNITED STATES

(Thousand short tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1985	3,613	2,549	13,990	19,065	39,217
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

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

TABLE 3

SALT PRODUCED IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

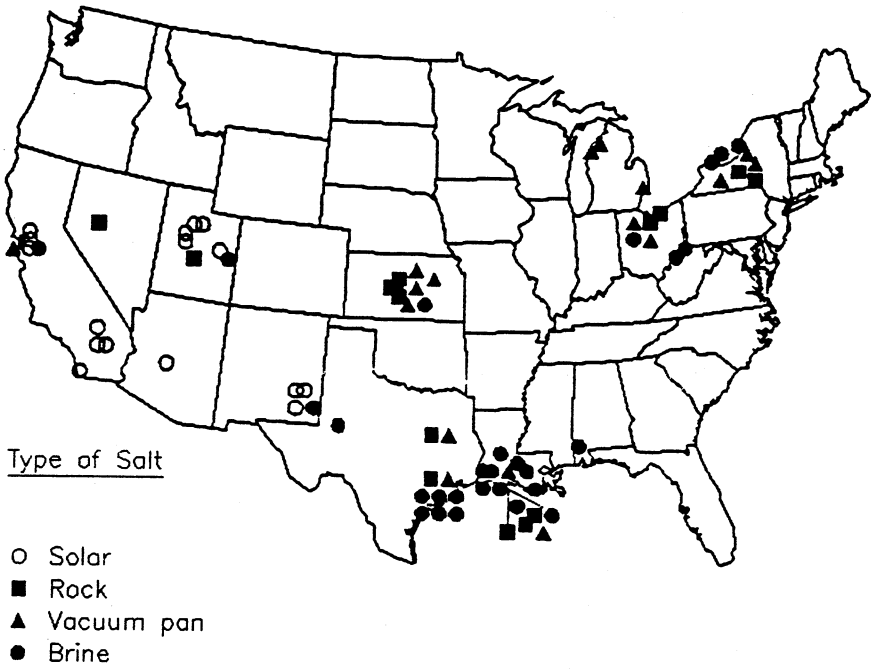
(Thousand short tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1988					
Bulk	686	2,516	12,142	19,218	34,562
Compressed pellets	1,023	108	XX	XX	1,130
Packaged	1,803	672	539	XX	3,014
Pressed blocks	312	83	69	XX	463
Total[1]	3,824	3,379	12,750	19,218	39,170
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

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

FIGURE 1

U.S. SALT PRODUCTION LOCATIONS IN 1989



The chlorine and caustic soda industry consumed about 19.5 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 domestic and imported salt for chlorine manufacture was 18.8 million tons, as noted in table 7. The difference between the calculated and reported quantities was the amount of salt unreported to the Bureau of Mines from imports or captive brine production of chloralkali producers. Production of chlorine gas and liquid sodium hydroxide, as reported by the Bureau of the Census and The Chlorine Institute, was as follows, in thousand short tons:

Organization	1988[r]	1989
Bureau of the Census:		
Chlorine gas (100%)	11,257	11,161
Sodium hydroxide, liquid (100%)	10,527	11,075
The Chlorine Institute:		
Chlorine gas (100%)	11,597	11,909
Sodium hydroxide, liquid (100%)	12,262	12,507

[r]Revised.

Table 16 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 90% of nominal capacity and 95% of effective capacity in 1989. Because these capacities include chlorine produce from nonsalt sources, i.e., from the electrolysis of magnesium chloride and the oxidation of hydrochloric acid, this data may differ from other reported chlorine capacity utilization information.

STOCKS

Total yearend stocks reported by producers were 2.4 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.

PRICES

Price quotations are not synonymous with average values reported to the Bureau of Mines. The quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They are quoted here to serve only as a reference to yearend price levels. The following yearend prices were quoted in Chemical Marketing Reporter.

Salt, evaporated, common:	
80-pound bags, carlots or truckloads:	
North, works, 80 pounds	$4.02
Bulk, same basis, per ton	60.00-61.20
Salt, chemical-grade, same basis:	
80 pounds	4.30
Salt, rock, medium, coarse:	
Same basis, 80 pounds	2.70
Bulk, same basis, per ton	8.00-25.00
Sodium chloride, USP:	
Granular bags, per pound	.29

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, 1990, 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 1989 nearly four 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

TABLE 4

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
1988										
Bulk	682	29,482	1,684	25,028	12,222	155,046	19,601	70,084	34,189	279,640
Compressed pellets	1,022	103,315	107	7,814	NA	XX	XX	XX	1,130	111,129
Packaged:										
Less-than-5-pound units	155	NA	1	NA	35	NA	XX	XX	194	NA
More-than-5-pound units	1,648	NA	742	NA	574	NA	XX	XX	2,966	NA
Total[2]	1,803	209,860	743	34,531	609	30,469	XX	XX	3,159	274,861
Pressed blocks:										
For livestock	150	NA	49	NA	1	NA	XX	XX	200	NA
For water treatment	161	NA	33	NA	67	NA	XX	XX	261	NA
Total[2]	311	22,830	82	5,580	68	5,284	XX	XX	462	33,693
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

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 7 and 8, which are derived from company reports.

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

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 less expensive abroad and currency exchange rates are more favorable.

The Journal of Commerce's Port Import/Export Reporting Service (PIERS) reported that Carey Salt Co., Cargill Inc., Domtar Industries Inc., International Salt Co., and Morton International imported 47% of the total imports of 4.9 million tons. Five companies that manufacture chlorine, which was the single largest domestic salt market, consumed 29% of total imports, which were primarily solar salt. These companies were Brunswick Pulp and Paper Co., LCP Chemical & Plastics Inc., Occidental Chemical Corp., Atochem North America (Pennwalt), and Weyerhaeuser Co. The salt and chloralkali producers imported 76% of total imports; the remainder were to many small direct buyers. Eight domestic salt producing companies exported 87% of the 588,306 tons exported in 1989, according to PIERS. The Journal of Commerce data contains 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 10 through 13 list the import and export statistics reported by the Bureau of the Census for 1988 and 1989.

WORLD REVIEW

Table 14 lists world salt production statistics for 97 countries based on reported and estimated information. World production increased 4% in 1989 compared with that of the previous year. Since 1970, world salt production has increased more than 30%, whereas world population has risen 44%, from 3.63 billion to 5.19 billion individuals. Based on these statistics, the world annual per capita consumption has decreased from 89 pounds to 80 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

TABLE 5

SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Kansas[2]	1,778	72,965	1,634	71,189
Louisiana	14,274	108,982	13,219	115,342
New York	4,614	127,994	5,424	161,427
Ohio	3,795	115,860	W	W
Texas	8,202	64,425	7,856	69,935
Utah	1,055	35,730	1,246	40,719
Other[3]	5,222	173,367	9,226	307,192
Total[4]	38,940	699,323	38,856	776,846
Puerto Rico[e]	40	900	45	1,250

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."
[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."
[3]Includes Alabama, Arizona, California, Kansas (brine only), Michigan, New Mexico, North Dakota, West Virginia and data indicated by symbol W.
[4]Data may not add to totals shown because of independent rounding.

TABLE 6

EVAPORATED SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Kansas[2]	915	63,572	880	63,120
Louisiana	213	20,405	214	20,582
New York	771	65,647	783	65,173
Utah	992	34,652	1,171	37,119
Other[2]	3,548	254,164	2,647	157,679
Total	6,439	438,440	6,570	431,204
Puerto Rico[e]	40	900	45	1,250

[e]Estimated.
[1]The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company.
[2]Includes Arizona, California, Michigan, New Mexico, North Dakota, Ohio, and Texas.
[3]Data do not add to total shown because of independent rounding.

capacity reduced the size of the industry to 31 companies and 69 plants by 1989.

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 15 through 17 are rated capacities for mines and refineries and salt requirements for salt-base chlorine facilities 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 maximum capital expenditure. Tables 15 and 16 list the annual production capacities of domestic rock salt, solar salt, vacuum pan salt, and salt brine producers. Table 17 incorporates the domestic capacity data with foreign salt capacities. Capacity data were derived from industry sources, published reports, and estimates based on production trends.

Rock.—Because the majority of rock salt was used for deicing, the operating rate of rock salt facilities fluctuated with the demand for deicing salt, again dependent on the severity of winter weather conditions. During periods of strong demand, production levels often achieve, or exceed in certain situations, the rated capacities. Full mine capacity generally is a function of the hoisting capabilities of the mines. Assuming that the workweek is 5 days (250 workdays per year), two working shifts and one maintenance shift per day, and at least one short-term planned turnaround for the mine and mill per year, tables 15 and 17 list the production capacities for domestic and foreign rock salt operations.

Solar.—Solar salt, also known as marine and sea salt, is obtained from the solar evaporation of seawater, of landlocked bodies of saline water, and of discharged brines. Because evaporation rates must exceed the precipitation rates, the climatic conditions and geographic locations of solar evaporation facilities are critical to the successful production and harvesting of solar salt. Therefore, rated capacities generally are based on the historical evaporation patterns within a region and vary depending on the location and the surface areas of the evaporation ponds. Only unpredictable seasonal precipitation and market conditions usually affect the production, and market conditions usually affect the production rates of the facilities.

TABLE 7

DISTRIBUTION OF DOMESTIC AND IMPORTED 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	Total[1]		Grand total
		Domestic	Imported[2]	Domestic	Imported[2]	Domestic	Imported[2]		Domestic	Imported[2]	
1988											
Chemical:											
Chloralkali producers	2812	55	—	351	—	1,277	135	18,150	19,833	135	19,968
Other chemical	28 (Excludes 2812,2899)	359	24	91	37	218	2	35	703	63	766
Total		414	24	442	37	1,495	137	18,185	20,536	198	20,734
Food-processing industry:											
Meat packers	201	183	14	53	9	196	4	—	432	28	460
Dairy	202	107	—	3	2	4	—	—	114	2	116
Canning	2091,203	131	—	40	23	78	4	1	250	28	278
Baking	205	128	—	11	1	11	—	—	150	2	152
Grain mill products	204 (Excludes 2047)	67	—	1	(3)	7	—	—	75	—	75
Other food processing	206-208,2047,2099	154	3	37	8	43	6	—	234	17	251
Total[1]		770	17	145	44	337	15	1	1,255	77	1,332
General industrial:											
Textiles and dyeing	22	90	54	10	35	33	1	6	139	90	229
Metal processing	33,34,35,37	14	1	20	15	318	6	(3)	352	22	374
Rubber	2822,30 (EX3079)	2	—	4	(3)	2	—	19	27	—	27
Oil	13,29	44	—	334	23	81	—	337	796	23	819
Pulp and paper	26	22	5	230	41	72	—	6	330	46	376
Tanning and/or leather	311	11	—	42	2	67	1	—	120	3	123
Other industrial	9621	89	—	65	18	71	5	—	225	23	248
Total[1]		272	60	705	135	645	16	368	1,989	207	2,196
Agricultural:											
Feed retailers and/or dealers-mixers	434	1	203	28	332	—	—	969	29	998	
Feed manufacturers	2048	69	—	89	17	262	—	—	420	17	437
Direct-buying end users	02	18	—	15	—	6	—	—	39	—	39
Total[1]		521	1	307	46	600	—	—	1,428	46	1,474
Water treatment:											
Government (Federal, State, local)	2899	24	—	28	12	181	2	3	236	14	250
Commercial or other	2899	20	—	110	23	41	—	19	190	23	213
Total[1]		44	—	138	34	222	2	22	426	37	463
Ice control and/or stabilization:											
Government (Federal State, local)	9621	6	1	160	85	8,168	2,171	1	8,335	2,257	10,592
Commercial or other	5159	12	—	77	11	379	53	1	469	64	533
Total[1]		18	1	236	96	8,547	2,224	2	8,804	2,321	11,125
Distributors:											
Agricultural distribution	5159	101	15	85	21	108	23	—	294	59	353
Grocery wholesalers and/or retailers	514,54	630	—	162	58	105	—	—	897	58	955
Institutional wholesalers and end users	58,70	29	—	33	5	113	—	—	175	5	180

See footnotes at end of table.

TABLE 7—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED 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	Total[1]		Grand total
		Domestic	Imported[2]	Domestic	Imported[2]	Domestic	Imported[2]		Domestic	Imported[2]	
Water-conditioning distribution	7399	309	2	294	167	220	58	1	824	227	1,051
U.S. Government resale	9199	7	—	3	—	—	—	—	10	—	10
Other wholesalers and/or retailers	5251	673	10	114	149	618	9	—	1,405	168	1,573
Total[1]		1,749	27	690	400	1,164	91	1	3,605	517	4,122
Other n.e.s.[4]		96	7	217	12	378	51	883	1,574	70	1,644
Grand total[1]		3,884	137	2,879	805	13,388	2,537	19,462	39,613	3,479	43,092
1989											
Chemical:											
Chloralkali producers	2812	51	(3)	399	—	1,347	117	16,865	18,663	117	18,780
Other chemical	28 (Excludes 2812,2899)	339	396	141	22	244	2	33	757	420	1,177
Total[1]		390	396	540	22	1,592	119	16,897	19,420	537	19,957
Food-processing industry:											
Meat packers	201	181	16	50	11	171	4	1	403	31	434
Dairy	202	133	—	3	2	4	(3)	—	139	2	141
Canning	2091,203	144	(3)	37	19	84	5	1	266	24	290
Baking	205	146	(3)	11	(3)	12	—	—	168	(3)	168
Grain mill products	204 (Excludes 2047)	77	(3)	(3)	(3)	11	—	—	88	(3)	88
Other food processing	206-208,2047,2099	183	1	47	4	41	7	—	271	12	283
Total[1]		860	17	148	36	323	16	2	1,333	70	1,404
General industrial:											
Textiles and dyeing	22	93	55	14	38	27	1	4	139	94	233
Metal processing	33,34,35,37	12	(3)	30	5	346	6	(3)	388	12	400
Rubber	2822,30 (Excludes 3079)	2	—	4	(3)	3	—	26	34	(3)	34
Oil	13,29	34	—	297	6	78	3	302	711	9	720
Pulp and paper	26	24	4	237	32	65	3	7	334	39	373
Tanning and/or leather	311	14	(3)	36	1	64	2	—	113	3	116
Other industrial	9621	113	1	64	12	83	4	3	263	16	279
Total[1]		292	60	682	95	666	20	342	1,982	173	2,155
Agricultural:											
Feed retailers and/or dealers-mixers		309	11	189	28	356	1	(3)	853	40	893
Feed manufacturers	2048	57	—	90	14	240	(3)	—	386	14	400
Direct-buying end user	02	17	—	13	—	18	—	—	48	—	48
Total[1]		383	11	292	42	614	1	(3)	1,287	54	1,341
Water treatment:											
Government (Federal, State, local)	2899	28	—	64	6	223	5	2	317	12	329
Commercial or other	2899	16	—	102	14	49	(3)	8	174	14	188
Total[1]		44	—	166	20	272	5	11	491	26	517
Ice control and/or stabilization:											
Government (Federal, State, local)	9621	4	1	171	54	9,123	1,577	1	9,298	1,632	10,930
Commercial or other	5159	6	(3)	62	4	347	99	12	428	103	531
Total[1]		10	1	233	58	9,470	1,676	13	9,726	1,735	11,461

See footnotes at end of table.

TABLE 7—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED 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	Total[1]		Grand total
		Domestic	Imported[2]	Domestic	Imported[2]	Domestic	Imported[2]		Domestic	Imported[2]	
Distributors:											
Agricultural distribution	5159	249	10	97	72	122	33	(3)	469	115	584
Grocery wholesalers and/or retailers	514,54	611	(3)	190	40	129	(3)	—	930	40	970
Institutional wholesalers and end users	58,70	26	—	22	4	27	1	(3)	77	5	82
Water-conditioning distribution	7399	275	—	310	155	196	31	4	785	185	970
U.S. Government resale	9199	6	—	2	—	1	—	—	9	—	9
Other wholesalers and/or retailers	5251	755	6	240	48	740	4	(3)	1,735	58	1,793
Total[1]		1,922	16	861	319	1,215	69	4	4,005	403	4,408
Other n.e.s.[4]		112	10	199	31	1,056	191	967	2,334	232	2,566
Grand total[1]		4,013	511	3,121	623	15,208	2,097	18,236	40,578	3,230	43,808

[1]Data may not add to totals shown because of independent rounding. Because data includes salt imported, produced and/or sold from inventory from regional distribution centers, salt sold or used by type may differ from totals shown in tables 1, 4, 5, and 6, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 8 because of changes in inventory and/or incomplete data reporting.
[2]Imported for distribution by U.S. producers only; included in totals in tables 11, 12, and 13.
[3]Less than 1/2 unit.
[4]Includes exports.

TABLE 8

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand short tons)

Destination	1988				1989			
	Evaporated		Rock	Total	Evaporated		Rock	Total
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Alabama	55	(2)	363	418	57	(2)	355	412
Alaska	1	W	—	1	1	W	(2)	1
Arizona	8	74	W	82	9	72	13	94
Arkansas	33	W	86	119	36	W	97	133
California	162	894	W	1,056	169	981	W	1,150
Colorado	21	121	73	215	20	91	81	192
Connecticut	11	11	225	247	11	9	165	185
Delaware	17	12	21	50	2	17	6	25
District of Columbia	1	(2)	W	1	1	5	W	6
Florida	97	51	28	176	101	64	31	196
Georgia	80	30	92	202	233	35	83	351
Hawaii	W	W	—	0	18	3	—	21
Idaho	6	71	W	77	8	60	W	68
Illinois	378	91	1,453	1,922	391	82	1,464	1,937
Indiana	161	45	737	943	176	48	792	1,016

See footnotes at end of table.

TABLE 8—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand short tons)

Destination	1988				1989			
	Evaporated		Rock	Total	Evaporated		Rock	Total
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Iowa	166	44	249	459	172	46	305	523
Kansas	95	11	315	421	98	6	394	498
Kentucky	40	W	393	433	52	W	393	445
Louisiana	57	W	357	414	52	W	344	396
Maine	6	54	116	176	132	3	248	383
Maryland	57	94	165	316	63	101	295	459
Massachusetts	39	37	508	584	38	6	323	367
Michigan	236	21	1,330	1,587	246	25	1,355	1,626
Minnesota	173	129	420	722	157	118	548	823
Mississippi	22	(2)	128	150	28	(2)	143	171
Missouri	116	22	415	553	127	17	360	504
Montana	2	46	W	48	1	31	W	32
Nebraska	90	4	152	246	91	22	147	260
Nevada	1	192	W	193	1	222	W	223
New Hampshire	2	27	96	125	3	3	136	142
New Jersey	127	166	270	563	122	121	299	542
New Mexico	6	W	2	8	6	97	1	104
New York	266	75	2,172	2,513	249	61	2,345	2,655
North Carolina	173	100	53	326	263	105	51	419
North Dakota	38	14	5	57	20	15	4	39
Ohio	347	29	1,787	2,163	347	28	1,778	2,153
Oklahoma	42	W	80	122	42	W	72	114
Oregon	12	64	—	76	13	46	(2)	59
Pennsylvania	152	111	1,078	1,341	192	185	1,258	1,635
Rhode Island	6	23	11	40	6	2	68	76
South Carolina	46	12	11	69	50	9	11	70
South Dakota	42	36	40	118	36	25	41	102
Tennessee	67	(2)	629	696	75	1	632	708
Texas	180	98	229	507	178	120	219	517
Utah	5	289	W	294	4	259	W	263
Vermont	5	W	190	195	6	W	265	271
Virginia	71	49	154	274	82	60	212	354
Washington	18	278	(2)	296	18	230	(2)	248
West Virginia	12	W	178	190	12	W	157	169
Wisconsin	231	55	939	1,225	227	65	919	1,211
Wyoming	1	33	1	35	(2)	23	1	24
Other[3]	56	303	489	848	83	139	536	758
Total[4]	4,036	3,816	16,040	23,892	4,525	3,658	16,947	25,130

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 1, 4, 5, and 6, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 7 because of changes in inventory and/or incomplete data reporting.

TABLE 9

AVERAGE VALUES[1] OF SALT, BY PRODUCT FORM AND TYPE

(Dollars per short ton)

	Vacuum pans and open pans	Solar	Rock	Brine
1988				
Bulk	43.22	14.86	12.69	3. 58
Compressed pellets	101.09	73.02	XX	XX
Packaged	116.39	46.48	50.03	XX
Average[2]	97.71	26.59	14.46	3.58
Pressed blocks	73.41	68.05	77.71	XX
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

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 4.

TABLE 10

U.S. EXPORTS OF SALT, BY COUNTRY[1]

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Argentina	2	17	—	—
Australia	2	18	13	182
Bahamas	1	41	6	262
Bahrain	7	74	10	158
Belize	(2)	3	1	20
Bolivia	—	—	10	115
Brazil	2	17	(2)	8
Canada	717	8,469	1,367	14,465
Chile	(2)	2	1	6
Costa Rica	2	27	(2)	11
Denmark	1	9	—	—
Dominican Republic	7	58	3	152
El Salvador	5	39	3	160
France	4	30	3	61
Germany, Federal Republic of	2	27	7	68
Honduras	1	14	(2)	4
Japan	3	124	8	184
Mexico	41	646	66	1,178
Netherlands Antilles	3	47	1	64
Panama	2	118	5	72
Saudi Arabia	48	606	43	2,072
Taiwan	r14	117	1	19
Trinidad	1	7	(2)	13
United Arab Emirates	1	11	3	102
United Kingdom	(1)	71	4	331
Venezuela	6	54	1	25
Other	26	210	11	479
Total	884	10,856	1,567	20,211

rRevised.
[1]Before 1989, the Schedule B export code no. was 4209500. In 1989, it was changed to Harmonized Tariff System code No. 2501000000.
[2]Less than 1/2 unit.
Source: Bureau of the Census.

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 and country brine capacities are not included in tables 15 and 17, expect in cases where capacities were derived from actual published brine statistics and the assumption made that brine capacity was equal to brine production. Table 16 lists the quantity, type, and source of the salt required to manufacture chlorine. The amount of brine purchased or used captively is close with the quantity of brine used for chloralkali production as noted in table 7.

Country capacities in table 17 may include data on solution-mined brine or naturally occurring brine, which were incorporated with other salt production statistics.

Brazil

The Government announced plans to construct a 138,000-ton-per-year chlorine facility in Sergipe that will use rock salt from nearby deposits. The plant was scheduled to come on-stream in the early 1990's.

Netherlands

Akzo NV, the world's largest producer of salt, will spend $50 million to modernize its salt processing plant in Hengelo. The project, scheduled to commence in 1990 and be completed in 1992, will feature new automated control equipment.

OUTLOOK

The environmental concerns raised during 1989 will continue into the 1990's. Greater emphasis will be placed in stricter air and water quality controls. The deterioration of the ozone layer because of the breakdown of CFC molecules in the up-

TABLE 11

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
1985	4	117	66	3,794	6,138	61,682
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

[1]Anhydrous salt content.
[2]Less than 1/2 unit.
[3]Data was adjusted to correct for erroneous notation of shipment from Italy in August.
[4]Included in bulk because categories were merged under Harmonized Tariff System code No. 2501000000 in 1989. Before 1989, salt imports were listed under TSUS code Nos. 4209200 for salt in brine, 4209400 for bulk salt, and 4209600 for other salt.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY COUNTRY[1]

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Bahamas[2]	478	6,895	607	7,405
Canada[2]	2,659	33,221	2,260	29,501
Chile	348	3,083	335	3,320
France[3]	7	497	243	579
German Democratic Republic	83	306	107	343
Germany, Federal Republic of[4]	5	563	90	927
Ireland	—	—	34	246
Italy	58	894	39	424
Korea Republic of	25	180	25	180
Mexico[5]	1,139	16,332	1,502	17,227
Netherlands	341	8,198	459	10,233
Netherlands Antilles	200	3,168	122	1,817
Spain[6]	22	252	28	102
Tunisia	—	—	60	462
United Kingdom	—	—	126	1,272
Other	134	3,958	47	436
Total	5,474	77,357	6,084	74,474

[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 Harmonized Tariff System code No. 2501000000.
[2]Includes salt in bags, sacks, and barrels through nine customs districts, 70,892 short tons ($3,077,427) in 1988.
[3]Includes salt in bags, sacks, and barrels through four customs districts, 135 short tons ($107,304) in 1988.
[4]Includes salt in bags, sacks, and barrels through eight customs districts, 2,918 short tons ($528,926) in 1988.
[5]Includes salt in bags, sacks, and barrels through two customs district, 292 tons ($30,052) in 1988.
[6]Includes salt in bags, sacks, and barrels through two customs districts, 11 tons ($10,053) in 1988.

Source: Bureau of the Census.

per atmosphere and dioxin contamination of surface waters from chlorine-base paper bleaching chemicals have begun to affect the future outlook of the chlorine industry, which uses a tremendous amount of salt brine and also a lot of purchased rock and solar salt. Discharges of salt into ground water supplies will also be more thoroughly studied. Some releases are of natural origin, such as the dissolution and collapse of certain underground salt formations in south-central Kansas, which led to contamination of fresh water wells and salinity increases in rivers. Other releases have been attributed to runoff from highway deicing and discharges from water softening units. Objective scientific investigations regarding the source of salt discharges can alleviate most of the public's concern about water quality without having to reduce sales of water conditioning salt, which is used to regenerate ion exchange water softening units, and highway salt.

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 using regular rock salt during the winter. Although calcium magnesium acetate (CMA) is a non-corrosive deicer, it is very expensive when compared with regular rock salt or the corrosion inhibitor-treated salt. The outlook for these treated-salt products is very favorable, especially in areas of the country that want to regulate the use of deicing salt.

Between 1970 and 1989, 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 by 1980. It closed in 1986.

In the 1980's, world production was 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 since 1980 while salt brine consumption decreased. Despite the adverse publicity in the 1980's regarding the use of salt (i.e., salt contributes to hypertension in some humans, corrosion from oversalting the highways, high sodium levels in drinking water), the dry salt industry has managed

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT[1]

(Thousand short tons and thousand dollars)

Customs district	1988		1989	
	Quantity	Value	Quantity	Value
Anchorage, AK	(2)	159	12	475
Baltimore, MD	278	2,473	304	3,418
Boston, MA	216	3,248	202	2,271
Buffalo, NY	100	987	32	837
Chicago, IL	388	5,321	453	6,160
Charleston, SC	79	3,115	122	2,428
Cleveland, OH	29	449	85	938
Dallas Fort Worth, TX	—	—	(2)	299
Detroit, MI	683	9,574	769	10,625
Duluth, MN	107	1,174	97	1,120
Great Falls, MT	(2)	7	(2)	19
Houston, TX	—	—	(2)	24
Laredo, TX	1	77	(2)	49
Los Angeles, CA	126	1,959	97	2,050
Miami, FL	2	117	(2)	92
Milwaukee, WI	642	9,607	540	6,909
Minneapolis, MN	—	—	(2)	6
New Orleans, LA	63	653	157	1,756
New York, NY	408	5,046	586	4,609
Nogales, AZ	—	—	1	31
Norfolk, VA	133	1,020	127	1,468
Ogdensburg, NY	31	460	73	668
Pembina, ND	1	35	(2)	15
Philadelphia, PA	129	1,410	263	2,657
Portland, ME	432	6,031	368	4,459
Portland, OR	290	4,775	449	4,216
Providence, RI	177	1,651	63	416
St. Albans, VT	1	71	1	63
St. Louis, MO	—	—	40	219
San Diego, CA	(2)	22	(2)	72
San Francisco, CA	(2)	268	44	378
San Juan, PR	39	355	16	368
Savannah, GA	359	5,116	309	5,505
Seattle, WA	435	6,786	585	6,425
Tampa, FL	104	1,474	123	1,051
Washington, DC	(2)	1	—	—
Wilmington, NC	220	3,915	165	2,378
Total[3]	5,474	77,357	6,084	74,474

[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 Harmonized Tariff System code No. 2502000000.

[2]Less than 1/2 unit.

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

Source: Bureau of the Census.

to strengthen its position by developing sensible salting policies for deicing salt and working cooperatively with the food processing industry to address the salt in human nutrition issue. 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 and promote the benefits of salt.

The outlook for salt in the 1990's is optimistic. The major producers have diversified into all types of salt across the Nation and have developed reliable import sources in Canada, the Caribbean, and Mexico. Consolidations and restructuring within the U.S. salt industry have strengthened it into a competitive North American enterprise in the Western Hemisphere. Domestic salt consumption is forecast to grow about 1.3% to 1995.

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 about 2000 B.C. in China where Emperor Yu decreed that Shandong Province would supply the court with salt. The Phoenicians (1200 B.C.-300 B.C.) were one of the first maritime civilizations to trade salt. Salt became an important universal medium of exchange. The English word "salary" is derived from the Latin term "Salarium argentum," which were the salt rations that Roman soldiers were partially paid for their services. Aside from its use as a medium of monetary exchange, salt 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. In 1862, the first 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 invented, which incorporated a vacuum

TABLE 14

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Afghanistan[e]	11	11	11	[r]39	39
Albania[e]	80	82	83	80	80
Algeria	185	209	220	[e]220	220
Angola[e]	[r]55	[r] 61	[r]66	[r]77	77
Argentina:					
Rock salt	1	1	1	[e]1	1
Other salt	1,595	1,342	1,048	1,372	1,210
Australia (marine salt and brine salt)	6,432	6,758	7,150	7,690	8,100
Austria:					
Rock salt	1	2	2	1	1
Evaporated salt	483	536	534	455	440
Salt in brine	[r]280	[r]237	198	282	270
Bahamas	[e]937	991	811	679	[3]946
Bangladesh[4]	539	[e]550	459	451	440
Benin[e]	([5])	([5])	([5])	([5])	([5])
Brazil:					
Rock salt	1,053	661	1,047	1,473	1,420
Marine salt	1,911	1,764	3,968	3,329	3,420
Bulgaria	98	100	101	114	110
Burma[6]	353	[e]354	376	[r] [e]274	275
Cambodia[e]	45	45	45	45	45
Canada	11,117	11,389	11,165	11,781	[3]12,279
Chile	831	1,138	954	1,149	1,100
China[e]	[3]15,924	19,070	19,800	24,250	30,850
Colombia:					
Rock salt	260	250	226	230	235
Marine salt	545	552	496	521	530
Costa Rica (marine salt)	33	[e]33	14	300	300
Cuba	244	293	255	222	220
Cyprus	[r]11	7	—	([7])	—
Czechoslovakia	385	373	99	97	97
Denmark	586	622	585	714	717
Dominican Republic	52	[e]60	[e]61	19	22
Egypt	1,170	[e]1,400	1,115	1,017	990
El Salvador	[e]3	3	3	4	3
Ethiopia:[e 4]					
Rock salt	17	17	17	17	11
Marine salt	130	130	130	130	110
France:					
Rock salt	407	425	1,627	[e]1,650	1,650
Brine salt	1,272	1,240	[e]1,180	[e]1,200	1, 200
Marine salt	1,569	1,775	[e]1,795	[e]1,820	1, 930
Salt in solution	4,593	4,368	[e]4,040	[e]4,050	4,080
German Democratic Republic:					
Rock salt[e]	3,395	3,390	3,390	3,300	3,300
Marine salt	64	65	65	66	64
Germany, Federal Republic of: Marketable:					
Rock salt and other[8]	10,642	13,777	14,178	[e]14,330	13,780
Marine salt[9]	[r]3,777	666	666	[e]667	660
Ghana[e]	55	55	55	55	55
Greece[e]	[3]215	210	210	210	210
Guatemala	19	43	41	46	50

See footnotes at end of table.

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 equivalent 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 varies 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 specification 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

TABLE 14—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Honduras[e]	35	35	35	35	35
Iceland[e]	[3]1	2	2	2	2
India:					
Rock salt[e]	4	2	2	[r]4	4
Marine salt	10,885	11,151	10,913	10,141	9,900
Indonesia[e]	660	660	660	660	660
Iran[e 10]	[3]775	770	770	770	770
Iraq[e]	80	80	80	80	110
Israel[e]	170	170	170	170	170
Italy:					
Rock salt and brine salt	3,501	3,784	4,072	4,069	4,079
Marine salt[e 11]	[3]628	[r]635	[r]630	[r]750	755
Jamaica	17	14	17	17	[3]11
Japan	[e]1,300	1,510	1,540	1,502	1,490
Jordan	35	[e]35	20	[e]20	20
Kenya (crude)	[r]73	[r e]100	79	104	[3]114
Korea, North[e]	630	630	630	630	630
Korea, Republic of	709	804	732	1,124	1,100
Kuwait	23	31	39	[e]40	40
Laos[e]	11	33	33	33	33
Lebanon[e]	6	[r]3	[r]3	[r]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	5	5
Malta[e]	([5])	([5])	([5])	([5])	([5])
Mauritania[e]	6	6	6	6	6
Mauritius[e]	7	7	7	7	7
Mexico	7,129	6,840	7,047	7,924	8,435
Mongolia[e]	18	18	18	18	18
Morocco	102	106	119	146	145
Mozambique[e]	30	30	30	30	30
Namibia (marine salt)	169	148	138	138	140
Netherlands	4,579	4,148	4,386	4,071	4,080
Netherlands Antilles[e]	390	390	390	390	390
New Zealand	57	—	[e]70	[e]70	70
Nicaragua[e]	17	17	17	17	17
Niger[e]	3	3	3	3	3
Pakistan:[5]					
Rock salt	643	635	554	554	550
Other salt	296	267	277	293	300
Panama (refined salt)	18	11	[e]11	[e]11	11
Peru	226	440	490	[e]390	390
Philippines	464	866	492	542	550
Poland:					
Rock salt	1,323	1,346	1,357	[e]1,320	1,320
Other salt	4,040	4,630	5,442	[e]4,960	4,960
Portugal:					
Rock salt	[e]512	506	566	[e]550	550
Marine salt[e]	[3]236	220	220	220	220
Romania	5,532	5,903	5,947	[e]5,950	5,500
Senegal	176	160	[e]110	83	110

See footnotes at end of table.

body. Kosher salt, seasalt, condiment salt, and salt tablets are special varieties of salt.

Water conditioning and animal feedstock salt are made into 50-pound pressed blocks. Sulfur, iodine, trace elements, and vitamins are occasionally added to salt blocks to provide missing nutrients not found naturally in the diet of certain livestock. Salt is also compressed into pellets and used for water conditioning.

Geology-Resources

The definitions of reserves and reserve base are published in the U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

The oceans are the world's largest resource of salt. Seawater contains 3.5% dissolved solids by weight with sodium chloride representing the major component, approximately 2.5% by weight. The world's oceans contain about 44 x 10^{15} 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

TABLE 14—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Sierra Leone[e]	220	220	220	220	220
Somalia[e]	33	33	33	33	33
South Africa, Republic of	796	829	778	748	[3]763
Spain:					
Rock salt	2,381	2,316	2,481	[e]2,300	2,300
Marine salt and other evaporated salt	1,190	1,102	1,041	[e]1,100	1,100
Sri Lanka	85	115	127	118	110
Sudan	42	[e]44	57	[e]55	[3]100
Switzerland	412	429	430	341	[3]268
Syria	[e]100	[e]100	89	140	1 43
Taiwan	206	150	110	123	195
Tanzania	23	24	45	22	22
Thailand:					
Rock salt	14	2	4	6	[3]17
Other salt[e]	180	180	180	180	180
Tunisia	421	457	468	535	530
Turkey	1,311	1,292	1,342	[e]1,490	1,490
Uganda[e]	6	6	6	6	6
U.S.S.R.	17,747	16,865	16,976	16,314	16,300
United Kingdom:					
Rock salt	2,238	2,249	2,045	967	1,100
Brine salt[12]	1,711	1,664	1,713	1,572	1,320
Other salt[12]	3,928	3,643	4,048	4,219	3,970
United States including Puerto Rico (sold or used by producers):					
Rock salt	14,690	12,598	11,965	12,900	[3]13,938
Other salt:					
United States	[r]24,377	24,065	24,528	25,428	[3]24,918
Puerto Rico[e]	35	40	40	40	45
Venezuela[e]	[3]374	[r e]565	[r e]550	[r e]550	550
Vietnam[e]	[r]418	500	250	330	350
Yemen (Aden)[e]	80	80	80	80	80
Yemen (Sanaa)	165	330	180	165	165
Yugoslavia:					
Rock salt	164	163	169	140	138
Brine salt	213	311	312	221	220
Marine salt	75	77	71	64	44
Total	[r]190,629	[r]192,755	196,852	202,785	209,988

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 13, 1990.

[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: 1985—49,061; 1986— 57,413; 1987—70,220; 1988—73,260; and 1989—65,000 (estimated).

[7]Revised to zero.

[8]Rock salt only for 1985.

[9]Marine salt and other for 1985.

[10]Data are for year beginning Mar. 21 of that stated.

[11]Does not include production from Sardinia and Sicily, estimated at 220,000 short tons annually.

[12]Data captioned "Brine salt" for the United Kingdom are the quantities of salt obtained from the evaporation of brines; that captioned "Other salt" are the salt content of brines used for purposes other than production of salt by evaporation.

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. Post evaporation 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.

TABLE 15

U.S. SALT ANNUAL PRODUCTION CAPACITIES IN 1989

(Thousand short tons)

Company	Plant	Type of salt			
		Rock	Solar	Vacuum pan	Total
Akzo Salt Inc.[1]	Avery Island, LA	2,400	—	—	2,400
Do.	St. Clair, MI	—	—	395	395
Do.	Manistee, MI	—	—	325	325
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	—	150	—	150
American Salt Co.	Lyons, KS	250	—	300	550
Do.	Grantsville, UT	—	300	—	300
Carey Salt Co.	Hutchinson, KS	300	—	225	525
Cargill Inc.	Hutchinson, KS	—	—	250	250
Do.	Breaux Bridge, LA	—	—	150	150
Do.	Lansing, NY	1,300	—	—	1,300
Do.	Watkins Glen, NY	—	—	250	250
Do.	Amboy, CA	—	75	—	75
Do.	Napa, CA	—	275	—	275
Do.	Newark, CA	—	750	150	900
Do.	Redwood City, CA	—	350	—	350
Domtar Industries Inc.	Baldwin, LA	1,700	—	—	1,700
Great Salt Lake Minerals and Chemicals Corp.	Ogden, UT	—	1,500	—	1,500
Huck Salt Co.	Fallon, NV	15	—	—	15
Independent Salt Co.	Kanopolis, KS	400	—	—	400
Moab Salt Inc.	Moab, UT	—	75	—	75
Morton International Inc.[2]	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
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	4,375	4,615	25,785
Brine producers[3]	Various locations	—	—	—	18,184
Grand total		16,795	4,375	4,615	43,969

[1]Formerly International Salt Co.

[2]Formerly Morton Thiokol Inc.

[3]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 2 and 3. Brine producers include those chloralkali manufacturers that purchase brine or use captive brine, as listed in table 16.

Note.—Cargill's Freedom, OK, solar plant; Akzo's Williston, ND,vacuum pan plant; and Morton's Trona, CA, solar plant have been closed.

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

TABLE 16

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.	Pittsburgh, CA	199	348	Purchased.
Do.	Plaquemine, LA	997	1,745	Captive brine.
E.I. DuPont de Nemours & Co. Inc.	Niagara Falls, NY	84	147	Purchased.
Formosa Plastics Corp USA	Baton Rouge, LA	200	350	Purchased brine.
Fort Howard Corp.	Green Bay, WI	9	16	Imported.
Do.	Muskogee, OK	9	16	Purchased.
General Electric Co.	Burkville, AL	27	47	Do.
Do.	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.
LCP Chemicals & Plastics Inc.	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 (DuPontOlin)	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.
Do.	Niagara Falls, NY	91	159	Purchased.
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 Chemicals	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		12,709	22,241	

[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 are available on standby basis; included in "Total."

TABLE 17

WORLD SALT ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand short tons)

	Rock	Solar[2]	Vacuum pan[3]	Total[4]
North America:				
Bahamas	—	1,650	—	1,650
Canada	[5]9,116	—	1,069	13,602
Mexico	—	8,900	NA	[6]9,600
Puerto Rico	—	40	—	40
United States	16,795	[5]4,375	4,615	43,969
Total	25,911	14,965	4,615	68,861
Caribbean:				
Cuba	—	300	—	300
Dominican Republic	[7]70	NA	—	70
Jamaica[8]	—	20	—	20
Leeward and Windward Islands[8]	—	60	—	60
Netherlands Antilles	—	400	—	400
Total	70	780	—	850
Central America:				
Costa Rica	—	30	—	30
El Salvador	—	20	—	20
Guatemala	—	50	—	50
Honduras	—	35	—	35
Nicaragua	—	60	—	60
Panama	—	90	—	90
Total	—	285	—	285
South America:				
Argentina	1	1,000	265	1,400
Bolivia	—	20	—	20
Brazil	1,500	4,000	100	5,600
Chile	1,650	—	—	1,650
Colombia	450	1,000	—	1,450
Peru	150	400	—	550
Venezuela	—	550	—	550
Total	3,751	6,970	365	11,220
Europe, Western:				
Austria	1	—	550	800
Belgium	—	—	—	500
Denmark	—	—	—	600
France	[9]1,600	1,900	1,150	11,450
Germany, Federal Republic of	[5]8,000	—	925	14,425
Greece	—	200	—	200
Iceland	—	—	—	[10]2
Ireland	275	—	—	275
Italy	1,980	1,550	1,000	5,630
Malta	—	([11])	—	([11])
Netherlands	—	—	NA	4,400
Portugal	125	NA	—	650
Spain	[12]1,700	1,650	NA	3,370
Switzerland	—	—	—	440
Turkey	100	1,050	—	1,400
United Kingdom	[5]2,810	—	[13]2,670	11,875
Total	16,591	6,350	6,295	56,017

See footnotes at end of table.

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 around 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 had been 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.

***Beneficiation.*—Rock Salt.**—About 68% of total rock salt produced and imported is for highway deicing. Crushing and screening to the proper physical size is usually the only processing that road salt undergoes. In many operations, these steps are done underground in the mine to minimize haulage and storage costs. In addition, the extremely fine fraction, which often is unusable, remains underground rather than on the surface, which would represent a waste product to be disposed.

TABLE 17—Continued

WORLD SALT ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand short tons)

	Rock	Solar[2]	Vacuum pan[3]	Total[4]
Europe, Eastern:				
Albania	—	—	—	80
Bulgaria	—	—	—	100
Czechoslovakia	—	—	—	350
German Democratic Republic	[5]3,500	—	—	3,600
Poland	1,650	—	—	4,000
Romania	2,000	—	—	6,000
U.S.S.R.	[5]10,100	2,000	1,760	20,600
Yugoslavia	300	110	—	700
Total	17,550	2,110	1,760	35,430
Africa:				
Algeria	—	200	—	200
Angola	—	50	—	50
Benin	—	([11])	—	([11])
Egypt	—	1,500	—	1,500
Ethiopia	20	150	—	170
Ghana	—	—	55	55
Kenya	—	60	—	60
Libya	—	15	—	15
Madagascar	—	35	—	35
Mali	—	5	—	5
Mauritania	—	6	—	6
Mauritius	—	7	—	7
Morocco	1,100	30	—	1,130
Mozambique	—	35	—	35
Namibia	—	200	—	200
Niger	—	3	—	3
Senegal	—	170	—	170
Sierra Leone	—	—	—	220
Somalia	—	35	—	35
South Africa, Republic of	—	900	—	900
Sudan	—	—	—	[14]80
Tanzania	—	30	—	30
Tunisia	—	500	—	500
Uganda	—	6	—	6
Zambia	—	—	—	([15])
Total	1,120	3,937	55	5,412
Middle East:				
Cyprus	—	30	—	30
Iraq	—	100	—	100
Iran	70	500	—	570
Israel	—	200	50	250
Jordan	—	[5]60	—	60
Kuwait	—	—	[16]25	[17]25
Lebanon	—	10	—	10
Saudi Arabia	—	—	—	([17])
Syria	125	—	—	125
Yemen (Aden)	—	80	—	80
Yemen (Sanaa)	100	—	—	100
Total	295	980	75	1,350

See footnotes at end of table.

Solar Salt.—After harvesting, the salt crystals are washed with dilute brine to remove residual bitterns and impurities. The salt is transferred to processing facilities where it is washed with saline water, dried for about 8 minutes at approximately 300° F, and screened into fine to coarse sizes, depending on the end use of the salt to be sold. Most operations ship solar salt in bags and in bulk, using barges, truck, and rail transportation.

Mechanical Evaporation.—Salt obtained by dehydrating brine using heat alone or in combination with a vacuum is vacuum pan salt. The vacuum pan process conserves energy by utilizing multiple-effect evaporators connected to vacuum pumps. A saturated salt solution will boil at a higher temperature than pure water. When a vacuum is applied, the brine boils at a lower temperature, enabling the superheated vapor that is generated to act as the heating medium for the next evaporator.

The grainer or open pan process uses open, rectangular pans with steam-heated immersion coils to evaporate the water in the brine. Rotating rakes scrape the salt precipitate into a sump or up a ramp, depending on the method, and onto conveyors for debrining and drying treatment. The final product is usually flake shaped rather than the typical cubic form. Flake salt is preferred for production of cheese, butter, and baked goods.

The Alberger process is a modified grainer operation that produces cubic salt with some flake salt. The pans are shallow, circular units with external heating units, rather than heating coils. The open pan process cannot be operated successfully in regions with high humidities because the evaporation rate is too slow and more energy is required to evaporate the brine.

Desalination.—The conversion of saline water into freshwater has important municipal, industrial, and agricultural applications. Aside from obtaining pure water, desalination also produces byproduct salt. There are four processes presently employed in water desalinization and each has different cost and energy factors. The processes are distillation, membrane, freezing, and ion exchange. Some salt from these processes is used by the chemical industry. In some regions, salt is returned to the saline water source. Seawater typically contains 3.5% to 4.5% salt, or 35,000 to 45,000 parts per million.

TABLE 17—Continued

WORLD SALT ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand short tons)

	Rock	Solar[2]	Vacuum pan[3]	Total[4]
Asia:				
Afghanistan	20	—	—	20
Bangladesh	—	600	—	600
Burma	—	—	—	400
China	8,000	25,000	—	33,000
India	6	14,000	—	14,006
Indonesia	—	1,000	—	1,000
Japan	—	1,600	—	1,600
Kampuchea	—	45	—	45
Korea, North	—	—	—	700
Korea, Republic of	—	900	—	900
Laos	35	—	—	35
Pakistan	600	NA	—	1,000
Philippines	—	600	—	600
Sri Lanka	—	140	—	140
Taiwan	—	620	—	620
Thailand	12	188	—	200
Vietnam	—	500	—	500
Total	8,673	45,193	—	55,366
Oceania:				
Australia	—	8,600	—	8,600
New Zealand	—	100	—	100
Total	—	8,700	—	8,700
World total	73,961	90,270	14,234	243,491

NA Not available, although production is known to occur.

[1]Capacities were derived from industry sources, published reports, and estimates based on production trends. Salt brine capacities are not meaningful because they vary with production levels of brine feedstock to chemical plants. Therefore, salt brine capacities are not included in the list, except for certain countries that incorporate brine statistics with other types of salt. In these exceptions, brine capacities are assumed to be equal to the quantity of brine produced in 1988.

[2]Also known as marine salt.

[3]Some countries report "refined salt," which may or may not be vacuum pan salt, but washed or screened rock or solar salt. Efforts were made to categorize refined salt into the appropriate type of salt.

[4]May include brine or salt from undisclosed sources.

[5]Contains salt produced as a byproduct or coproduct from potash mining. Additional salt may be recovered but discharged as a waste product.

[6]Contains salt produced as a byproduct or coproduct from sulfur mining.

[7]Contains salt produced as a byproduct or coproduct from gypsum mining.

[8]Salt is imported, washed, repackaged, and exported.

[9]Byproduct salt from potash mining is 8.5 million tons, of which only about 880,000 tons are sold and the remainder discharged.

[10]Recovered from geothermal brines.

[11]Less than 1/2 unit.

[12]Byproduct salt from potash mining is 2.65 million tons, of which only about 500,000 tons are sold and the remainder discharged.

[13]Includes about 220,000 tons of sea salt recovered using open pan process.

[14]From evaporating brine from salt springs or wells over wood fires.

[15]Plants from brine marshes are washed to obtain a salt solution, which is heated in containers to recover salt.

[16]From mechanical evaporation of seawater at petrochemical complex.

[17]Salt is obtained from several seawater desalination plants but amount of recovery is uncertain.

The standard for drinking water in the United States is 500 parts per million.

Byproducts and Coproducts

Salt is a coproduct from various seawater and saline lake operations. Depending on the cost of recovery and processing, certain magnesium, potassium, and bromine compounds can be produced from the bitterns. Subterranean brines also contain borax, calcium chloride, sodium carbonate, and sodium sulfate in addition to the above. Certain potash operations in the world also produce salt as a coproduct. When discharged to tailing ponds as a byproduct of potash mining, salt is often harvested and sold by second parties.

Economic Factors

Energy and labor costs are important factors that affect production costs, and ultimately the selling price, for all types of salt. After the salt is produced, shipping costs become very important when attempting to sell to a customer that is in proximity to other salt producers. Industry sources indicate that within the United States, a 300-mile radius is an effective limit of competition for a producing location before the influence of other competitors is noticed. Some of the major U.S. producers also have foreign subsidiaries that produce salt, which is imported at prices favorable to many consumers because transportation costs are less.

Capital investment and energy costs are important factors that influence the selling price of the type of salt produced. Vacuum pan and open pan processing requires more equipment and energy than solution mining, and consequently, the average value of evaporated salt is considerably higher than that of salt in brine.

Prices.—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 that 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 19 lists the historical values of the different types of salt since 1970. The data are compared with 1989 constant dollars to show the effect of inflation and general economic conditions on the values.

Tariffs.—The United States imports about four to six times the quantity of salt that it exports. Imports from countries having most favored nation (MFN) status enter duty free. However, salt imported from non-MFN countries have 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

TABLE 18

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
WORLD PRODUCTION										
Production:										
United States	46,764	44,700	44,010	44,298	46,423	41,710	43,801	42,922	42,878	46,317
Rest of world[e]	114,317	114,407	117,340	126,185	136,813	136,497	133,304	130,185	142,584	144,790
Total[e]	161,081	159,107	161,350	170,483	183,236	178,207	177,105	173,107	185,462	191,107
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	46,764	44,700	44,010	44,298	46,423	41,710	43,801	42,922	42,878	46,317
Sold or used[1]	45,896	44,077	45,022	43,910	46,536	41,030	44,191	43,412	42,869	45,793
Imports	3,536	3,855	3,463	3,207	3,358	3,215	4,352	4,529	5,380	5,275
Industry stocks, Jan. 1[2]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	49,432	47,932	48,485	47,117	49,894	44,245	48,543	47,941	48,249	51,068
Distribution of U.S. supply										
Industry stocks, Dec. 31[2]	—	—	—	—	—	—	—	—	—	—
Exports	423	670	869	609	521	1,332	1,007	1,008	776	697
Industrial demand	49,009	47,262	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371
U.S. DEMAND PATTERN[3]										
Agriculture	1,925	1,941	1,963	2,083	1,983	1,862	1,925	1,825	1,851	1,917
Alkalies and chlorine	27,918	26,075	26,725	28,344	28,600	24,154	25,970	25,111	24,511	26,962
Deicing	10,092	9,859	11,248	7,306	9,111	8,840	10,193	10,416	10,690	11,138
Food products	2,562	2,942	2,953	2,951	2,970	2,734	2,766	2,756	2,815	2,526
Metal production	260	182	227	228	252	265	342	351	346	356
Other chemicals	1,409	1,286	1,063	1,402	1,734	1,021	1,158	1,122	1,159	1,222
Paper products	380	279	201	209	165	172	213	222	221	194
Petroleum	214	164	202	215	242	261	312	361	451	550
Textiles and dyeing	197	193	207	201	205	180	204	196	182	188
Water treatment	908	790	842	816	1,029	905	720	812	890	958
Other[4]	2,779	3,070	2,833	2,917	3,328	3,254	3,655	3,620	3,504	3,528
Undistributed[5]	365	481	-848	-164	-246	-735	78	141	853	832
Total U.S. primary demand	49,009	47,262	47,616	46,508	49,373	42,913	47,536	46,933	47,473	50,371
VALUES[6]										
Average annual value (dollars/ton):										
Salt in brine	3.67	3.57	3.29	3.57	3.69	3.91	3.80	3.91	4.24	4.51
Rock salt	6.60	6.41	6.19	6.19	7.14	8.94	7.82	8.94	10.10	10.00
Solar salt	6.62	11.02	8.40	8.99	9.30	14.21	14.36	14.21	14.67	12.16
Vacuum pan and open pan salt	25.51	26.28	26.76	29.65	34.50	43.01	50.73	52.01	58.86	61.64

See footnotes at end of table.

TABLE 18—Continued

US SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand short tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION										
Production:										
United States	41,483	38,899	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278
Rest of world[e]	144,673	150,054	143,406	142,126	151,077	151,412	155,473	159,909	163,615	170,710
Total[e]	186,156	188,953	181,071	175,099	190,258	190,629	192,755	196,852	202,785	209,988
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply										
Domestic sources	41,483	38,899	37,665	32,973	39,181	39,217	37,282	36,943	39,170	39,278
Sold or used[1]	40,352	38,907	37,894	34,573	39,225	40,067	36,663	36,493	38,940	38,856
Imports	5,263	4,319	5,451	5,997	7,545	6,207	6,665	5,716	5,474	6,084
Industry stocks, Jan. 1[2]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply	45,615	43,226	43,345	40,570	46,770	46,274	43,328	42,209	44,414	44,940
Distribution of U.S. supply										
Industry stocks, Dec. 31[2]	—	—	—	—	—	—	—	—	—	—
Exports	831	1,046	1,001	517	820	904	1,165	541	884	1,567
Industrial demand	44,784	42,180	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373
U.S. DEMAND PATTERN[3]										
Agriculture	1,834	1,788	1,566	1,605	1,722	1,718	1,651	1,755	1,827	1,925
Alkalies and chlorine	24,744	22,722	19,151	20,240	20,142	20,436	18,983	17,955	19,968	18,780
Deicing	7,476	8,257	10,839	6,889	10,721	11,180	10,541	9,878	11,125	11,461
Food products	2,368	2,203	2,352	2,292	2,175	2,109	2,171	2,328	2,287	2,374
Metal production	272	294	294	242	326	382	304	311	374	400
Other chemicals	1,020	1,133	865	952	1,258	768	818	760	766	1,177
Paper products	230	247	209	274	337	311	307	387	376	373
Petroleum	709	837	1,035	918	870	965	627	597	819	720
Textiles and dyeing	177	220	165	171	191	186	226	237	229	234
Water treatment	865	1,006	806	795	1,948	1,441	1,553	1,455	1,514	1,487
Other[4]	3,275	3,754	3,954	4,049	4,188	3,382	3,063	4,074	3,805	4,875
Undistributed[5]	1,814	-281	1,108	1,626	2,072	2,492	1,919	1,931	440	-433
Total U.S. primary demand	44,784	42,180	42,344	40,053	45,950	45,370	42,163	41,668	43,530	43,373
VALUES[6]										
Average annual value (dollars/ton):										
Salt in brine	650	591	621	522	505	614	515	493	358	567
Rock salt	1465	1376	1389	1343	1378	1515	1451	1434	1446	1638
Solar salt	1565	1835	1789	2147	1967	2310	2376	2540	2659	2788
Vacuum pan and open pan salt	7644	7968	8672	8739	9278	9266	9127	9421	9771	9273

[e]Estimated.

[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 are 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 wholesales 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.

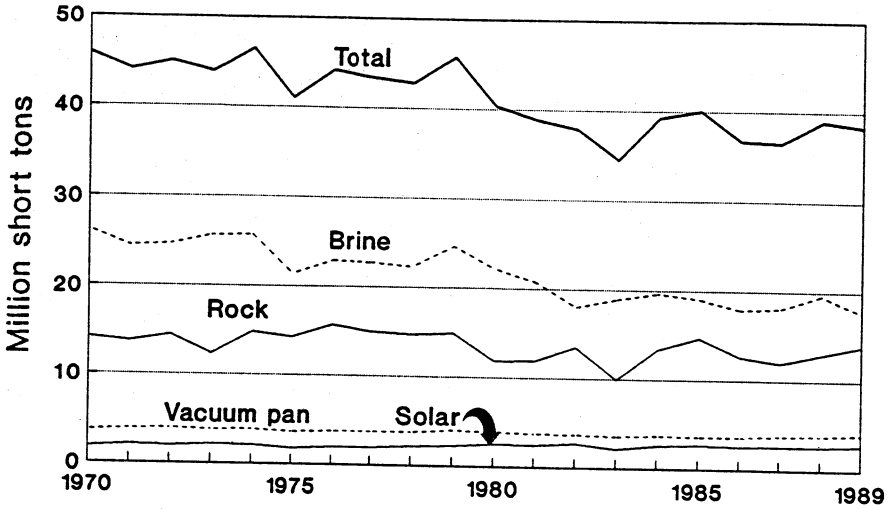
[5]Represents the difference between the quantity reported to the Bureau of Mines and total U.S. primary demand. The amount of discrepancy is attributed to variances in inventory and import statistics.

[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.

FIGURE 2

U.S. SALT SOLD OR USED, BY TYPE



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 groundwater 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 Mines salt survey, 4,284 people were employed in the mining and processing of salt in 1988. The quantity employed by type of salt and by mine and mill activity was as follows: rock salt, 1,021 in the mine and 278 in the mill; solar salt, 105 in harvesting and 610 in the processing plant; vacuum pan salt, 2,197 in the processing plant; and salt brine, 54 in solution mining and 19 in the processing plant.

TABLE 19

TIME-VALUE RELATIONSHIPS FOR VARIOUS TYPES OF SALT[1]

(Average annual value and 1989 constant dollars,[2] dollars per short ton)

Year	Salt in brine		Rock salt		Solar salt		Vacuum pan and open pan salt	
	Annual value	Based on constant 1989 dollars	Annual value	Based on constant 1989 dollars	Annual value	Based on constant 1989 dollars	Annual value	Based on constant 1989 dollars
1970	3.67	11.04	6.60	19.85	6.62	19.91	25.51	76.71
1971	3.57	10.16	6.41	18.23	11.02	31.46	26.28	74.76
1972	3.29	8.94	6.19	16.81	8.40	22.82	26.76	72.68
1973	3.57	9.11	6.19	15.79	8.99	22.94	29.65	75.65
1974	3.69	8.63	7.14	16.70	9.30	21.75	34.50	80.69
1975	3.91	8.33	8.94	19.04	14.21	30.27	43.01	91.60
1976	3.80	7.61	7.82	15.65	14.36	28.74	50.73	101.54
1977	3.91	7.34	8.94	16.78	14.21	26.67	52.01	97.61
1978	4.24	7.43	10.10	17.67	14.67	25.66	58.86	102.96
1979	4.51	7.25	10.00	16.07	12.16	19.54	61.64	99.05
1980	6.50	9.58	14.65	21.59	15.65	23.06	76.44	112.65
1981	5.91	7.94	13.76	18.49	18.35	24.66	79.68	107.06
1982	6.21	7.84	13.89	17.54	17.89	22.60	86.72	109.53
1983	5.22	6.35	13.43	16.33	21.47	26.10	87.39	106.23
1984	5.05	5.92	13.78	16.16	19.67	23.07	92.78	108.80
1985	6.14	6.99	15.15	17.25	23.10	26.31	92.66	105.53
1986	5.15	5.72	14.51	16.10	23.76	26.37	91.27	101.30
1987	4.93	5.30	14.34	15.43	25.40	27.33	94.21	101.35
1988	3.58	3.73	14.46	15.06	26.59	27.69	97.71	101.74
1989	5.67	5.67	16.38	16.38	27.88	27.88	92.73	92.73

[1]Values are based on the average of all salt producers' valuations reported to the 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 1989 implicit price deflators for gross national product, by the Council of Economic Advisors. Based on 1982 = 100.

TABLE 20

SPECIFICATIONS APPLYING TO THE SALT INDUSTRY

Type specification	Title	Designation	Jurisdiction
Analysis	Standard Methods for Chemical Analysis of Sodium Chloride	ASTME-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.

Transportation.—The locations of the salt supplies often are not in proximity of the consumers location, and transportation can become an important cost. Pumping salt brine through pipelines is an economic means of transportation, but cannot be used for dry salt. Large bulk shipments of dry salt in ocean freighters or river barges are low in cost, but are restricted in points of origin and consumption. River and lake movement of salt in winter is often severely curtained because of frozen waterways. As salt is packaged, handled, and shipped in smaller units, the costs are increased and are reflected in higher selling prices.

Ocean borne 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.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Salt. Ch. in Mineral Commodity Summaries.
Directory of Companies Producing Salt in the United States, in annual Mineral Industry Surveys.

Other Sources

Canadian Minerals Yearbook, Chapter on Salt, annual.
The Chlorine Institute.
Handbook of World Salt Resources. Stanley J. Lefond, 1969, 384 pp.
The Salt Institute.
Sodium Chloride.
Solution Mining Research Institute.

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 Bureau of Mines since 1979. Domestic survey data were prepared by Olga E. Valdes, mineral data assistant.

A total of 897 million short tons of construction sand and gravel was estimated to have been produced in the United States in 1989, a 2.8% decrease compared with that of 1988. This tonnage represents the fourth consecutive year of production over 880 million tons, indicating a continuation of the strong demand for construction aggregates.

Foreign trade of construction sand and gravel remained relatively minor. Exports increased 16.6% to 1.1 million tons, while value increased 23% to $13.6 million. Imports increased 21.7% to 427,000 tons, while the value increased 109% to $6.6 million. Domestic apparent consumption of construction sand and gravel was 897 million tons.

The new regulatory requirements being proposed by the Occupational Safety and Health Administration (OSHA) regarding its revised asbestos standards governing occupational exposure to nonasbestiform varieties of actinolite, tremolite, and anthophyllite (AT&A) minerals, and the final promulgation of the permissible exposure limit for crystalline silica, measured as respirable silica, constitute major areas of concern for the industry.

DOMESTIC DATA COVERAGE

Domestic production data for construction sand and gravel are developed by the 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, a preliminary survey that collects production information on a sample basis is used to generate only annual estimates for each State. In addition, a new quarterly sample survey for crushed stone and sand and gravel was implemented by the Bureau of Mines in 1989, providing for the first time production estimates by quarters for each State and the nine geographic regions. The results of this survey are published each quarter in a separate publication, the Quarterly Mineral Industry Survey. Both sample surveys canvass most of the large companies in each State, accounting for up to 80% of each State's total tonnage.

LEGISLATION AND GOVERNMENT PROGRAMS

On January 13, 1989, OSHA announced the final promulgation of exposure limits for 400 air contaminants, establishing a permissible exposure limit (PEL) of 0.1 milligrams per cubic meter (mg/m^3) for crystalline silica, measured as respirable silica.[1] Despite this ruling, some statements in the preamble indicate that OSHA may in the future consider the need to lower the standard, based on "emerging developments in this area."

On August 29, 1989, the Mine Safety and Health Administration (MSHA) published a new proposed rule that revises MSHA's existing standards for air quality and chemical substances at coal and metal nonmetal mines. The proposed rule contains permissible exposure limits for substances that may pose health hazards at these operations. In addition, the proposed rule contains revised requirements for exposure monitoring, carcinogens, and respiratory protection programs. The original deadline for receiving comments about the proposed ruling was November 27, 1989, and was extended to March 2, 1990.[2]

On July 21, 1989, OSHA announced another extension, through November 30, 1990, of the stay for the new provisions of its revised asbestos standards governing occupational exposure to nonasbestiform varieties of AT&A minerals. The revised asbestos exposure standards were originally published by

TABLE 1

SALIENT U.S. CONSTRUCTION SAND AND GRAVEL STATISTICS[1]

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
Sold or used:					
Construction sand and gravel:					
Quantity	e800,100	883,000	e896,200	923,400	e897,300
Value	e$2,438,000	$2,747,200	e$3,002,500	$3,126,000	e3,249,100
Exports:					
Quantity	1,513	1,166	1,137	965	1,125
Value	$8,935	$7,838	$10,533	$11,048	$13,591
Imports for consumption:					
Quantity	246	205	283	351	427
Value	$1,572	$1,412	$2,367	$3,163	$6,618

eEstimated.

[1] Puerto Rico excluded from all sand and gravel statistics.

OSHA on June 20, 1986. The former asbestos standard remains in effect for the extent of the stay. Based on OSHA's Hazard Communication Standard, a product is considered carcinogenic if it contains 0.1% or more of an OSHA-designated carcinogen. The inclusion of nonasbestiform AT&A minerals in the asbestos exposure standards effectively designates large areas of the United States as containing carcinogenic minerals. 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.

In 1989, MSHA established a new program to combat illegal mining. The program will be enforced through an Illegal Mining Task Force, as well as MSHA officials at the local level. MSHA considers a mining site illegal when the operator fails to register the site with the agency.

ISSUES

On June 20, 1986, OSHA published a final rule titled "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite; Final Rules." The regulation, which was amended in September 1988, established exposure limits for asbestos and nonasbestiform varieties of the amphibole minerals AT&A. Under OSHA regulation, all products containing a specified concentration of these minerals must be labeled as having a constituent that is a carcinogen.

In an effort to assist OSHA in its decision regarding implementation of the final asbestos standard, the Bureau of Mines completed in August 1989 a study entitled, "Analysis of the Cost Effectiveness of the OSHA Regulation of Nonasbestiform Amphiboles with Respect to Selected Sectors of the Domestic Minerals Industry." The Bureau's analysis questions "whether OSHA has conclusively demonstrated a health risk associated with AT&A and, consequently, that these minerals should be regulated at all, given that no discernible net benefits will result." The study has also "identified a basic inconsistency between OSHA's definition of asbestos and its asbestos standard," and found that "the regulation will result in economic impacts on several minerals industry sectors."

"The economic impact of the OSHA regulation is expected to be greatest on the aggregates industry. Due to product liability considerations," it is suggested that "every sand and gravel deposit in the United States would have to be examined at least at the cursory level, at a minimum cost of $1,000 per deposit. Sales losses in the aggregates industry are possible and would be contingent on the availability and cost of material that is essentially free of AT&A, and the liability concerns associated with using products containing AT&A."

In the concluding section of the study, "it is recommended that OSHA not regulate AT&A as asbestos unless medical data conclusively show that these minerals present a health risk which would be reduced through regulations;" that "OSHA should revise its asbestos and fiber definitions, to make the two terms consistent from a mineralogical standpoint;" and that "OSHA should specifically address the economic impact of its proposed regulation on the minerals industry and weigh these costs against possible benefits."

PRODUCTION

The production estimates indicate that in 1989 the U.S. production of construction sand and gravel was 897 million tons, a 2.8% decrease compared with that of 1988. Of the four major geographic regions, the West again led the Nation in production of construction sand and gravel with 330 million tons, or 36.7% of the U.S. total, followed by the Midwest with 271 million tons, or 30.3% of the total; the South with 188 million tons, or 20.9%; and the Northeast with 109 million tons, or 12.1%. Compared with 1988, production by major geographic regions decreased 16.2% in the Northeast and 7% in the South, but increased 2.8% in the West and only 0.1% in the Midwest.

Of the nine geographic regions, the Pacific again led the Nation with 208 million tons, or 23.2% of the U.S. total. Next was the East North Central with 177 million tons, or 19.7% of the total, followed by the Mountain with 121 million tons, or 13.5% of the total. Compared with 1988, production increased in three of the nine regions, the largest increases being recorded in the Mountain region, 5.9%; the West North Central, 4.6%; and the Pacific region with only 1.1%. The production decreased in the remaining six geographic regions with the major decreases occurring in New England, 26.6%; West South Central, 9.9%; and Middle Atlantic, 8%.

The estimated production by quarters for 1989 indicated that most of the construction sand and gravel in the United States was produced in the third quarter of 1989, followed by the second quarter and the fourth quarter. Estimated production by each quarter of 1989 was also available for most of the States.

Construction sand and gravel was produced in every State, and the 10 leading States were, in descending order of tonnage, California, Michigan, Ohio, Texas, Washington, Arizona, Minnesota, Illinois, New York, and Indiana. Their combined production represented 52.9% of the national total.

Compared with 1988, production increased in only 16 States, including 4 of the top 10 States. The increases were significant in Washington, 21.3%; Indiana, 14.2%; and Illinois, 9.6%.

Fewer acquisitions by foreign or domestic companies and mergers occurred in the construction sand and gravel industry in 1989. Lone Star Industries Inc., of Greenwich, CT, completed in January 1989 the sale of its remaining 40% interest in Tarmac-Lone Star joint venture to Tarmac America of Herndon, VA, a division of Tarmac PLC of Wolverhampton, United Kingdom. The original joint venture was established in 1986. The latest transaction included remaining interest in aggregates, cement, concrete, and concrete products operations located in North Carolina, South Carolina, and Virginia.

Great Lakes Dredge & Dock Co. of Chicago, IL, sold 25% of its 75% interest in McCormack Aggregates Co. of South Amboy, NJ, to Ralph Clayton & Sons Materials of Lakewood, NJ. Clayton also bought McCormack Sand Co.'s entire 25% stake in the company and changed its name to Amboy Aggregates. McCormack, presently the largest offshore producer of sand and

FIGURE 1

PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1989, BY GEOGRAPHIC REGION

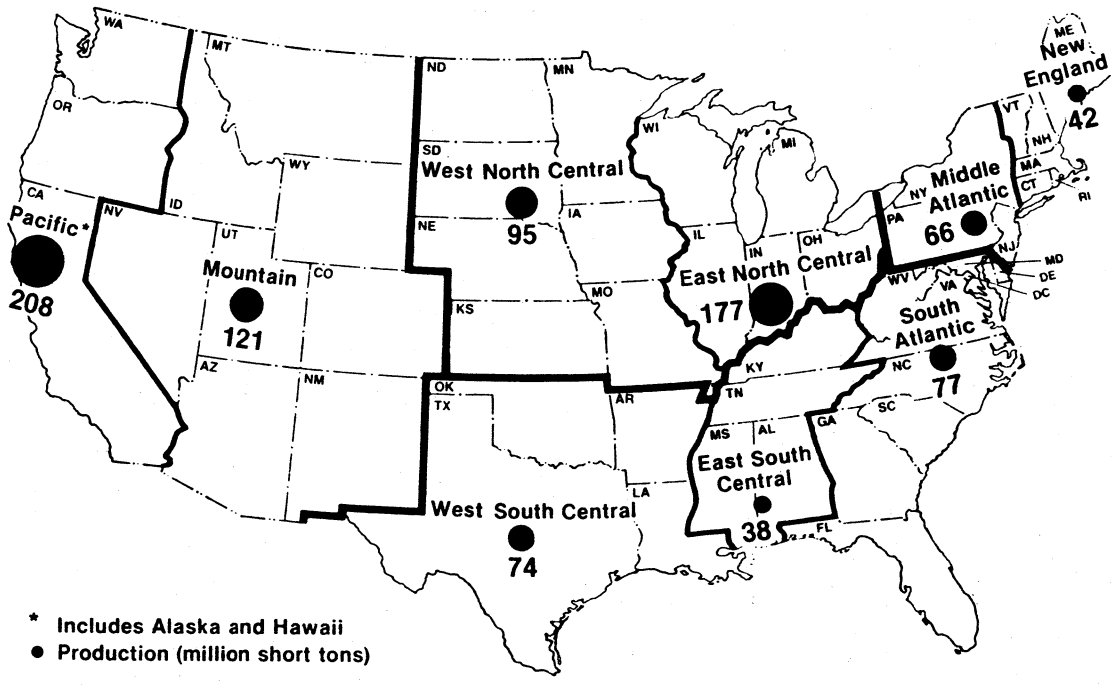


TABLE 2

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1988				1989[e]			
	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	57,614	6	$202,413	7	42,300	5	$156,500	5
Middle Atlantic	72,027	8	290,490	9	66,300	7	281,500	9
Midwest:								
East North Central	180,681	20	528,057	17	176,700	20	545,200	17
West North Central	90,555	10	222,723	7	94,700	11	256,800	8
South:								
South Atlantic	82,187	9	292,308	9	76,700	9	288,500	9
East South Central	38,216	4	118,810	4	37,600	4	125,000	4
West South Central	81,598	9	272,842	9	73,500	8	255,700	8
West:								
Mountain	114,635	12	377,300	12	121,400	13	443,000	13
Pacific	205,848	22	821,055	26	208,100	23	896,900	27
Total[1]	923,400	100	3,126,000	100	897,300	100	3,249,100	100

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

gravel in the United States, will continue to supply sand and gravel in Connecticut, New Jersey, and New York.

Redland PLC of Gorby, United Kingdom, acquired through its subsidiary, Western-Mobile Inc. of Denver, CO, Flatiron Sand & Gravel Co. of Boulder, CO. The transaction included the assets of Flatiron Sand & Gravel, Flatiron Paving, Flatiron Premix Concrete, and Plains Aggregate Co. Redland also owns in the United States Genstar Stone Products Co. of Hunt Valley, MD, and Redland-Worth Corp. of San Antonio, TX.

CalMat Co. of Los Angeles, CA, formed a joint venture with Owl Rock of Arcadia, CA, to acquire Kirst Construction Co., the owners and operators of Azusa Rock of Fish Canyon, CA.

ARC America Corp., of Newport Beach, CA, a subsidiary of ARC Ltd. of Bristol, United Kingdom, and one of the major sand and gravel and crushed stone producers in the United States, was acquired by Hanson Trust PLC of London, United Kingdom. The change in ownership followed the acquisition by Hanson PLC of the Consolidated Gold Fields PLC, of London, United Kingdom, the parent company of ARC Ltd. At the end of 1989, Hansen PLC was in the process of selling all ARC America operations to Colonial Sugar Refineries (CSR) Ltd. of Sydney, Australia, a major sugar and building-material producer. The transaction includes American Aggregates Co. of Greenville, OH; Associated Sand and Gravel Co. of Everett, WA; and WMK Co. of Las Vegas, NV. CSR already owns Rinker Materials Corp. of West Palm Beach, FL.

Limited information about the production of construction sand and gravel in foreign countries may be found in the 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.

CONSUMPTION AND USES

Sand and gravel reported by producers to the Bureau of Mines is actually material that is "sold or used" by the companies and is defined as such. Stockpiled production is not reported until it is sold to a user or consumed by the producer outside its own operation. Because no consumption surveys are conducted by the Bureau of Mines, the "sold or used" tonnage is assumed to represent the amount produced for domestic consumption and export.

The largest use of construction sand and gravel is as aggregate for the production of concrete, used in nearly all residential, commercial, and industrial buildings and in most public works projects such as highways and roads, bridges, dams, airport runways, sewer systems, tunnels, etc. Over the past several years this use represented about 28% of the total. The second largest use is as base material in the construction and repair of highways, railways, runways, etc; it represented about 15% of the total. Other major uses are as aggregate in asphaltic concrete used for paving highways, streets, and parking lots, about 9%, and as fill in highway construction, earth dams, and other applications where recontouring of the original land surface is required, about

TABLE 3

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATE IN 1989, BY GEOGRAPHIC REGION AND QUARTERS

(Thousand short tons and thousand dollars)

Region	1989						Number of Companies[1]
	Quantity					Value total[r]	
	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	Total[r]		
Northeast:							
New England	5,400	11,400	12,000	12,400	42,300	156,500	32
Middle Atlantic	7,200	20,000	23,500	15,600	66,300	281,500	33
Midwest:							
East North Central	16,000	50,900	65,000	47,300	176,700	545,200	54
West North Central	6,100	28,800	36,400	21,500	94,700	256,800	57
South:							
South Atlantic	16,900	18,200	21,700	20,000	76,700	288,500	55
East South Central	7,100	9,500	10,900	9,300	37,600	125,000	30
West South Central	15,000	17,500	20,500	21,500	73,500	255,700	31
West:							
Mountain	26,700	33,000	40,600	31,400	121,400	443,000	44
Pacific[2]	38,400	51,500	53,000	47,100	190,500	845,200	29
Total[3]	138,700	240,800	283,600	226,000	[4]897,300	[4]3,249,100	XX

[r] Revised. 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 and Hawaii.

TABLE 4

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989[e]	
	Quantity	Value	Quantity	Value
Alabama	11,742	41,417	10,400	36,500
Alaska	17,200	48,749	17,000	48,500
Arizona	32,399	123,854	33,900	133,900
Arkansas	7,722	26,201	7,500	25,500
California	141,946	622,074	138,300	670,800
Colorado	21,566	69,882	25,300	104,000
Connecticut	8,275	32,102	5,800	24,700
Delaware	1,933	5,988	1,900	6,200
Florida	18,654	53,083	17,900	55,500
Georgia	9,526	30,185	6,100	18,900
Hawaii	652	3,173	600	3,200
Idaho	6,914	19,897	5,800	18,900
Illinois	30,098	93,504	33,000	108,900
Indiana	25,923	79,985	29,600	99,200
Iowa	11,880	36,087	12,800	37,800
Kansas	10,760	25,329	13,000	33,200
Kentucky	6,325	15,243	5,500	15,100
Louisiana	14,233	52,820	13,600	54,400
Maine	10,183	33,007	8,600	30,100
Maryland	19,266	95,169	16,900	84,500
Massachusetts	22,168	79,364	13,900	57,000
Michigan	53,508	138,171	48,000	132,000
Minnesota	33,769	72,678	33,700	82,600
Mississippi	13,314	38,806	15,600	51,500
Missouri	11,217	32,941	10,000	32,500
Montana	7,984	20,225	5,800	13,900
Nebraska	11,229	28,928	15,200	41,800
Nevada	15,729	50,928	20,000	70,000
New Hampshire	9,089	32,614	6,000	20,400
New Jersey	18,318	74,183	15,200	68,400
New Mexico	8,787	31,367	11,800	45,400
New York	33,884	124,341	31,600	118,500
North Carolina	11,076	38,459	11,200	43,700
North Dakota	3,772	8,079	3,600	8,100
Ohio	46,104	156,318	44,400	148,700
Oklahoma	9,273	22,654	8,500	20,000
Oregon	14,880	52,657	14,400	49,700
Pennsylvania	19,826	91,966	19,500	94,600
Rhode Island	1,853	7,847	1,100	3,900
South Carolina	7,529	20,751	7,500	23,300
South Dakota	7,929	18,681	6,400	20,800
Tennessee	6,836	23,343	6,100	21,900
Texas	50,370	171,167	43,900	155,800
Utah	17,843	49,796	14,300	41,500
Vermont	6,047	17,478	6,900	20,400
Virginia	12,551	42,573	12,900	49,700
Washington	31,170	94,402	37,800	124,700

See footnote at end of table.

7%. The above percentages were calculated based on the information provided by the producers. It should be noted that over the past several years, about 39% of the total U.S. production was included in "unspecified uses—actual and estimated" because some producers reported only total production or did not report at all, and then their production was estimated. The percentage of estimated amounts for nonrespondents decreased from 23.5% in 1984 to 13.1% in 1988, while the percentage of production reported only as totals increased from 16.2% in 1984 to 25.9% in 1988.

Sand and gravel are usually used mixed, but some uses require only sand or only gravel. Sand is used in mortar, plaster, and gunite and for snow and ice control. Gravel is used to improve or control drainage and as covering and stabilizer on load-bearing surfaces such as unpaved roads, driveways, and parking areas. In 1989, only production estimates were generated for construction sand and gravel, and, therefore, no information by end uses is available for this year.

PRICES

As a result of rising costs of labor, energy, and mining and processing equipment, the average unit value of construction sand and gravel increased from $1.11 per ton, f.o.b. plant, in 1970 to $3.62 in 1989. However, the constant dollar value fluctuated between $2.63 and $3.06 per ton for the same period. Increased productivity achieved through increased use of automation and more efficient equipment were mainly responsible for these trends.

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.

TABLE 4—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989[e]	
	Quantity	Value	Quantity	Value
West Virginia	1,653	6,099	2,300	6,700
Wisconsin	25,048	60,080	21,700	56,400
Wyoming	3,413	11,351	4,500	15,400
Total[1]	923,400	3,126,000	897,300	3,249,100

[e] Estimated.

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

Exports

Exports of construction sand decreased 46% to 273,000 tons compared with that of 1988, while value increased 21% to $5.9 million. Mexico was the major destination, receiving about 36.3% of the total, followed by Canada with 22.7%. Exports of construction gravel increased 85.6% to 852,000 tons, while value increased 115.7% to $7.7 million. Canada was the major destination, with 85% of the total, followed by Mexico with 3%.

Imports

Imports of construction sand and gravel increased 21.7% to 427,000 tons compared with that of 1988, while the value increased 109% to $6.6 million. The Bahamas was the major source of imported construction sand and gravel with 54.3% of the total, followed by Japan with 11.9%, and Canada and Norway with 9.6% each.

CURRENT RESEARCH

The 5-year $150 million Strategic Highway Research Program (SHRP)

FIGURE 2

PRODUCTION AND UNIT VALUE IN ACTUAL AND 1970 CONSTANT DOLLARS OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES FOR 1970–89

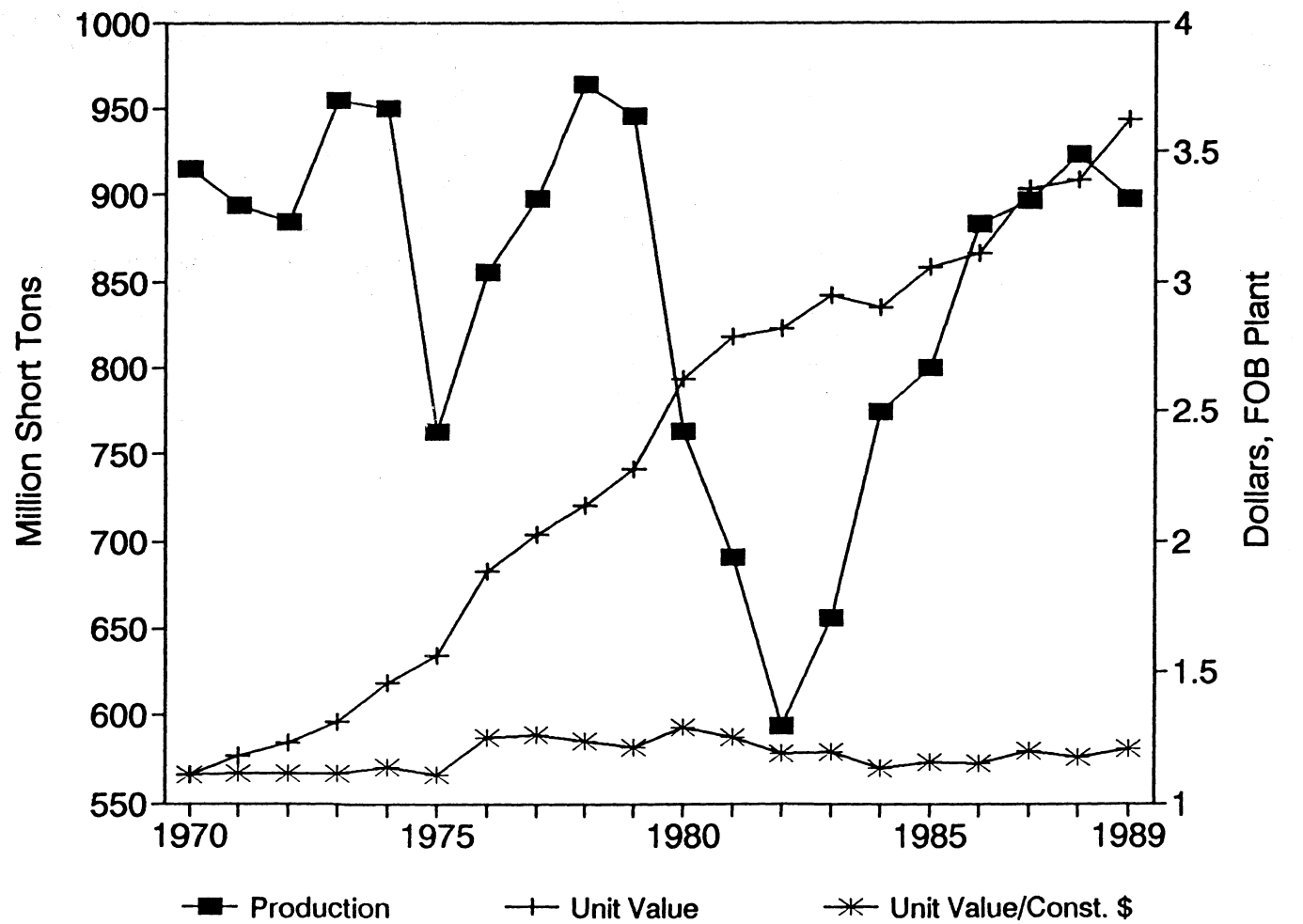


TABLE 5

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE AND QUARTERS

(Thousand short tons and thousand dollars)

State	1989						Number of Companies[1]
	Quantity					Value total	
	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	Total		
Alabama	2,600	2,600	2,800	2,400	10,400	36,500	8
Alaska[2]	—	—	—	—	17,000	48,500	—
Arizona	7,600	8,700	8,400	9,200	33,900	133,900	7
Arkansas	1,500	1,900	2,200	1,900	7,500	25,500	5
California	29,100	38,200	37,600	33,400	138,300	670,800	16
Colorado	2,700	5,800	11,400	5,400	25,300	104,000	10
Connecticut	1,000	1,500	1,800	1,500	5,800	24,700	8
Delaware	400	400	600	500	1,900	6,200	5
Florida	4,500	4,200	4,600	4,600	17,900	55,500	9
Georgia	1,600	1,600	1,600	1,300	6,100	18,900	9
Hawaii[2]	—	—	—	—	600	3,200	—
Idaho	3,500	3,400	2,500	1,500	5,800	18,900	4
Illinois	2,800	10,400	11,100	8,700	33,000	108,900	8
Indiana	3,000	7,800	11,200	7,600	29,600	99,200	13
Iowa	900	4,200	4,800	2,900	12,800	37,800	8
Kansas	1,400	3,700	5,100	2,800	13,000	33,200	10
Kentucky	600	1,500	1,900	1,500	5,500	15,100	5
Louisiana	3,000	4,000	4,500	2,100	13,600	54,400	4
Maine	1,300	3,100	2,200	3,200	8,600	30,100	5
Maryland	3,500	4,400	4,800	4,200	16,900	84,500	10
Massachusetts	2,400	4,000	3,300	4,200	13,900	57,000	7
Michigan	3,400	14,500	18,200	11,900	48,000	132,000	8
Minnesota	900	9,700	13,800	9,300	33,700	82,600	16
Mississippi	3,000	3,900	4,300	4,400	15,600	51,500	9
Missouri	1,300	3,200	3,500	2,000	10,000	32,500	7
Montana[2]	—	—	—	—	5,800	13,900	—
Nebraska	1,000	5,400	5,900	2,900	15,200	41,800	8
Nevada	4,700	5,100	6,000	4,200	20,000	70,000	5
New Hampshire	100	2,100	2,300	1,500	6,000	20,400	5
New Jersey	2,700	4,300	4,500	3,700	15,200	68,400	7
New Mexico	2,300	2,900	3,900	2,700	11,800	45,400	5
New York	3,300	9,500	12,100	6,700	31,600	118,500	12
North Carolina	2,300	2,300	3,300	3,300	11,200	43,700	6
North Dakota[2]	—	—	—	—	3,600	8,100	—
Ohio	4,600	11,000	17,200	11,600	44,400	148,700	12
Oklahoma	1,500	2,300	2,400	2,300	8,500	20,000	7
Oregon	2,700	3,600	6,400	5,300	14,400	49,700	4
Pennsylvania	1,100	6,200	7,400	4,800	19,500	94,600	14
Rhode Island[2]	—	—	—	—	1,100	3,900	—
South Carolina	1,700	1,300	2,500	2,000	7,500	23,300	5
South Dakota	500	2,100	2,900	900	6,400	20,800	6
Tennessee	1,100	1,700	2,100	1,200	6,100	21,900	8
Texas	8,700	9,000	11,000	15,200	43,900	155,800	15
Utah	3,500	5,700	10,100	4,600	14,300	41,500	6
Vermont	600	1,000	2,400	2,900	6,900	20,400	5
Virginia	2,400	3,000	3,800	3,700	12,900	49,700	7

See footnotes at end of table.

TABLE 5—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE AND QUARTERS

(Thousand short tons and thousand dollars)

State	1989						Number of Companies[1]
	Quantity					Value total	
	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	Total		
Washington	6,300	9,700	11,500	10,300	37,800	124,700	9
West Virginia	200	700	800	600	2,300	6,700	4
Wisconsin	1,800	6,600	6,600	6,700	21,700	56,400	13
Wyoming	1,000	900	1,900	700	4,500	15,400	6
Total	XX	XX	XX	XX	897,300	3,249,100	XX

XX Not applicable.
[1] Number of companies reporting for the quarterly survey.
[2] Due to a low number of reporting companies, no production estimates by quarters were generated.

TABLE 6

CONSTRUCTION SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY MAJOR USE[1]

Use	1984			1986			1988		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Concrete aggregate (including concrete sand)	196,914	$678,617	$3.45	219,009	$814,860	$3.72	230,576	$887,422	$3.85
Plaster and gunite sands	8,688	33,487	3.85	10,049	39,972	3.98	9,227	43,226	4.68
Concrete products (blocks, bricks, pipe, decorative, etc.)	10,950	40,066	3.66	16,274	55,648	3.42	10,403	38,916	3.74
Asphaltic concrete aggregates and other bituminous mixtures	68,632	218,758	3.19	87,410	322,666	3.69	82,417	318,662	3.87
Road base and coverings	111,604	287,521	2.58	128,112	354,740	2.77	136,597	413,330	3.03
Road stabilization (cement)	1,412	3,282	2.32	1,509	3,928	2.60	2,390	6,452	2.70
Road stabilization (lime)	1,291	2,445	1.89	901	3,342	3.71	984	2,592	2.63
Fill	51,554	104,619	2.03	66,094	128,780	1.95	62,611	134,709	2.15
Snow and ice control	5,620	14,317	2.55	5,797	17,210	2.97	5,974	20,086	3.36
Railroad ballast	1,299	4,044	3.11	1,512	5,662	3.74	638	2,849	4.47
Roofing granules	400	1,833	4.58	564	3,102	5.50	623	2,517	4.04
Filtration	—	—	—	—	—	—	69	372	5.39
Other	8,988	28,246	3.14	13,981	55,706	3.98	20,578	72,443	3.52
Unspecified:									
Actual	125,023	366,117	2.93	167,891	539,043	3.21	238,924	828,733	3.47
Estimated	181,500	460,604	2.54	163,900	402,515	2.46	121,352	353,689	2.91
Total[2] or average	773,900	2,244,000	2.90	883,000	2,747,200	3.11	923,400	3,126,000	3.39

[1] Full surveys of construction sand and gravel producers are conducted for even-numbered years only; therefore, no information by end use is available for odd-numbered years.
[2] Data may not add to totals shown because of independent rounding.

reached its midpoint in 1989. Management of ongoing research, rather than the initiation of contracts, became the focus of SHRP's activities. 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. The four areas of research are Asphalt, Concrete and Structures, Highway Operations, and Long-Term Pavement Performance Programs.

SHRP's main objective in asphalt research is to produce new performance-based specifications for asphalt binders.[3] A wide range of advanced materials characterization techniques like nuclear magnetic resonance and spectroscopy and computer-aided tomography (CAT) scans are being tested. The CAT scan research conducted at the University of Southern California at Los Angeles could provide a powerful new nondestructive test technique for diagnosing problems in asphalt pavements.

The concrete and structure program includes research in the area of im-

proved concrete materials and corrosion of concrete structures. Under this program, a rapid laboratory test that will determine aggregate reactivity in less than 2 weeks has been developed. Current tests require 9 months to 3 years.

About $20 billion is spent on highway maintenance in the United States each year, which represents about one-third of total highway spending. This expenditure is growing at a rate of about 9% annually. More cost-effective maintenance methods, equipment, and materials are badly needed. SHRP is addressing this problem through its Highway Operations Program by conducting a series of nationwide field performance tests. Texas A&M Research Foundation has designed an experiment to compare the cost-effectiveness of six preventive maintenance methods to be tested under various climate and traffic conditions. The performance of the maintenance methods will be monitored over 5 years at specially constructed side-by-side test sections on inservice roads throughout the country. The snow-and-ice control is another area of interest for the Highway Operations

TABLE 7

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

[e] Estimated.

TABLE 8

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1989, BY COUNTRY

(Thousand tons and thousand dollars)

Country	Sand		Gravel	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Anguilla	—	—	3	24
Antigua	—	—	3	65
Bahamas	(2)	16	4	350
Bermuda	(2)	33	5	42
British Virgin Islands	4	85	15	286
Canada	62	1,252	724	4,357
Cayman Islands	—	—	2	254
Dominican Republic	9	39	4	202
Guadalupe	3	24	3	48
Haiti	5	2	—	—
Honduras	(2)	3	1	78
Martinique	—	—	7	88
Mexico	99	939	26	684
Netherlands Antilles	19	137	3	20
St Christopher-Nevis-Anguilla	—	—	2	11
Turks and Caicos Islands	—	—	8	91
Other[3]	1	96	1	43
Total[4]	204	2,624	811	6,642
South America:				
Chile	1	131	(2)	3
Other[5]	1	170	1	68
Total[4]	2	301	1	71
Europe:				
Belgium	1	36	(2)	71
United Kingdom	(2)	37	2	80
Yugoslavia	—	—	19	25
Other[6]	2	549	1	199
Total[4]	4	621	23	375
Asia:				
Japan	26	284	(2)	11
Korea, Republic of	9	965	(2)	58
China	1	13	7	174
Singapore	16	346	4	116
Taiwan	1	129	2	83
Other[7]	2	204	1	32
Total[4]	55	1,941	14	474
Oceania[8]	2	36	2	91
Middle East and Africa[9]	7	365	2	49
Grand total[4]	273	5,888	852	7,703

[1] Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2] Less than 1/2 unit.
[3] Includes Barbados, Costa Rica, El Salvador, Grenada, Guatemala, Jamaica, Panama, St. Lucia, and Trinidad.
[4] Data may not add to totals shown because of independent rounding.
[5] Includes Argentina, Brazil, Colombia, Ecuador, and Venezuela.
[6] Includes Federal Republic of Germany, Finland, France, Greece, Iceland, Ireland, Italy, Netherlands, Poland, Switzerland, and Sweden.
[7] Includes Hong Kong, India, Indonesia, Pakistan, Philippines, and Thailand.
[8] Includes Australia and New Zealand.
[9] Includes Algeria, Angola, United Arab Emirates, Bahrain, Congo (Brazzaville), Egypt, Gabon, Ghana, Guinea, Israel, Kuwait, Nigeria, Oman, Saudi Arabia, Sierra Leone, Republic of South Africa, Syria, Tanzania, and Tonga.

Source: Bureau of the Census.

Program. The Department of Mechanical Engineering of the University of Wyoming is using computer simulation, model studies, and full-scale prototyping to design and test more efficient and flexible snow-and-ice control equipment and methods.

The University of Washington is developing a rapid laboratory test method for identifying aggregates that are susceptible to freeze-thaw damage. Concrete bridge corrosion is a major problem, affecting a large number of structures around the country. The evaluation of the effectiveness of electrochemical chloride removal technology, an experimental but promising technique for extracting chloride from concrete using electrical current, is advancing under SHRP's Concrete Structure Program.

SHRP's Long-Term Pavement Performance (LTPP) Program is a first-ever major effort to measure pavement performance in different climate and soil conditions at about 1,000 in-service test sections in all 50 States and in Canada. The LTPP program has been planned to run for 20 years, SHRP funding the first 5 years of data gathering and analysis. The data collected as part of the SHRP program is expected to provide sufficient information to refine pavement design that will significantly improve the performance of new pavements.

The Third International Symposium on Unbound Aggregates in Roads (UNBAR3) was held on April 11 through 13, 1989, at the University of Nottingham, United Kingdom.[4] These symposiums are dedicated entirely to the utilization and characterization of unbound aggregate bases. The in situ testing of compacted pavement layers, innovative methods for placing unbound aggregates to obtain a more uniform end product with a leveled surface, and the use of vibrating hammers or computerized vibratory rollers for compacting both unbound base material and asphalt concrete were some of the topics discussed at this year's symposium.

In response to growing concern over rutting of asphalt concrete pavements, in July 1987, the American Association of State Highway and Transportation Officials (AASHTO) organized a joint taskforce of Federal, State, and industry representatives to study the problem. Participating agencies included AASHTO, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, the National Stone Association (NSA), the National Aggregates Association (NAA), the Construction Industry Manufacturers Association (CIMA), the National Cooperative Highway Research Program (NCHR), SHRP, and the Federal Highway Administration (FHWA).[5]

About 70% of all paved public roads and streets and 57% of the interstate highways are surfaced with flexible pavements (asphalt). Asphalt concrete rutting is a longitudinal deformation that develops under the action of channelized loads. It occurs because of consolidation or shear failure in the subgrade or pavement structure. Aggregates make up about 95% of the weight of asphalt concrete and provide most of the pavement's load carrying capacity. The quality and physical properties of aggregates, especially gradation, are critical in preventing rutting and in improving pavement performance in general.

One way to make a mix more resistant to rutting is to increase friction between the particles by using more crushed aggregates. FHWA Technical Advisory T5040.27, "Asphalt Concrete Mix Design and Field Control," recommends that natural sands be limited to 15% to 20% of the total weight of aggregates for high-volume roads.

Another gradation problem that causes rutting is an excessive amount of minus No. 200 material in the mix. FHWA's Technical Advisory recommends that mixes be designed with dust to asphalt ratio between 0.6 and 1.2. The Task Force final report was published in February 1989. It concludes that most of the causes of rutting are known and the solutions to the rutting problem are now available. The report also indicates that FHWA Technical Advisory T5040.27 is a state-of-the-art technical document.

About 240,000 highway bridges in the United States are currently classified as "structurally deficient," mainly because of bridge-deck deterioration. Reinforced concrete bridge decks and piers are particularly vulnerable to salt penetration. The salt affecting the reinforced concrete structures comes from deicing salts as well as from seawater. The combination of chloride ions from the salt, reinforcing bars, and moisture leads to an electrochemical process that causes the rebars to corrode and expand in size. As the bars expand, they

TABLE 9

U.S. IMPORTS FOR CONSUMPTION OF CONSTRUCTION SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

	1988		1989	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua	62	433	33	237
Australia	3	493	1	88
Bahamas	2	14	232	588
Barbados	6	36	—	—
British Virgin Islands	10	188	1	31
Canada	262	1,215	41	309
Dominica	—	—	12	59
Germany, Federal Republic of	(2)	26	8	4,133
Japan	(2)	34	51	148
Norway	—	—	41	482
Taiwan	(2)	41	6	82
Other	6	r682	1	461
Total	351	[3]3,163	427	6,618

r Revised.
[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 do not add to total shown because of independent rounding.

Source: Bureau of the Census.

exert internal pressure on the concrete, which splits along the rebars and leads to rapid deterioration of the concrete. The deterioration process of reinforced concrete can be significantly reduced trough cathodic protection that reverses the flow of electrical current developed when corrosion occurs. Several anode systems for cathodic protection of bridges now available were evaluated in two reports published by FHWA.[6]

OUTLOOK

The demand for construction sand and gravel in 1990 is expected to be about 900 million tons, a slight increase from 1989. The weakness in the nonresidential and multifamily residential building construction markets is expected to be compensated by a stronger demand in road construction and repair work. Gradual increases in demand for construction aggregates are anticipated after 1990, based on increased volume of work on the infrastructure. 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[7] 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 (GNP) 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 will rise over the above forecasts. However, the delivered prices of construction sand and gravel are expected to increase significantly, especially in and near metropolitan areas, mainly because more and more aggregates are transported from distant sources.

BACKGROUND

Sand and gravel is a granular, unconsolidated, and usually rounded agglomeration of particles of rocks and minerals, resulting primarily from the natural disintegration and abrasion of rocks through weathering or erosion. Sand and gravel, as one of the most accessible natural resources, has been used since the earliest days of civilization, mostly as a construction material. At the beginning of the 20th century, the U.S. production of construction sand and gravel, the sand and gravel used mostly for construction purposes, was relatively small and its uses limited. Today, annual sand and gravel production tonnage ranks second in the nonfuel minerals industry after crushed stone and is the only mineral commodity produced in all 50 States. The United States is, in general, self-sufficient in sand and gravel, producing enough to meet all domestic needs and to be a small net exporter, mainly to consumption points along the United States-Canadian and United States-Mexican borders.

Most of 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 NAA.[8]

Specifications for sand and gravel used in roadbuilding and concrete construction are often rigid regarding particle size gradation and shape and include physical as well as some chemical properties. However, these specifications can differ in detail from State to State or even from city to city within the State. Soil conditions, climate, and peculiarities in different deposits may necessitate adjustments of requirements of sand and gravel mixtures and chemical composition.

Specifications are written by commercial users; Government agencies, including Federal, State, county, and city construction and highway departments; and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have

different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Products for Trade and Industry

Concrete is made by mixing properly sized aggregate, portland cement, and water into a slurry. Chemical action between the cement and the water results in the crystallization of hydrous calcium aluminum silicates, which causes the mass to bind and harden. Round particles in the aggregate are desirable because they improve the workability of the concrete as it is poured. If broken material is used and angular or flattish fragments exceed about 15% of the total volume, workability can be maintained only by increasing the amount of sand and water, thus reducing strength, or by adding more cement, thus increasing the cost of the concrete.

Sized and broken sand and gravel is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than do rounded surfaces and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than do rounded particles and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses.

Industry Structure

Because of the low unit value, construction sand and gravel is produced near the point of use; therefore, the industry is concentrated in or nearby large, rapidly expanding urban areas and, on a transitory basis, in areas where highways, dams, and other large-scale public and private works are under construction. In the United States, sand and gravel is produced in every State. The largest operations tend to be concentrated in the States with the largest population and largest production of sand and gravel.

Construction sand and gravel is produced in virtually all countries, but relatively few of them survey this industry and even fewer regularly publish official statistics on sand and gravel.

On the basis of tonnage, the construction sand and gravel industry is the second largest nonfuel mineral industry in the United States. In 1988, the last year when a full survey was conducted, there were 4,175 companies producing construction sand and gravel operating 5,687 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 26 operations reporting more than 2.0 million tons each in 1988 represented only 0.4% of the total number of operations, but produced 9.5% of the total tonnage, while 95 operations reporting between 1 and 2 million tons each, representing only 1.6% of the total number of operations, produced 13.6% 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—1,109 operations, representing 19.5%, produced 50.3% of the total tonnage.

The leading companies producing construction sand and gravel, in descending order of tonnage, based on the 1988 survey, were CalMat Co. of Los Angeles, CA; Beazer U.S.A. Inc. of Pittsburgh, PA; ARC America Corp. now CSR Ltd., of Sydney, Australia; Granite Construction Co. of Watsonville, CA; and Dravo Corp. of Kenner, LA. The top 5 companies operated 118 pits and produced 10% of the U.S. total. Two of these five companies are subsidiaries of foreign companies. Many producers are in the sand and gravel business exclusively, but others are diversified in various degrees in the production of other mineral raw materials, intermediate construction products such as ready-mixed concrete and concrete blocks, final manufactured products, or construction of buildings, roads, and other structures. At the same time, construction companies are entering more and more into the sand and gravel business to integrate their operations.

Geology-Resources

The processes of formation and deposition impart to sands and gravels the physical characteristics that largely determine the commercial value for a particular use and influence the manner of development. The principal types, based on origin, are stream, glacial, residual, marine, and lake. Windblown deposits are of minor importance. Much of the commercial production is from stream deposits, many of which are deficient in the fines required by present-day grading specifications for concrete aggregates. Stream deposits usually exhibit stratification and often large size gradation. The beds vary in thickness and sometimes have interspersed lenses of clay or fine sand. The degree of roundness and the particle size varies with the hardness and distance transported. Glacial deposits have the least sorting of all transported deposits, while marine and lake deposits exhibit the best sorting with coarse and fine particles, often well segregated. Residual deposits are found overlying the parent rock and are unstratified mixtures of pebbles, boulders, sand, and clay. They often contain much soft material that prohibits commercial production. Marine or offshore deposits could become more important as inland deposits become depleted or environmentally less desirable to extract. A comprehensive report showing geologic occurrences of potential sources of sand and gravel and crushed stone of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.[9]

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, unit-

ized plants for versatility of plant capacity, new prospecting methods utilizing aerial and geophysical surveying methods, and greatly increased rehabilitation and resale of mined areas. Use of mined-out pits as lake beds and as sanitary landfill areas has been successful at numerous localities. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations; these, along with the use of improved equipment, have permitted recovery of salable fractions from deposits previously considered too low in quality for profitable exploitation. These practices will increase as pressures build to increase productivity and minimize environmental conflicts.

Exploration.—Sand and gravel deposits, like any mineral deposit, must be explored and evaluated before development. Preliminary examination can establish the extent and nature of the deposits. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information on the quantity of material available, the degree of uniformity throughout the deposit, and especially, variations in particle size, both vertically and horizontally. Also, the nature and amount of waste materials and the economic feasibility of their removal must be studied.

Geophysical methods are of value in preliminary surveys. Detailed exploration may be achieved by a systematic arrangement of test pits, trenches, boreholes, or other procedures designed to obtain a cross section of the deposit in conjunction with sampling and testing. Advances in interpretation of aerial photographs and increased application of geophysical techniques have made evaluation of sand and gravel deposits more quantitative. For underwater exploration, mining devices such as dredges and draglines are used. Pilot runs are necessary to determine if required specifications can be met consistently and economically.

Much of the sand and gravel that is being mined in stream, flood plain, alluvial fan, riverbeds and terrain, and glacial deposits is good quality material with nearly equal amounts of gravel and sand and small amounts of unusable material. As these deposits become depleted in future years, less desirable and more expensive sources will have to be developed where mining, reserves, ratio of sand to gravel, quality of material, waste factors, and environmental factors such as waste disposal will present more problems.

Exploration and planning will become more important in assessing deposits, particularly hillslope deposits of older sand and gravel. Grading to meet required slope and setback requirements at hillslope sites may necessitate leaving large tonnages of material unmined. Many millions of tons of material are available, but it may not be of proper quality or ratio of sand to gravel. More deposits of marginal quality will have to be developed to provide for future demand.

Mining.—Sand and gravel generally occur in the same deposit, but the relative proportions of each vary greatly within most deposits. Consequently, the control problem of producing aggregate to rigid specifications involves combinations of many types of equipment like screens, washers, classifiers, crushers, and grinding mills. The two basic sand and gravel mining methods are open pit excavation and dredging. Open pit excavation and processing has four major steps: (1) site clearing—removing trees and vegetation, stripping overburden and topsoil, and transporting, redepositing, or stockpiling it at or off the site; (2) mining—removing the sand and gravel from the deposit; (3) processing—screening, washing, crushing, blending, and stockpiling the mined material to conform to standards and specifications; and (4) reclamation of the extraction area. Processing may or may not take place at the mining site. Mining equipment ranges from small, simple units such as tractor-mounted high-loaders and dump trucks to more sophisticated systems involving large power shovels, draglines, bucketwheel excavators, and belt conveyors. Increasingly, mining systems are being designed to provide for more efficient and economical land reclamation.

Mining with a dredge usually involves mounting the equipment on boats or barges. Suction or bucket-type dredges are used most commonly to harvest sand and gravel from the bottom of a body of water. The sand and gravel is processed either on board or transported to land for processing.

Processing.—Although small amounts of unprocessed bank-run sand and gravel are used for fill, most of the U.S. production is processed in some way. Present methods include washing with water during the screening process, in some cases followed by crushing of the larger particles in cone or gyratory crushers. Secondary crushing may be done by roll crushers. Sizing is done, in most plants by horizontal or sloped single or multideck vibratory screens. If necessary, heavy-media separation or jigging is used to remove heavy, unusable materials. Sand for use in construction is freed from clay by log washers or rotary scrubbers. The scrubbing is followed by classification, use of separatory cones or hydroseparators to remove water, and fine screening for grading. Rodmilling is often required for production of small-sized fractions of sand. Transfer of processed sand and gravel from the processing plant to stockpiles or bins is accomplished by flexible combinations of conveyor belts, bucket elevators, and screw conveyors.

Permanent installations are built when large deposits are to be operated for many years. Portable and semiportable units are used in many pits that have an intermediate working life. Several such units can be tied together to obtain large initial production capacity or to add capacity as needed. Mobile screening plants can be quickly moved from one deposit to another without undue interruption or loss of production.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Local scarcity or high cost of construction aggregates in some areas as well as waste disposal problems are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement, and also because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will

require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.[10] 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. Modernization, automation at newer, larger plants, and competition from crushed stone have helped to keep production costs and prices from escalating. Constant dollar prices are expected to rise in the future because of decreased deposit quality and more stringent environmental and land use regulations.

Accessibility is a problem for the construction sand and gravel industry. The high-volume and low-unit value of sand and gravel requires that operations be close to the market location. Markets for sand and gravel are construction sites that are mostly in areas of high population density. New operations, close to population centers, are difficult to develop because the land is often attractive for other uses such as housing, shopping centers, agriculture, parks or recreational areas, and because of public dislike for mining operations close to populated areas. Existing operations in expanding communities face increasing costs because of increasing land values and increasing restrictions on operations as suburban development comes closer. Deposits are often small and, once exhausted, the operation must be moved to a new site that invariably is farther from the market because closer sites are being used for other purposes.

The industry also faces increasing competition from crushed stone that can substitute for sand and gravel in most of its applications. Stone operations are generally longer-lived, can afford greater capital investment for higher efficiency, and are often located where competing land use pressures are less severe. The topographically rugged stone-bearing areas are usually less desirable for construction purposes than sand-and-gravel-bearing areas, which are generally flatter.

Depletion Provisions.—A 5%-depletion allowance based on gross income is allowed for construction sand and gravel. There are no import tariffs.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a sand and gravel company owns or leases land within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines or regulations of the appropriate governmental agency must also be approved. Environmental concerns such as noise, dust, beautification, and storage of wastes must be accounted for in a manner satisfactory to the governmental entity involved. Wastewater discharge requirements must be planned for and met. If the deposit to be worked is on a river or land controlled by a river or water or flood control agency, whether municipal, State, or Federal, that agency's requirement must also be satisfied.

In most States, permits for sand and gravel operations require an Environmental Impact Report (EIR) or Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Two main points are involved in environmental land use and reclamation factors. First, the industry must be concerned about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution; to reclaim pits after the operation is complete; and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards.

Because sand and gravel is a local commodity, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of sand and gravel into the marketplace. Also, stringent controls by the local government that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of sand and gravel into the marketplace.

Although much progress is being made through premining planning, the sand and gravel industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas. Major environmental considerations that must be dealt with in mining and processing sand and gravel are emission of particulate matter into the air, processing water discharge, noise abatement, and employee and public health and safety.

Transportation.—Transportation is a major factor in the delivered price of construction sand and gravel. The cost of moving construction sand and gravel from the plant to the market often exceeds the sales price of the product at the plant. Because of the high cost of

transportation, construction sand and gravel continues to be marketed locally. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the construction sand and gravel industry. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of sand and gravel, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable or down. Rail and water transportation combined account for about 10% to 20% of total construction sand and gravel shipments.

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INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

Mr. Bolen, a physical scientist, is a graduate of the University of Virginia and has been the commodity specialist for industrial sand and gravel since October 1988. Domestic survey data were prepared by Howard L. Sullivan, mineral data assistant, and the international production table was prepared by William Zajac, Chief, Branch of Geographic Data.

Production of industrial sand and gravel in 1989 increased to 29.2 million tons, about a 3% increase over that of 1988. Production increased for the third consecutive year and was attributable to increased silica usage for fiber and specialty glasses, chemicals, roofing granules, and hydraulic fracturing (frac sand).

Exports of silica sand and gravel increased about 94% in quantity and 31% in average value per ton, compared with that of 1988. Imports of industrial sand and gravel decreased about 19% in quantity, but the associated value increased 7%. Domestic apparent consumption of industrial sand and gravel in 1989 was 27.2 million short tons, a small decrease from 1988.

Domestic production data for industrial sand and gravel were developed by the Bureau of Mines from voluntary surveys of U.S. producers. Of the 160 industrial sand and gravel operations surveyed, 153 (96%) reported to the 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 160 operations, 153 (96%) were active and 7 idle.

LEGISLATION AND GOVERNMENT PROGRAMS

The Department of Labor's Mine Safety and Health Administration (MSHA) issued a proposed rule titled "Air Quality, Chemical Substances, and Respiratory Protection Standards" on August 29, 1989. A section of the proposed rule would revise standards for air quality at metal-nonmetal mines.

For silica, the revision proposed accepting a 0.1 milligram per cubic meter (mg/m^3) of respirable silica (quartz) exposure limit in place of the former formula that measured and limited exposure. This change did not effectively alter the standard but rather conformed the silica exposure limit to the format used for all other hazardous dusts. For cristobalite and tridymite, the less common forms of silica (SiO_2), the proposed exposure limit was 0.05 mg/m^3. Additionally, the proposed rule reviewed current standards on dust control and detailed the use and maintenance of respirators.[1]

ISSUES

A major issue of concern for the silica industry revolved around the 1986 International Agency for Research on Cancer (IARC) findings that there was limited evidence that silica is a carcinogen to humans. A hazard communication statement was required by the Occupational Health and Safety Administration (OSHA) because respirable silica is known to induce silicosis, a noncancerous lung disease, and is considered a probable carcinogen. This meant that employers must inform and train their employees about the proper handling of silica due to its potential hazards.

Additionally, MSHA recommended that producers label products that contain respirable silica to alert their customers of the hazards associated with silica. Many producers have begun this practice, and training of employees has been regular and continuous at most operations. The greatest concern for producers of silica was negative reaction from consuming industries and

TABLE 1

SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS[1]

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
Sold or used:					
Sand:					
Quantity	29,070	26,940	27,380	27,207	27,819
Value	$370,730	$354,460	$357,660	$376,202	$395,807
Gravel:					
Quantity	357	484	631	1,272	1,385
Value	$3,340	$4,853	$6,424	$11,796	$14,388
Total industrial:[2]					
Quantity	29,430	27,420	28,010	28,480	29,205
Value	$374,070	$359,300	$364,100	$388,000	$410,200
Exports:					
Quantity	866	849	758	1,060	2,060
Value	$22,580	$20,363	$21,253	$30,843	$78,308
Imports for consumption:					
Quantity	81	88	104	43	35
Value	$1,513	$1,014	$1,071	$1,918	$2,057

[1] Puerto Rico excluded from all industrial sand and gravel statistics.
[2] Data may not add to totals shown because of independent rounding.

possible additional restrictive legislation and penalties from MSHA and OSHA.

PRODUCTION

The Midwest (East and West North Central regions) continued to lead the Nation in production with about 42% of the 29.2 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 14%. Compared with 1988, the output of industrial sand and gravel increased 5% in the South and 3% in the Midwest, but decreased 4% in the Northeast (Middle Atlantic and New England regions) while the West's production increased slightly.

Based on the 1988 census estimations on population, 1989 U.S. per capita industrial sand and gravel production was 0.12 ton. Per capita production by major geographic region was 0.21 ton in the Midwest, 0.12 ton in the South, 0.08 ton in the West, and 0.05 ton in the Northeast.

The five leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, Michigan, California, New Jersey, and Texas. Their combined production represented 46% of the national total. Significant changes within the five major producing States included Illinois, where production increased 6%, and Michigan, where production decreased by 6%.

The Bureau of Mines canvassed 87 producers of industrial sand and gravel with 153 active operations. About 75% of the industrial sand and gravel was produced by 46 operations, each with

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1989, BY GEOGRAPHIC REGION

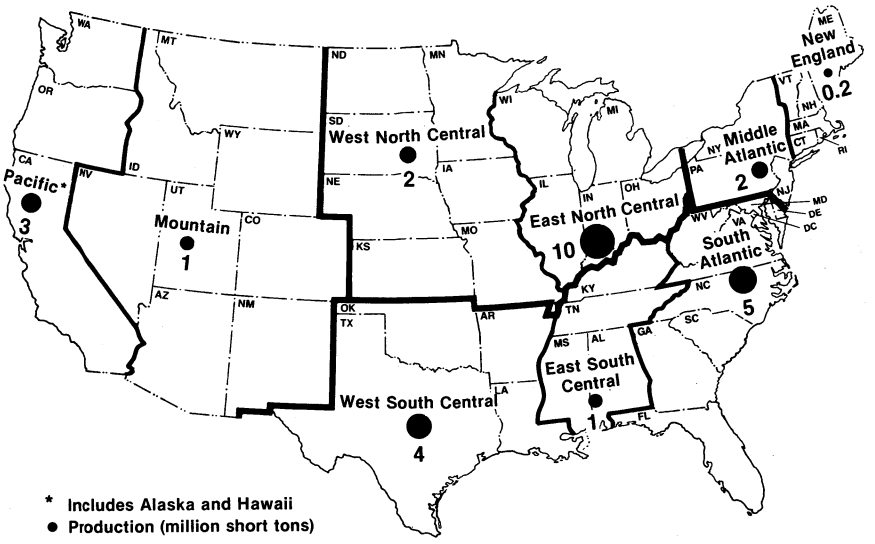

TABLE 2

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1988				1989			
	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	159	1	$4,254	1	154	1	$4,193	1
Middle Atlantic	2,579	9	36,052	9	2,475	8	36,478	10
Midwest:								
East North Central	10,447	37	124,020	32	10,488	36	124,955	30
West North Central	1,595	5	22,701	6	1,881	6	27,108	7
South:								
South Atlantic	4,414	15	65,770	17	4,715	16	71,242	17
East South Central	1,380	5	14,688	4	1,446	5	16,571	4
West South Central	3,885	14	55,595	14	3,994	14	62,589	15
West:								
Mountain	1,272	4	17,607	5	1,315	5	17,657	4
Pacific	2,748	10	47,311	12	2,737	9	49,402	12
Total[1]	28,480	100	388,000	100	29,205	100	410,200	100

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

TABLE 3

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY STATE

(Thousand short tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Alabama	871	8,507	805	8,092
Arizona	119	3,045	W	W
Arkansas	669	6,784	545	5,507
California	2,444	42,078	2,426	43,863
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	636	6,928	681	7,768
Georgia	W	W	537	7,013
Idaho	483	5,089	459	5,037
Illinois	4,328	56,142	4,582	52,935
Indiana	362	1,829	W	W
Kansas	W	W	230	2,690
Kentucky	—	—	W	W
Louisiana	318	4,786	572	9,664
Maryland	W	W	W	W
Massachusetts	W	W	34	601
Michigan	3,045	27,150	2,865	24,577
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	744	9,876	750	9,972
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	602	W	718	W
New Jersey	1,860	25,437	1,797	26,138
New York	53	625	53	633
North Carolina	1,246	15,953	1,627	19,902
Ohio	1,361	23,441	1,394	24,662
Oklahoma	1,268	17,381	1,216	18,310
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	859	15,271	842	16,635
Tennessee	W	W	W	W
Texas	1,631	26,645	1,661	29,107
Utah	3	60	3	60
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,351	15,458	1,514	22,399
Other	4,228	75,513	3,891	74,630
Total[1]	28,480	388,000	29,205	410,200

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

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., Manley Brothers of Indiana, Badger Mining Corp., Oglebay Norton Co., Construction Aggregates Corp., Simplot Industries, Inc., and W. R. Bonsal and Co. Their combined production, from 59 operations, represented 71% of the U.S. total.

Green River Silica Co. in Hart County, KY, began operations in 1989 and produced sand for blasting, filtration, and golf courses.

U.S. Silica, based in Berkeley Springs, WV, purchased Card Silica Co., IN, and after renovations expected to begin production in early 1990.

Bonsal, Lilesville, NC, a major producer of industrial gravel for the production of silicon metal, neared completion of another lump silica production facility at Beech Island, SC. The rural dredging operation was located near the Savannah River and Augusta, GA.

The Monterrey City Council refused to renew a mining permit for Monterrey Sand Co., Monterrey County, CA; and, after 46 years of production, the operation ceased activities at its Sand City and Marina beaches locations.

Manley Brothers ceased its operation at Michigan City, IN, because it was unable to obtain additional adjacent reserves as a result of high property costs in the area.

Additionally, 11 small producers of silica sand for industrial uses either ceased operations or moved out of industrial sand production and became solely construction sand producers.

CONSUMPTION AND USES

Sand and gravel production reported by producers to the 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 29.2 million tons of industrial sand and gravel sold or used, 42% was consumed as glassmaking sand and 24% as foundry sand. Other important uses were abrasive sand (8%) and frac sand (5%). Because some producers

did not report a breakdown by end use, their total production as well as the estimated production for nonrespondents were included in "Other uses, unspecified," which represented about 3% of the U.S. total.

On the regional level, more than one-third of the glassmaking sand was produced in the South (38%), followed by the Midwest (29%), and the West (18%). Three-fourths of the foundry sand was produced in the Midwest (75%). About three-fourths of the hydraulic fracturing sand was produced in the Midwest (74%), and about one-half of the abrasive sand was produced in the South (51%).

Northeast

Cumberland County, NJ, continued to be the largest source for the glass, foundry, and blast 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 produced a major percentage of the abrasive blast sand in the region.

Midwest

Unimin's plants in LaSalle and Ogle Counties, IL; LeSueur County, MN; and Columbia County, WI; were among the leaders in producing sand for the glass, foundry, frac sand, and blasting markets. Fairmount Minerals, operating plants in Geauga County, OH, and La Salle County, IL, was a major producer for the foundry and glass markets in the region. U.S. Silica's plant in La Salle County, IL, and Badger Mining's plant in Jackson County, WI, were large producers for the glass and frac sand markets, respectively. Construction Aggregates Corp. in Ottawa County, MI, and Manley Brothers in Van Buren County, MI, were major producers of foundry sand in the region. Unimin's Ogle County and Badger Mining's Green Lake County operations 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; and Johnston County, OK, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL, and Tennessee plants were large producers of foundry and glass sand, respectively, in the region. Pioneer Concrete of Texas, Inc., Southern Silica of Louisiana, Specialty Sand Co., LA, and Foster-Dixianna, SC, produced the bulk of the blasting sand. Bonsal and B. V. Hedrick Sand and Gravel, both in Anson County, NC, produced most of the industrial gravel used in the processing of silicon and ferrosilicon. Bonsal also produced large quantities of material for roofing granules.

West

Owens-Illinois, Simplot Industries, and Unimin were the three largest pro-

TABLE 4

INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1989, 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	26	17.0	280	1.0
25,000 to 49,999	24	15.6	879	2.9
50,000 to 99,999	26	17.0	1,888	6.5
100,000 to 199,999	31	20.3	4,385	15.0
200,000 to 299,999	11	7.2	2,765	9.5
300,000 to 399,999	11	7.2	3,880	13.3
400,000 to 499,999	9	5.9	4,231	14.5
500,000 to 599,999	4	2.6	2,217	7.6
600,000 to 699,999	4	2.6	2,525	8.6
700,000 and over	7	4.6	6,154	21.1
Total	153	100.0	[1]29,205	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 1989, BY GEOGRAPHIC REGION

Geographic region	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No plants or unspecified		
Northeast:						
New England	3	—	—	1	—	4
Middle Atlantic	5	—	2	1	6	14
Midwest:						
East North Central	33	1	1	—	2	37
West North Central	7	—	—	—	4	11
South:						
South Atlantic	17	—	—	3	6	26
East South Central	11	—	—	—	2	13
West South Central	12	—	—	2	10	24
West:						
Mountain	7	2	—	—	1	10
Pacific	11	—	—	1	2	14
Total	106	3	3	8	33	153

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1989, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand:															
Glassmaking:															
Containers	1,276	$17,148	$13.44	2,013	$16,876	$8.38	2,769	$32,595	$11.77	1,800	$30,164	$16.76	7,858	$96,782	$12.32
Flat (plate and window)	W	W	13.54	844	8,304	9.84	1,299	15,501	11.93	W	W	14.66	2,589	30,198	11.66
Specialty	W	W	15.15	387	6,419	16.59	W	W	14.71	7	131	18.71	762	12,049	15.81
Fiberglass (unground)	W	W	10.76	302	3,837	12.71	W	W	25.62	105	1,681	16.01	837	15,539	18.57
Fiberglass (ground)	—	—	—	W	W	15.08	W	W	31.88	W	W	20.89	247	6,463	26.17
Foundry:															
Molding and core	430	6,196	14.41	5,095	51,864	10.18	1,093	12,443	11.38	131	2,273	17.35	6,749	72,776	10.78
Molding and core facing (ground)	—	—	—	W	W	26.93	—	—	—	—	—	—	W	W	26.93
Refractory	W	W	5.40	330	1,942	5.88	—	—	—	W	W	33.00	336	2,002	5.96
Metallurgical:															
Silicon carbide	—	—	—	W	W	11.70	—	—	—	—	—	—	W	W	11.70
Flux for metal smelting	—	—	—	W	W	6.96	W	W	3.83	13	80	6.15	45	285	6.33
Abrasives:															
Blasting	212	4,184	19.74	446	6,653	14.92	1,175	22,590	19.23	455	8,763	19.26	2,287	42,190	18.45
Scouring cleansers (ground)	W	W	32.50	W	W	25.68	W	W	56.00	—	—	—	W	W	26.51
Chemicals (ground and unground)	W	W	27.33	376	3,073	8.17	338	5,211	15.42	W	W	16.18	817	10,580	12.95
Fillers (ground):															
Rubber, paints, putty, etc.	25	711	28.44	55	3,512	63.85	71	6,095	85.85	8	136	17.00	159	10,454	65.75
Silica flour	—	—	—	W	W	27.11	W	W	24.14	—	—	—	68	1,781	26.19
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	41.10	132	3,898	29.53	94	3,150	33.51	W	W	39.00	238	7,537	31.67
Filtration	89	1,619	18.19	W	W	23.50	152	2,662	17.51	W	W	27.42	310	6,033	19.46
Traction (engine)	37	152	4.11	185	1,650	8.92	66	661	10.02	23	439	19.09	311	2,902	9.33
Coal washing	—	—	—	W	W	28.36	—	—	—	—	—	—	W	W	28.36
Roofing granules and fillers	W	W	34.24	89	1,242	13.96	561	8,067	14.38	W	W	21.26	790	13,453	17.03
Hydraulic fracturing	—	—	—	1,126	25,430	22.58	W	W	21.97	W	W	27.22	1,531	34,494	22.53
Other uses, specified	551	10,437	18.94	576	12,163	21.12	1,313	27,756	21.14	1,095	19,910	18.18	XX	XX	XX

See footnotes at end of table.

TABLE 6—Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1989, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton	Quantity (thousand short tons)	Value (thousands)	Value per ton
Sand—Continued															
Other uses, unspecified[2]	W	W	$27.00	223	2,802	$12.57	450	5,388	$11.97	W	W	$20.07	810	10,940	$13.51
Total[1] or average	2,620	40,449	15.44	12,178	149,662	12.29	9,382	142,119	15.15	3,638	63,577	17.48	27,819	395,807	14.23
Gravel:															
Metallurgical:															
Silicon, ferrosilicon	—	—	—	W	W	10.00	W	W	11.13	—	—	—	758	8,295	10.94
Filtration	8	W	W	W	W	8.33	W	W	9.03	—	—	—	48	591	12.31
Nonmetallurgical flux	—	—	—	—	—	—	W	W	8.78	W	W	8.43	508	4,311	8.49
Other uses, specified	—	—	—	190	W	W	772	8,282	10.73	414	3,481	8.41	XX	XX	XX
Total[1] or average	8	W	W	190	W	W	772	8,282	10.73	414	3,481	8.41	1,385	14,388	10.39
Grand total[1] or average	2,629	W	W	12,369	W	W	10,155	150,401	14.81	4,053	67,059	16.55	29,205	410,200	14.05

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.

ducers of glass sand in the region, with major operations in Amador County, CA; Clark County, NV; and Contra Costa County, CA; respectively. Corona Industrial Sand Co., Riverside County, CA, supplied the majority of sand for the sand blasting industry in the region. Simplot Industries also supplied a large portion of the foundry sand consumed.

TRANSPORTATION

Of the total industrial sand and gravel produced, 58% was transported by truck from the plant to the site of first sale or use, up from 56% in 1988; 34% was transported by rail, unchanged from 1988; 3% by waterway, down from 4% in 1988: and 5% not transported, down from 6% in 1988. Because most of the producers did not report shipping distances or cost per ton per mile, no transportation cost data were available.

FIGURE 2

SAND USED IN SELECTED END USES, 1989

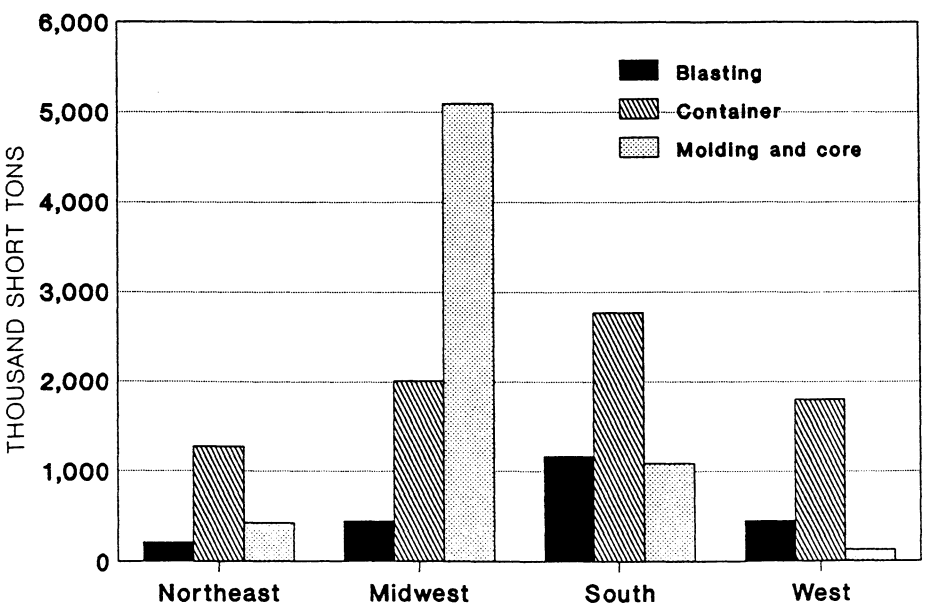

TABLE 7

TRANSPORTATION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1989 TO SITE OF FIRST SALE OR USE

Method of shipment	Quantity (thousand short tons)	Percent of total
Truck	16,863	58
Rail	9,949	34
Waterway	825	3
Not transported	1,568	5
Total	29,205	100

PRICES

Compared with 1988, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased nearly 3% to $14.05 per ton. Average unit values for industrial sand and industrial gravel were $14.23 and $10.39 per ton, respectively. Nationally, industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($65.75), followed by silica sand used in ceramics ($31.67), coal washing ($28.36), molding and core facings ($26.93), scouring cleansers ($26.51), silica flour ($26.19), and fiberglass (ground) ($26.17).

The average value per ton of industrial sand was highest in the West ($17.48), followed by the Northeast ($15.44), the South ($15.15), and the Midwest ($12.29). Glass sand average value per ton varied markedly, from $16.50 in the West to $10.11 in the Midwest. Tighter supplies and higher production and transportation cost in the West increased the cost of sand and gravel in this region.

FOREIGN TRADE

Exports

Exports of industrial sand, compared with 1988, increased 94% to 2,060,000 tons, and the value increased 154% to $78.3 million. Of this, 51% went to Canada, 21% went to the Netherlands, 7% went to Japan, and the remainder went to numerous other countries throughout the world.

TABLE 8

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bahamas	6	58	(2)	30
Canada	790	11,260	1,054	11,374
Mexico	67	2,284	40	1,631
Panama	5	86	1	34
Other	26	501	5	642
Total[3]	893	14,189	1,100	13,709
South America:				
Argentina	(2)	51	(2)	137
Chile	2	450	4	275
Colombia	1	105	5	54
Ecuador	7	176	(2)	194
Peru	14	747	8	214
Venezuela	3	296	15	184
Other	1	152	6	386
Total[3]	29	1,977	39	1,445
Europe:				
Belgium	15	974	37	937
Finland	2	48	1	22
France	1	222	1	86
Germany, Federal Republic of	8	1,006	62	1,805
Italy	6	654	2	672
Netherlands	12	4,737	426	2,850
United Kingdom	12	579	90	2,116
Other	2	424	4	607
Total[3]	57	8,643	622	9,095
Asia:				
Indonesia	6	662	9	476
Japan	9	1,407	148	47,723
Korea, Republic of	6	424	50	1,687
Malaysia	15	298	(2)	35
Singapore	19	1,514	45	2,232
Taiwan	10	493	9	507
Other	7	373	8	665
Total[3]	71	5,172	270	53,324
Middle East and Africa:				
Saudi Arabia	(2)	16	(2)	9
South Africa, Republic of	5	259	(2)	27
United Arabic Emirates	2	123	(2)	4
Other	2	191	2	274
Total[3]	9	588	2	314
Australia	1	241	25	356
Oceania	(2)	33	(2)	64
Grand total[3]	1,060	30,843	2,060	78,308

[1] Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Imports

Compared with 1988, imports for consumption of industrial sand decreased 19% to 35,000 tons valued at $2.1 million. Of this, 91% came from Australia and 6% came from Japan. Small amounts of specially prepared silica sand from Canada, the Federal Republic of Germany, France, Japan, Mexico, and the United Kingdom sold for very high values per ton.

TABLE 9

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

(Thousand short tons and thousand dollars)

Country	1988		1989	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua	36	264	—	—
Australia	(2)	874	32	874
Canada	1	47	1	191
Germany, Federal Republic of	(2)	556	(2)	240
Japan	(2)	2	2	262
United Kingdom	(2)	27	1	60
Other	5	147	(2)	430
Total[3]	43	1,918	35	2,057

[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.

WORLD REVIEW

World production of industrial sand and gravel, based on information usually provided by foreign Governments, was estimated to be 137.5 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

Research related to the industrial sand and gravel industry continued to advance on many fronts. Newly fabricated materials, including chemicals, ceramics, and other related materials, provided new markets for silica producers while simultaneously placing more stringent requirements on silica as a raw material.

During 1989, several articles were centered on the use of silicon nitride (Si_3N_4), a ceramic, for engine components. Si_3N_4 components had begun to replace traditional metals in engines, functioning in many applications, including turbocharger rotors, valves, and ball bearings. Advantages of Si_3N_4 included improved durability, lower wear and friction, increased fuel efficiency, and greater impact resistance. As materials and production costs come down, usage of Si_3N_4 and other ceramics, such as silicon carbide, could become commonplace.[2 3]

Advances in glass melting technologies will be necessary for the glass industry to remain competitive with alternate materials. Partially funded by the Department of Energy (DOE), Air Products and Chemicals, Allentown, PA, experimented with using oxygen in place of air to improve the efficiency of the furnaces used in glassmaking. Improved efficiency was realized because oxygen raises the flame temperature and minimizes heat losses to the flue.[4] Additionally, KTG Glassworks Technology Inc., Pittsburgh, PA, worked to improve thermal efficiency through the use of segmented furnaces. The system, called Seg-Melt, maintained the separate processing of batch and cullet at the furnace. According to KTG, this method will cut the cost of container glass by 11%.[5]

The DOE continued work on the Defense Waste Processing Facility near Aiken, SC. The operation will use a vitrification process to secure waste of radioactive liquid plutonium by fusing the waste with borosilicate particles to form a glass. The glass will be poured into stainless steel canisters and then sealed before being moved to the glass waste storage building. Eventually the canisters will be stored in the DOE's permanent underground waste facility at Yucca Mountain, NV. Commencement of the process was scheduled for 1992 and should continue for at least 20 years.[6 7]

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

TABLE 10

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	12,513	11,452	9,974	10,455	10,470
Australia	2,304	2,305	2,602	2,170	2,210
Austria	810	880	754	833	830
Belgium	2,169	2,275	2,500	2,690	2,900
Brazil	2,409	3,019	2,829	2,880	2,980
Canada	2,106	2,911	2,934	2,987	3,000
Chile[e]	330	330	330	330	330
Cuba	708	546	571	[e]610	610
Denmark	2	2	[e]2	2	2
Ecuador[e]	55	55	55	55	55
Egypt[3]	[e]140	[e]140	257	38	37
Finland	246	256	257	300	300
France	6,076	5,878	8,236	[e]8,250	8,250
Germany, Federal Republic of	7,739	7,228	6,755	6,386	6,600
Greece[e]	40	40	40	45	45
Guatemala	25	25	34	35	34
Hungary	617	572	696	714	720
Iceland	5	4	5	[e]5	13
India	3,368	1,856	4,173	2,671	3,420
Ireland	7	7	6	7	8
Italy	4,850	4,630	4,740	4,740	4,960
Jamaica	18	14	22	14	17
Japan	4,836	4,327	4,291	4,630	[4]4,826
Kenya	([3])	([3])	([e 5])	([e 5])	[4]12
Korea, Republic of	1	1	1	2	2
Luxembourg	2	—	—	—	—
Mexico	1,630	977	1,065	1,021	[4]1,137
Netherlands	22,033	25,178	24,553	28,659	28,270
New Zealand[e]	55	55	55	[4]61	60
Norway[e]	855	880	880	880	880
Pakistan	223	127	164	148	140
Paraguay	1,653	2,094	2,111	2,105	2,105
Peru	2,096	5,343	8,833	[e]5,510	5,510
Philippines	[e]165	[e]165	185	281	240
Portugal[e]	6	6	6	6	6
South Africa, Republic of	1,673	1,824	2,135	2,216	[4]2,405
Spain	2,507	2,888	1,707	2,205	2,205
Sweden[e]	760	770	770	770	770
Tanzania	10	10	7	13	10
Thailand	168	169	169	267	270
Turkey	399	[e]420	438	[e]440	440
United Kingdom	4,605	4,528	3,599	4,740	4,630
United States (sold or used by producers)	29,430	27,420	28,010	28,480	[4]29,205
Venezuela[e]	3,750	3,860	4,200	4,200	4,200

See footnotes at end of table.

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 auto makers 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 1989, surging to over 1.5 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, the Bahamas, 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 were located. A significant amount of silica sand was also produced in the West and Southwest, mostly in Califor-

TABLE 10—Continued

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Yugoslavia	2,905	2,939	2,379	2,231	2,320
Zimbabwe	113	159	45	61	[4]68
Total[6]	126,413	128,566	133,375	135,143	137,501

[e] Estimated. [p] Preliminary.
[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.
[6] Data may not add to totals shown because of independent rounding.

nia 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 were expected to continue. This will enhance development of lower grade silica sand deposits located closer to markets but not presently mined. Such developments were expected to increase silica sand reserves.

BACKGROUND

Probably no other nonmetallic mineral has more diversified uses than silica 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. 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 around 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 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 1989, a total of 29.2 million tons of silica sand was produced in the United States for a variety of uses, of which 12.3 million tons was for glassmaking. Today, glass has become an invaluable product with a multitude of forms and applications.

TABLE 11

TIME-PRICE RELATIONSHIP FOR SILICA SAND

Year	Average annual price, dollars per ton, f.o.b. quarry	
	Actual price	Based on constant 1988 dollars
1970	$3.47	$10.02
1971	3.49	9.53
1972	3.81	9.94
1973	3.80	9.31
1974	4.83	10.85
1975	5.50	11.25
1976	5.70	10.96
1977	6.82	12.29
1978	7.65	12.85
1979	8.57	13.23
1980	9.98	14.13
1981	11.15	14.39
1982	12.03	14.59
1983	12.63	14.75
1984	12.92	14.55
1985	12.75	13.95
1986	13.16	14.03
1987	13.06	13.49
1988	13.83	13.83
1989	14.23	13.67

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 and are retained on a No. 200 mesh (0.0029-inch) sieve, and are the result of natural disintegration or comminution of cemented rock. Industrial sand or silica sand is the term used by the industry for sands that have a very high percentage of silicon dioxide (SiO_2), and are essential materials in glass manufacture, in ferrous and nonferrous foundry operations, in certain chemical and metallurgical processes, for hydraulic fracturing of oil and gas deposits, and in many manufactured products as fillers or extenders.

Most industrial sands have been named for their specific uses; for example, glass, foundry, abrasive, filler, and hydraulic fracturing sands. Almost invariably these sands, in addition to being high in silica, consist mostly of quartz grains.

TABLE 12

PROJECTIONS AND FORECASTS FOR U.S. INDUSTRIAL SAND, BY END USE, IN THE YEAR 2000

(Million short tons)

End use	1989	Year 2000		
		Forecast range		Probable
		Low	High	
Glass sand	12.3	12.0	16.0	14.0
Foundry sand	7.1	9.0	11.0	9.5
Hydraulic fracturing sand	1.5	1.7	2.7	2.3
Other	8.3	8.0	11.0	10.0
Total	29.2	30.7	40.7	35.8

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%

TABLE 13

TEN-YEAR STATISTICAL DATA FOR INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS, BY SELECTED END USES

(Thousand short tons)

End use	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Glass[1]	12,905	12,078	12,252	9,436	11,341	10,293	10,993	11,873	12,141	12,293
Foundry[2]	9,036	9,948	7,118	6,670	7,239	5,143	5,777	[3]6,932	7,610	[3]7,085
Silicon carbide	156	463	140	94	135	121	W	130	W	W
Flux for metal smelting	141	246	191	74	97	67	46	114	117	45
Abrasive[4]	1,928	1,958	2,208	1,950	2,030	1,681	1,947	[5]1,848	2,113	[5]2,287
Chemicals	456	426	335	271	425	378	317	513	655	817
Fillers	225	284	192	141	200	158	267	394	225	227
Ceramics	148	179	226	179	184	150	198	225	280	238
Filtration	234	249	299	102	217	345	494	433	407	310
Traction (engine)	403	398	450	195	246	292	177	465	305	311
Roofing granules and fillers	203	162	517	296	289	403	261	392	575	790
Hydraulic fracturing	1,177	1,407	1,481	990	2,057	2,102	1,130	1,396	1,299	1,531

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).
[3] Excludes molding and core facings (ground).
[4] Includes blasting, sawing and sanding (1980–82,1984–86), and scouring cleansers (ground).
[5] Excludes scouring cleansers (ground).

should pass a No. 100 screen. Sand for first-quality optical glass should contain 99.8% SiO_2 and a maximum of 0.1% Al_2O_3 and 0.02% 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.[8 9]

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.[10 11]

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.[12]

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 existed 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.

Industry Structure

In 1989, 87 U.S. companies with 153 active operations produced silica sand. 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, including 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; the Tuscarora quartzite of Lower Silurian age in Pennsylvania and Virginia used for the manufacture of refractory bricks; the Sylvania sandstone of Devonian age in the Detroit area; the Oil Creek and McLish formations of Lower Ordovician age in Oklahoma, a southwestward extension of the St. Peter sandstone; and the Hickory sandstone of Cambrian age in central Texas that produced mostly hydraulic fracturing sand.

In the west, the most important sources of industrial sand were the Ione formation of Eocene age in northern California, the Silverado (Paleocene) and Tejon (Eocene) formations in southern California, and the Eureka quartzite of Middle Ordovician age in central California.

Approximately two-thirds of the U.S. industrial sand or silica sand 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 1989 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 in close proximity 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, including the availability of power and water supply, mining and processing costs and requirements, the condition of nearby roads and highways, 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, but 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, if 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.

Beneficiation.—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 proc-

essing 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; and 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 air-blasting 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 closely located markets or go out of business.

Prices.—As a result of rapidly rising costs of labor, energy, and mining and processing equipment, 1988 constant dollar prices of industrial sand rose steadily between 1973 to 1983. From 1984 to 1989, 1988 constant dollar prices fluctuated in the 13.50 to 14.50 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 upon 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 like 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. The largest tonnage, 58% of all industrial sand, was shipped by truck because most users require a versatile and rapid delivery system. Substantial quantities, 34% of the total, were also shipped by rail, especially when large volumes were sent long distances.

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SELENIUM AND TELLURIUM

By Daniel Edelstein

Mr. Edelstein is a physical scientist (geologist) with more than 15 years of combined experience working for the Bureau of Mines in minerals processing research, process evaluation, and mineral commodities. He has been a commodity specialist for selenium, tellurium, and copper for 7 years.

Domestic demand for selenium and tellurium declined in 1989 owing to weakness in demand for selenium used in photoreceptors and tellurium used in ferroalloys. The apparent world demand for selenium increased, and that for tellurium remained unchanged. World demand for selenium continued to be strong and stocks of refined selenium declined. However, prices continued to fall from the high level experienced in 1987. World production and shipments of tellurium were nearly balanced, and the price for refined tellurium was essentially unchanged throughout the year.

TABLE 1

SALIENT SELENIUM AND TELLURIUM STATISTICS

(Kilograms of contained metal unless otherwise specified)

	1985	1986	1987	1988	1989
SELENIUM					
United States:					
Production, primary refined	W	W	W	285,633	253,427
Shipments to consumers	W	W	W	260,838	294,672
Exports, metal, waste and scrap	154,122	161,007	162,217	243,096	372,126
Imports for consumption	400,658	462,646	495,862	474,234	[1]417,095
Apparent consumption, metal[2]	W	W	W	[r]590,000	560,000
Stocks, yearend, producer[3]	W	W	W	W	W
Dealers' price, average per pound, commercial grade[4]	$7.44	$5.70	$6.51	$9.84	$7.61
World: Refinery production	[r]1,318,391	[r]1,214,645	1,235,663	[p]1,540,538	[e]1,553,285
TELLURIUM					
United States:					
Imports for consumption	33,235	30,721	26,700	76,890	[5]42,871
Exports	—	—	—	—	72,892
Producer price quote, yearend, commercial grade	$10.00	$10.00	$20.00	$35.00	$34.00

[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. 1988 consumption was revised to exclude imports of compounds.

[3]Granular selenium, a semirefined form of selenium, is included in stocks.

[4]Source: Metals Week. Calculated from published price ranges.

[5]Includes only unwrought and waste and scrap.

STRATEGIC CONSIDERATIONS

In August 1987, under contract to the Federal Emergency Management Agency (FEMA), 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 was 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.[1]

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 the Environmental Protection Agency (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.

While selenium is toxic in high doses, it is an essential micronutrient in the diet of humans and livestock. In April 1987, the Food and Drug Administration (FDA), U.S. Department of Health and Human Resources, published new regulations concerning the use of selenium as an additive in feed for major food-producing animals. The new regulations increased the maximum allowable selenium supplementation level in complete animal feed from 0.1 to 0.3 part per million, as well as proportional increases in feed and mineral supplements. Five organizations subsequently filed objections to the 1987 amendments over concern that the environmental impact had not been adequately addressed. The organizations contended that the new limits increased the potential for bioaccumulation or concentration of selenium, thereby creating potential environmental problems, particularly in aquatic ecosystems. In July 1989 FDA published its analysis of the objections to the 1987 rule and invited written comments on its analysis.[2]

In May 1989 EPA reproposed maximum contaminant level goals (MCLGs) and National Primary Drinking Water Standards (NPDWRs) for 38 chemicals including selenium. EPA first proposed new standards in 1985. The MCLG for selenium of 0.05 milligram per liter, unchanged from the new standard proposed in 1985, was five times greater than the existing 0.01 milligram per liter standard. In proposing the new standard, EPA recognized that selenium was an essential micronutrient and that a standard below the proposed level might result in selenium deficiency in the human diet. EPA believed that the proposed standard would adequately balance the potential deficiency and toxicity effects of selenium.[3]

According to the Bevill Amendment to the Resource Conservation and Recovery Act (RCRA) solid wastes from the extraction, beneficiation, and processing of ores and minerals were exempted from regulation as hazardous waste under Subtitle C of RCRA, pending completion of certain studies by EPA. In 1980, EPA interpreted this exemption, on a temporary basis, to include all solid wastes from exploration, mining, milling, smelting, and refining of ores and minerals. However, in July 1988, a Federal Court of Appeals, directed EPA to confine the exclusion to only those special wastes that met certain high-volume and low-hazard criteria. A list published by EPA in April 1989, conditionally retained process wastewater from primary selenium processing within the Bevill exclusion. However, the Notice of Proposed Rulemaking (NPRM), released in September, excluded this waste stream from the list of waste streams being conditionally retained within the Bevill exclusion. A final NPRM was required by mid-January 1990.[4]

A significant operating problem that has affected domestic selenium and tellurium production indirectly has been the control of air pollution at copper smelters. As of January 1988, smelters were to comply with the ultimate control standards for sulfur dioxide emissions as stated in the 1977 amendments to the Clean Air Act of 1970. ASARCO Incorporated decided not to retrofit its Tacoma, WA, smelter with the necessary engineering controls to bring it into compliance with arsenic and sulfur dioxide emissions regulations, and in 1985 closed the smelter. Owing to the high arsenic content of the ores, the Tacoma smelter was the only domestic smelter capable of processing high-selenium-tellurium concentrates imported from the Philippines. Closure of several other noncompliance primary domestic copper smelters further reduced smelting capacity. Consequently, the United States has become a net exporter of copper concentrates, which effectively reduces the potential domestic recovery of byproduct selenium and tellurium.

PRODUCTION

Primary selenium was recovered in the United States at three electrolytic copper refineries: Asarco at Amarillo, TX; Phelps Dodge Refining Corp. at El Paso, TX; and Rio Tinto Zinc Corp. Ltd. (formerly BP Minerals America Corp.) 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.

Domestic production of refined selenium declined despite an increase in primary refined copper production. In the United States most of the increase in refined copper production was from solvent extraction/electrowinning, which precluded recovery of selenium. Domestic shipments of selenium continued to outstrip production, and stocks of refined selenium continued to drop. 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.

About 150 to 200 metric tons of 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 markedly during 1989 in response to a decline in domestic demand. Stocks of semirefined feedstock rose slightly from the low level established in 1988.

CONSUMPTION AND USES

Selenium demand by end use can be divided broadly into five applications: electronics (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 to compensate for the yellow-green tint imparted by ferrous ions. 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 steel, copper, and lead alloys to improve machinability and casting and forming properties.

Domestic demand for selenium in 1989 declined slightly from that of 1989 owing to a decline in photoreceptor demand and to weakness in the automotive industry. Demand for selenium by end use was estimated as follows: Electronics, 35%;

pigments and chemicals, 20%; glass manufacturing, 25%; and other, including agriculture and metallurgy, 20%.

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 machinability. Similarly, the addition of tellurium to copper and other nonferrous alloys improves their machinability, 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.

Apparent domestic demand for tellurium and its compounds, as calculated from production, trade, and stock data, declined markedly. The decrease in apparent demand was largely attributed to reduced shipments to manufacturers of free-machining steels. A drawdown of unreported merchant and consumer inventories, which had been accumulated during 1988, was believed to account for some of the fall-off in calculated demand. Substitution of other free-machining alloys may have been stimulated by the high price of tellurium and environmental concerns over lead, which is used in conjunction with tellurium in some free-machining alloys.

In 1989 iron and steel products remained the largest end use, followed by nonferrous metals, chemicals, and other uses.

PRICES

The merchant price for commercial-grade refined selenium, quoted by Metals Week on a weekly basis, continued to decline during the first 6 months of 1989 before stabilizing during the third quarter at $6.50 to $7.00 per pound. Prices had peaked during the first half of 1988 at about $11.00 per pound. The price decline occurred despite continued strong world demand for selenium and an almost 30% decline in reported world stocks of refined selenium. Significant premiums were charged for higher purity forms of selenium.

The price for commercial-grade tellurium metal remained at or 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 $34 per pound.

FOREIGN TRADE

Imports of selenium metal were at about the same level as in 1988. Though Canada remained the largest source of imports, Canadian imports declined by about 37%. Exports of selenium metal, waste, and scrap rose by over 50%. It is believed that between 200 and 250 tons of that material were either scrap materials for reprocessing, or unrefined anode slimes or residues. Under the Harmonized Tariff System (HTS) adopted in 1989, imports of sodium selenite and other selenium compounds were no longer distinct categories. Similarly, imports of tellurium compounds and salts were no longer distinguishable. Though imports of unwrought tellurium, waste, and scrap, were included with imports of boron metal under the HTS, imports of boron were thought to be negligible.

WORLD REVIEW

World production of refined selenium was at about the same level as in 1988. Despite a decline in apparent demand in the United States, world demand for refined selenium rose slightly and continued to outstrip production. According to data compiled by the American Bureau of Metal Statistics (ABMS), inventories of refined selenium held by reporting companies declined by about 225 tons. However, at the prevailing rate of consumption, yearend inventories of selenium still constituted almost a 6-month supply.

According to ABMS shipment data for market economy countries, the United States was the largest recipient of selenium, followed by the United Kingdom, Japan, the Netherlands, Belgium, and China. Combined, these countries accounted for about 82% of shipments. However, in addition to these shipments, China was believed to consume about 125 tons per year of domestically produced selenium, making it the fourth largest world consumer.

According to ABMS shipment data, world demand for refined tellurium remained at about the same level as in 1988 despite the large decline in U.S. apparent consumption. Supply and demand were balanced and reported world inventories were essentially unchanged.

Capacity

In the past 5 years, annual world selenium production capacity increased by about 200 tons, while that for tellurium remained stable, or could have declined. In North America, selenium production and capacity increased, while that for tellurium decreased. In the United States, closure of AMAX Copper Inc.'s selenium and tellurium refinery in New Jersey was balanced by the opening of the new Phelps Dodge Corp. selenium refinery at El Paso, TX. In 1987, BP Minerals America Corp. reopened its Bingham Canyon operations and associated copper/selenium/precious metals refinery, which had been shuttered since 1985. In Canada, Noranda commissioned a new anode slimes treatment plant in 1988. Canadian production of tellurium declined when the tellurium-rich Horne mine closed in 1987.

In Asia, the Philippines began recovering selenium in 1984 at the new Philippine Associated Smelter and Refining Corp. (PASAR) copper smelter/refinery. Prior to this, Philippine concentrates exported to the United States had been a major source of selenium and tellurium. However, while PASAR recovered selenium, no production of tellurium from the PASAR smelter was reported. International Recoveries Inc. of Manila began producing tellurium dioxide in 1984, and secondary selenium, on a toll basis in 1987. In 1989 it commissioned an electrowinning circuit to produce up to 3 tons of tellurium metal per month. In Europe, Metallurgie Hoboken-Overpelt (MHO) completed expansion of its selenium refinery at its Hoboken operations during 1988. Capacity of the refinery, which processed slimes generated at the Olin refinery, increased from 260 tons per year to 360 tons per year.

CURRENT RESEARCH

The Fourth International Symposium on Uses of Selenium and Tellurium was held on May 8-10 in Banff, Alberta, Canada. More than 60 papers were presented covering environmental health and safety,

TABLE 2

U.S. EXPORTS OF SELENIUM METAL, WASTE, AND SCRAP, BY COUNTRY

Country	1987		1988		1989[1]	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Argentina	998	$10,704	—	—	—	—
Belgium	17,941	140,504	48,299	$365,430	40,650	$658,524
Benin	—	—	—	—	3,614	57,760
Brazil	59	3,250	—	—	362	22,640
Canada	2,772	44,307	2,110	54,872	9,766	161,518
Chile	—	—	—	—	2,040	29,908
China	1,955	28,290	—	—	—	—
Colombia	—	—	5,987	129,809	4,000	52,720
France	1,159	18,526	6,966	111,358	—	—
Germany, Federal Republic of	—	—	23,788	468,050	7,570	81,589
India	—	—	200	6,600	4,186	66,910
Italy	299	4,290	299	4,290	507	5,282
Japan	34,611	270,252	27,746	347,881	86,839	322,632
Korea, Republic of	1,031	21,662	4,049	64,717	998	29,887
Malaysia	—	—	2,654	42,426	—	—
Mexico	30,385	462,450	10,113	161,641	35,921	304,199
Netherlands	7,484	83,160	26,090	452,636	57,308	730,817
Philippines	9,072	6,000	—	—	—	—
Senegal	—	—	—	—	1,664	22,130
Sierra Leone	—	—	—	—	11,035	21,749
Singapore	—	—	—	—	30,623	417,150
Spain	1,014	12,258	427	5,158	1,044	12,461
Tanzania	—	—	—	—	4,097	65,480
Uganda	—	—	—	—	2,891	46,200
United Kingdom	51,246	546,020	79,879	926,756	47,610	235,759
Venezuela	1,814	28,987	412	6,593	—	—
Zaire	—	—	—	—	16,808	44,973
Other	377	5,520	4,077	49,107	2,593	39,136
Total	162,217	1,686,180	243,096	3,197,324	372,126	3,429,424

[1]Under the Harmonized Tariff System begun in Jan. 1989, this category is listed as "selenium."

Source: Bureau of the Census.

photoelectric and photovoltaic applications, catalysis, biology and nutrition, chemical technology, and agricultural applications.[5]

OUTLOOK

World production of refined selenium has fluctuated greatly over the past 10 years. However, the overall trend has been flat, with production over the 10 years averaging about 1,500 tons per year. Meanwhile, world mine and refinery production of copper have increased by more than 10%. Factors leading to a disparity between copper production and refined selenium production include an increasing production of refined copper by electrowinning, which precludes selenium recovery, and shutdowns of mines having a high selenium content in their ores. Perhaps the most important factors leading to the disparity between copper and selenium production trends, have been the effects of selenium price and demand on the rate of recovery of selenium from slimes. During times of weak prices and stagnant demand, selenium refineries, lacking the economic incentive to recover selenium, may stockpile crude selenium intermediates for future refining or may bypass selenium recovery circuits altogether.

The Bureau of Mines forecasts a significant increase in copper mine capacity for the next 5 years. However, as noted above, selenium production over a 10-year period has remained flat and has not followed the upward trend in copper production. If this trend in selenium production continues, and demand remains at the high level of the past 2 years, the current production deficit

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF SELENIUM, BY CLASS AND COUNTRY[1]

Class and country	1987		1988		1989	
	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value	Quantity (kilograms, contained selenium)	Value
Unwrought and waste and scrap:[2]						
Belgium	94,477	$2,649,893	66,197	$2,087,313	73,654	$2,234,265
Canada	136,621	2,784,833	163,066	4,226,140	102,507	2,368,336
China	4,475	47,503	—	—	2,000	4,761
Finland	1,000	13,302	2,296	45,958	—	—
Germany, Federal Republic of	1,940	25,767	2,000	38,327	10,566	274,700
Hong Kong	—	—	—	—	2,268	78,600
Japan	85,657	1,759,989	57,358	1,456,867	65,266	1,517,688
Korea, Republic of	1,500	13,524	1,000	14,881	12,514	188,780
Netherlands	—	—	2,296	49,386	6,940	106,960
Peru	—	—	475	9,270	—	—
Philippines	12,000	111,667	18,275	291,962	12,910	143,243
Spain	—	—	—	—	10	1,070
Sweden	—	—	50	1,709	—	—
United Kingdom	76,379	1,245,330	100,854	1,640,007	69,631	1,173,918
Venezuela	—	—	—	—	920	10,103
Yugoslavia	20,000	153,657	—	—	40,320	491,760
Total	434,049	8,805,465	413,867	9,861,820	399,506	8,594,184
Selenium dioxide:						
Belgium	—	—	—	—	1,241	40,730
Canada	—	—	8	1,491	—	—
Germany, Federal Republic of	3,594	70,990	9,791	271,507	6,296	109,263
India	—	—	—	—	229	3,650
Japan	6,227	138,782	—	—	—	—
United Kingdom	1,314	29,724	1,527	54,250	9,823	186,431
Total[3]	11,135	239,496	11,325	327,248	17,589	340,074
Selenium salts:						
France	46	1,233	—	—	—	—
United Kingdom	300	7,677	125	5,325	—	—
Total	346	8,910	125	5,325	NA	NA
Sodium selenite:						
Belgium	230	5,550	2,300	58,825	—	—
Canada	345	8,454	4,600	144,119	—	—
Germany, Federal Republic of	19,734	259,174	19,819	61,619	—	—
Japan	414	35,260	184	19,798	—	—
United Kingdom	26,640	597,024	13,708	402,691	—	—
Total[3]	47,363	905,462	40,610	687,052	NA	NA
Other selenium compounds:						
Belgium	464	35,478	324	24,444	—	—
Canada	48	2,400	—	—	—	—
Germany, Federal Republic of	250	5,324	22	2,225	—	—
Italy	—	—	12	1,238	—	—
Japan	—	—	3	4,027	—	—
Sweden	264	6,296	—	—	—	—
United Kingdom	1,943	99,668	7,946	226,418	—	—
Total	2,969	149,166	8,307	258,352	NA	NA
Grand total	495,862	10,108,499	474,234	11,139,797	NA	NA

NA Not available.

[1]Because of 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 "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 Bureau of Mines.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF TELLURIUM, BY CLASS AND COUNTRY[1]

Class and country	1987		1988		1989	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Unwrought and waste and scrap:[2]						
Australia	—	—	—	—	8,030	$256,379
Belgium	1,041	$32,401	1,246	$73,622	5,485	463,840
Canada	4,525	463,462	5,966	543,787	10,637	1,117,746
Germany, Federal Republic of	5	1,441	6	3,080	3,904	442,614
Hong Kong	—	—	321	13,760	—	—
Japan	347	38,149	15,044	705,514	1,802	209,261
Mexico	—	—	1,500	78,540	699	40,874
Netherlands	—	—	1,000	42,108	3,604	241,229
Philippines	—	—	13,700	302,033	240	15,121
United Kingdom	2,962	72,904	13,419	626,424	8,470	462,036
Total	8,880	608,357	52,202	2,388,868	42,871	3,249,100
Compounds:						
Canada	(3)	1,879	1,416	71,688	—	—
Germany, Federal Republic of	133	6,463	10,706	107,605	—	—
Japan	188	9,743	200	10,821	—	—
Netherlands	—	—	1,901	22,661	—	—
Switzerland	7	1,633	42	7,577	—	—
United Kingdom	932	114,192	645	37,564	—	—
Total	1,260	133,910	14,910	257,916	NA	NA
Salts:						
Germany, Federal Republic of	16,550	64,238	9,778	41,732	—	—
United Kingdom	10	1,355	—	—	—	—
Total	16,560	65,593	9,778	41,732	NA	NA
Grand total	26,700	807,860	76,890	2,688,516	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.
[3]Less than 1/2 unit.

for selenium will continue. This trend could be reversed if demand weakens, or if higher prices, brought about by declining stocks, stimulate increased recovery rates for both primary and secondary selenium.

Data on demand for and production of tellurium are incomplete. However, available data indicate that market economy country demand over the past 5 years has been comparatively stable, averaging about 220 tons per year. Demand peaked in the 1978-1979 period at about 400 tons per year, stimulated by a short-lived demand for tellurium catalysts by a North America producer of ethylene glycol.

World production of refined tellurium, according to ABMS data, has trended downward. Excess supply following the demand turndown depressed prices and discouraged recovery of tellurium. The closing in 1985 of Asarco's Tacoma smelter, which had processed high-tellurium Philippine concentrates, significantly reduced the tellurium content of the company's anode slimes, and hence its tellurium recovery. Production of tellurium by Noranda in Canada has fallen to about 20% of the 1978 level, owing to a drop in the tellurium content of its ores. By 1986, the supply of tellurium had fallen short of the demand, and by the end of 1987 stocks of crude and refined tellurium were sufficiently low to precipitate a 350% price rise.

The near-term outlook is for the continued tight balance between the supply and demand for tellurium. The high price for tellurium was expected to moderate the future demand for tellurium in traditional metallurgical applications and stimulate the substitution of alternative materials. 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 was expected, additional resources, such as the gold telluride ores found in Fiji and Colorado, are potential new sources of tellurium.

[1]Assessment of Quality and Material Form of Minor Metals for the National Defense Stockpile. ASM International panel, ASM International, Metals Park, OH, 1988, 27 pp.
[2]Federal Register. Selenium; Environmental Impact; Opportunity for Comment. V. 54, No. 131, July 11, 1989, pp. 29019-29025.
[3]_____. National Primary and Secondary Drinking Water Regulations. V. 54, No. 9, May 22, 1989, pp. 22062-22151.

[4]Federal Register. Mining Waste Exclusion and Definition of Designated Facility; Proposed Rule. V. 54, No. 184, Sept. 25, 1989, pp. 39298-39318.

[5]Carapella, S. C., ed. Proceedings of the Fourth International Symposium on Uses of Selenium and Tellurium, May 7-10, 1989. Selenium-Tellurium Development Assoc. Inc., Darien, CT, 1989.

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American Bureau of Metal Statistics, Inc., Non-Ferrous Metal Data.

The Bulletin of Selenium-Tellurium Development Assoc., Inc., Darien, CT.

Metal Bulletin

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TABLE 5

U.S. SELENIUM AND TELLURIUM IMPORT DUTIES

Tariff item	Number	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Selenium	2804.90.0000	Free	Free
Selenium dioxide	2811.29.2000	Free	Free
Tellurium	2804.50.0000	Free	25.0% ad val.

TABLE 6

PRINCIPAL MARKET ECONOMY COUNTRY PRODUCERS OF SELENIUM AND TELLURIUM AND ANNUAL CAPACITY, DECEMBER 31, 1989

(Metric tons)

Continent and country	Company	Primary capacity	
		Selenium	Tellurium
North America:			
Canada	Noranda Mines Ltd.	[1]400	40
	INCO Ltd.	50	20
Mexico	Cobre de Mexico S.A.	45	—
United States	ASARCO Incorporated	W	W
	Kennecott, Utah Copper Corp.	W	—
	Phelps Dodge Corp.	W	—
Total U.S.		400	W
South America:			
Brazil	Cariaba Metais S.A. Industria e Comercio	20	—
Chile	Empresa Nacional de Mineria	40	—
Peru	Empresa Minera del Centro del Peru	20	20
Europe:			
Belgium	Metallurgie Hoboken-Overpelt S.A.	[1]360	100
Finland	Outokumpu Oy	90	—
Sweden	Boliden Metall AB.	70	—
Yugoslavia	Rudarsko Topionicarski Bazen Bor	50	—
Africa: Zambia	Zambia Consolidated Copper Mines Ltd.	25	—
Asia:			
Japan	Mitsubishi Metal Corp.	250	60
	Mitsui Mining and Smelting Co. Ltd.	100	15
	Nippon Mining Co. Ltd.	120	15
	Sumitomo Metal Mining Co. Ltd.	70	10
Philippines	International Recoveries Inc.	([2])	[3]100
	Philippine Associated Smelting and Refining Corp.	70	—
Grand total (rounded)		2,200	W

W Withheld to avoid disclosing company proprietary data.

[1]Includes secondary capacity.

[2]Secondary selenium capacity is about 100 tons per year.

[3]Tellurium dioxide and tellurium metal; tellurium content.

TABLE 7

SELENIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Kilograms, contained selenium)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Belgium[e]	230,000	250,000	230,000	250,000	250,000
Canada[3]	361,000	345,000	300,000	321,000	[4]363,000
Chile	50,037	47,000	45,909	47,051	47,000
Finland	14,038	5,693	[e]10,000	28,935	25,000
India	4,850	[e]4,800	4,026	[r e]4,100	4,200
Japan	496,835	426,567	481,109	471,020	[4]470,658
Mexico	42,000	23,000	29,000	13,000	20,000
Peru	14,506	12,035	11,438	4,937	5,000
Sweden	46,000	24,000	31,000	30,000	30,000
United States	W	W	W	285,600	[4]253,427
Yugoslavia	43,720	54,400	66,362	60,812	60,000
Zambia[5]	[r]15,405	[r]22,150	26,819	24,083	25,000
Total	[r]1,318,391	[r]1,214,645	1,235,663	1,540,538	1,553,285

[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 25, 1990.

[2]In addition to the countries listed, Australia, the Federal Republic of Germany, 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]The 1985 refinery output is from all sources including imported materials and secondary sources; 1986-89 excludes secondary production.

[4]Reported figure.

[5]Data for fiscal year beginning Apr. 1 of year stated. In addition to refined selenium metal produced domestically as shown, Zambia is believed to have exported anode slimes from electrolytic copper production that have been estimated to additionally contain more than 30,000 kilograms per year of selenium.

TABLE 8

TELLURIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Kilograms, contained tellurium)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Canada[3]	19,000	20,000	13,000	19,000	[4]9,000
Japan	65,600	55,600	53,305	55,181	[4]51,031
Peru	15,007	9,836	7,457	4,078	5,000
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 Belgium, the U.S.S.R., and the United States. Table includes data available through May 31, 1990.

[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]For 1985, refinery output from all sources, including imports and secondary sources; for 1986 onward, primary recoverable output.

[4]Reported figure.

SILICON

By Joseph Gambogi

Mr. Gambogi, a physical scientist with more than 7 years of Government and industry experience, has been the commodity specialist for silicon since 1988. Domestic survey data and trade data were prepared by Ms. Robin Johnson, Mineral Data Assistant in the Branch of Data Collection and Coordination.

For most of 1989, demand for silicon products remained near the high levels reached in 1988. However, a reactivation of idle capacity, combined with new global capacity, resulted in an oversupply of silicon materials. Prices that had reached record highs in 1988 decreased significantly. Consequently, production cutbacks were scheduled by several domestic producers in the second half of 1989.

LEGISLATION AND GOVERNMENT PROGRAMS

Several proposals were introduced in the 101st Congress that would limit the amount of sulfur dioxide emissions from coal-based power utilities. The Bureau of Mines conducted a study to determine the possible effects of these proposals on the minerals industry. The study found that, if passed into law, significant cost increases could be incurred by certain utilities. These costs would in turn be passed along to their consumers, which included several silicon and ferrosilicon producers. The study estimated the legislation proposed would increase the average cost of production from 2 to 4.5 cents per pound of contained silicon metal. At yearend, a resolution regarding this legislation had not been reached.[1]

Under Title III provisions of the Defense Production Act, the Air Force System Command awarded two contracts totaling more than $33 million to encourage development of commercial suppliers of metal matrix composites (MMC). The contracts were awarded to Advanced Composite Materials Corp., Greer, SC, and DWA Composite Specialties Corp., Chatsworth, CA. The Air Force indicated the goal of the program was to make MMC materials "market competitive."[2] Aluminum matrix composites with silicon carbide fiber reinforcement appeared to show the most promise for achieving this goal.

STRATEGIC CONSIDERATIONS

Silicon semiconductors played an essential role in electronic devices for military and commercial applications. In 1989, the United States was one of the world's leaders in semiconductor device manufacture. However, portions of the domestic semiconductor market were dominated by imports. An area of significant concern was the domestic capability to produce infrared (IR) detector-grade silicon metal. IR detector-grade silicon was used by the Department of Defense for the manufacture of devices that guide highly advanced weapons. IR materials also served numerous functions as part of satellite surveillance systems. Nevertheless, these materials were obtained almost exclusively from foreign sources in 1989.[3]

PRODUCTION

Overall gross production and shipments of silicon containing products were comparable to those of 1988. Overall production increased 4% while shipments were nearly unchanged. However, production and shipments of

TABLE 1

PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON, FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1989

(Short tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks Dec.31, 1988[r]	Gross production	Net shipments	Producers' stocks Dec.31, 1989
	Range	Typical				
Silvery pig iron	5-24	18	W	W	W	W
Ferrosilicon	25-55	48	51,687	377,974	294,521	60,841
Do.	56-95	76	13,948	137,593	110,143	22,692
Silicon metal (excluding semiconductor grades)	96-99	98	6,875	154,268	146,573	9,666
Miscellaneous silicon alloys (excluding silicomanganese)	32-65	—	15,111	90,561	77,309	22,293

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

certain products changed significantly. The most significant change occurred in production and shipments of 75%-grade ferrosilicon. Shipments of this product rose 28% while production rose 56% compared to that of 1988. Producer stocks of silicon-containing material rose 32% overall. Estimated ferrous scrap consumption was 275,000 tons in 1989.

Globe Metallurgical Inc., Beverly, OH, purchased Materials & Methods Ltd., Reigate, England. Materials & Methods held several patented processes used to produce foundry ductile iron. Many of these processes used silicon ferroalloys, which Globe produced at its operations in the United States. This was Globe's first major acquisition since its management buyout in 1987. By mid-year, Globe terminated its 34-year-old relationship with its sales representatives, Pickands Mather & Co., to form an internal sales force. Late in 1989, Globe shut down one of its 13-megavolt-amphere (MV•A) ferrosilicon furnaces for repair.

Following a financial reorganization in 1988, Simetco Inc., Montgomery, AL, bought Quadracast Inc., and its Harrison Handling Division. Quadracast specialized in metals fabrication. Harrison built patented belt conveyors and other equipment used in the mining industry.

Silicon Metaltech Inc., Wenatchee, WA, expanded its operations in Rock Island, WA, with the construction of a new chemical lab. The new facility allowed the company to perform detailed analyses of silicon metal. This type of analysis was essential for Silicon Metaltech to produce chemical-grade silicon metal.

Cominco American Resources Inc. rekindled an idle ferrosilicon furnace at its Glenbrook Ferronickel Operations where ferrosilicon was consumed in the ferronickel process. The company reported some of the furnace's 18,000 short tons per year (tpy) of capacity was intended for commercial sales. For most of the year, Cominco American Resources was a wholly owned subsidiary of Cominco Resources International Ltd. and USA Investments. However, Cominco International purchased the remaining Cominco American interest late in 1989.[4]

In September, American Alloys Inc. began production of silicon metal at its New Haven, WV, plant. The new furnace was reported to be capable of producing 6,000 tpy of contained metal. The furnace represented the first new addition to the company, which was formed in a management buyout of Foote Minerals Co. in 1987.[5]

In June, Elkem Metals Co. temporarily idled a ferrosilicon furnace at Ashtabula, OH, after a burnthrough in the furnace lining. The furnace was brought back on-line in October after maintenance repairs had been completed. Late in the year, Elkem Metals announced plans to shut down one of two furnaces at its Ashtabula, OH plant.

Several companies made plans late in 1989 for reducing output of silicon products during 1990. Among these companies, SKW Alloys Inc. planned to shut down one of two 35-MV•A ferrosilicon furnaces at its Calvert City, KY, plant. Meanwhile, Globe Metallurgical also planned to shut down individual furnaces for maintenance during 1990.

Monsanto Electronics Materials Co. (MEMC) was sold to Huels AG of the Federal Republic of Germany. MEMC was the last major domestic silicon wafer producer catering to independent chip makers. All other major producers made wafers for their own chip production.[6]

TABLE 2

PRODUCERS OF SILICON ALLOYS AND/OR SILICON METAL IN THE UNITED STATES IN 1989

Producer	Plant location	Product
American Alloys Inc.	New Haven, WV	FeSi and Si.
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi.
Cominco American Resources	Riddle, OR	Do.
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.

CONSUMPTION AND USES

Apparent consumption (demand) of silicon-containing ferroalloys and silicon metal decreased 5% compared with that of 1988. The continued strong demand reflected high production levels in the aluminum, iron and steel, and silicon-base chemical industries. Specifically, consumption of silicon metal decreased 11% while ferrosilicon applications decreased 2%. The aluminum industry used silicon metal in the production of wrought and cast products while ferrosilicon was used as a deoxidizing and alloying agent in the production of iron and steel products. Ferrosilicon and miscellaneous silicon alloys used in the production of iron and steel accounted for 70% of all the silicon materials consumed, based on silicon content.

Metallurgical-grade silicon metal produced by tonnage methods was used as the basic raw material in the manufacturing of many chemical products and intermediates such as silicones and silanes. Silanes were used in the production of high-purity silicon for semiconductor devices and solar cells (photovoltaic cells). The Bureau of Mines did not collect data on electronic grades of silicon, which were relatively low in quantity but high in unit value.

Union Carbide Corp. reorganized its silicone fluids, silicone surfactants, and silanes business into a new worldwide operating unit called Organo-Silicon

TABLE 3

REPORTED CONSUMPTION, BY MAJOR END USE, AND STOCKS OF SILICON ALLOYS AND METAL IN THE UNITED STATES IN 1989

(Short tons, gross weight, unless otherwise specified)

Silicon content (percentage)	Silvery pig iron	Ferrosilicon[1]				Silicon metal	Miscellaneous silicon alloys[2]	Silicon carbide[3]
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	24	122,220	—	87,550	818	1,761	2,263	210
Cast irons	17,739	125,962	1,147	15,209	336	(4)	22,862	22,304
Superalloys	—	(4)	—	260	(4)	117	—	—
Alloys (excluding superalloy and alloy steel)	(4)	4,105	—	(4)	(4)	54,997	47	—
Miscellaneous and unspecified	12	1,896	—	671	35	[5]142,334	1	—
Total reported	17,775	254,183	1,147	103,690	1,189	199,209	25,173	22,514
Consumers' stocks, Dec. 31	778	8,272	87	7,460	48	2,569	1,035	1,451

[1] Includes briquettes.
[2] Primarily magnesium-ferrosilicon but also includes other silicon alloys.
[3] Does not include silicon carbide for abrasive or refractory uses.
[4] Included with "Miscellaneous and unspecified."
[5] Consists primarily of consumption of silicon metal for the production of silicones and silanes and estimated consumption for the production of fumed silica and other chemicals.

Products, Systems and Service Group. The announcement follows a 1988 decision not to form a joint venture with General Electric Co. due in part to objections by the Federal Trade Commission. The new group made plans to expand its silane operations in Sisterville, WV, as well as its silicone facility at Italiba, Brazil. Union Carbide was one of the major consumers of chemical-grade silicon metal in 1989.[7]

PRICES

Following record high prices in 1988, published prices for silicon containing materials decreased significantly in 1989. However, overall demand for these products was only slightly lower than in 1988. Several factors contributed to an oversupply of material forcing lower market prices. One of the most influential factors affecting prices was the recent reactivation of idle U.S. capacity. Other factors affecting prices were the development of new production capacity in South America and the escalation of low cost imports from China, South America and the U.S.S.R. into the United States. Large stockpiles of Chinese material developed by Japanese consumers and traders in the second half of 1988 contributed to the fall in prices worldwide. The average published prices for silicon-base commodities are listed in the following table. All prices are posted in cents per pound of contained silicon.

Year	Si Met	50% FeSi	75% FeSi
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

Source: Metals Week

FOREIGN TRADE

In 1989, several domestic producers increased their sales efforts in the global market. Meanwhile, global demand remained relatively high. As a result, ferrosilicon exports increased significantly compared with those of 1988. The major markets for ferrosilicon exports included Canada, the Republic of Korea, and the United Kingdom. In contrast to ferrosilicon, silicon metal exports decreased by nearly one half. This depression was believed to be caused by a saturation of Chinese material within the Japanese market. Exports of silicon metal were shipped primarily to Mexico, the Netherlands, and Venezuela.

Under the Omnibus Trade and Competitiveness Act (Public Law 100-418, Subtitle B), tariff schedules were revised on January 1, 1989, to conform to the internationally established Harmonized Tariff System (HTS). Consequently, U.S. customs import and export categories for silicon-base alloys were revised. The law was designed to enhance the competitiveness of the Nation's industries and to improve the management of the U.S. trade strategy. The revisions significantly changed the tariff categories for silicon-base products as shown on the following table:

Item	Harmonized Tariff Schedule Number	Most Favored Nation (MFN)[1]	Non-MFN[1]
Ferrosilicon, 55%–80% Si:			
More than 3% Ca	7202.21.1000	1.1% ad val.	11.5% ad val.
Other	7202.21.5000	1.5% ad val.	11.5% ad val.
Ferrosilicon, 80%–90% Si	7202.21.7500	1.9% ad val.	9.0% ad val.
Ferrosilicon, more than 90% Si	7202.21.9000	5.8% ad val.	40.0% ad val.
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 val.	25.0% ad val.
Silicon, 99.00%–99.99% Si	2804.69.1000	5.3% ad val.	21.0% ad val.
Silicon, other	2804.69.5000	9.0% ad val.	45.0% ad val.

[1]Tariff effective Jan. 1, 1989.

In accordance with the United States-Canadian Free Trade Agreement, U.S. duties on ferrosilicon products imported from Canada were removed on January 1, 1989. Also effective on January 1, duties on Canadian silicon metal imports were lowered. Duties on all grades of metal were scheduled to be eliminated by 1998.[8] The new U.S. duty rates per kilogram of silicon metal originating in Canada were as follows:

Year[1]	Harmonized Tariff Code		
	2804.61.00	2804.61.10	2804.69. 50
1989	2.9%	4.7%	8.1%
1990	2.2%	4.2%	7.2%
1991	1.4%	3.7%	6.3%
1992	.7%	3.1%	5.4%
1993	Free	2.6%	4.5%
1994	Free	2.1%	3.6%
1995	Free	1.5%	2.7%
1996	Free	1.0%	1.8%
1997	Free	.5%	.9%
1998	Free	Free	Free

[1]Rates of duty effective Jan. 1, 1989.

In April, the Office of the U.S. Trade Representative (USTR) released its 1988 Product Review of the Generalized System of Preference. The U.S. Ferroalloy Association had requested an end to duty-free imports of 99.00 to 99.99% silicon metal from Argentina and Yugoslavia. The USTR decided to continue Generalized System of Preference (GSP) status of these imports. However, effective July 1, 1989, the USTR removed GSP status of Brazilian silicon metal less than 99.99% but not less than 99% silicon and ferrosilicon containing by weight more than 55% but less than 80% silicon and more than 3% calcium.[9]

Late in 1989, the Office of Foreign Availability, Bureau of Export Administration, Deptartment of Commerce, began an investigation to assess the foreign availability of high purity polycrystalline rods and chunks. These materials were the basic raw materials for most semiconductor devices in 1989. Subsequently, the sale of these materials was regulated for national security reasons. A decision on this investigation was pending at yearend.[10]

WORLD REVIEW

Australia

Barrack Mines Ltd. successfully commissioned its silicon metal plant near Perth, Western Australia. When fully operational, the furnaces were reported to be capable of producing 36,400 tpy of silicon metal. However, the production output for 1990 was targeted at 27,600 short tons. Silicon metal from these furnaces was expected to meet the stringent purity requirements of the primary aluminum and chemical industries. Barrack was reported to have long term contracts with both Thyssen Handesunion AG, West Germany, and Dow Corning Corp., Midland, MI. The company also had announced plans for an additional two furnaces scheduled for start up in July 1991.[11]

Brazil

Brazilian ferroalloy producers announced several expansions and expansion plans during 1989. However, because of poor market conditions in the second half of 1989, the completions of these plans were in question.[12]

Electrovale SA Industria e Comercio, a Brazilian-Japanese joint venture, began construction of a 31 MV•A furnace at its Nova Era Works, Minas Gerais state. The expansion was expected to double the output of 75%-grade ferrosilicon from 26,500 to 55,100 tpy.[13]

Late in the year, Cia. de Ferro Ligas da Bahia (Ferbasa) began a project to convert five 75%-grade ferrosilicon furnaces to produce silicomanganese. The company also planned to build four hydroelectric plants in Bahia. The first two plants were planned for completion in 1992.[14]

Cia. Ferroligas Minas Gerais (Minas Ligas) moved into silicon metal production for the first time in 1989. The company commissioned a 15 MV•A furnace at its Pirapora site. The new furnace was provided by Delp Engenharia Mecancia, Minas Ligas' parent company. Minas Ligas also planned to start up a second furnace in 1990. Because of escalating energy costs, Minas Ligas conducted feasibility studies into constructing its own hydroelectric plant at Retiro.[15]

Cia. Paulista de Ferro Ligas delayed its move into ferrosilicon production until late 1991. Two 18-MV•A furnaces were planned for installation at Cia Paulista's subsidiary, Electrosiderúrgica Brasileira SA (Sibra).[16]

Camargo Corrêa Metais started production at its second 18-MV•A silicon metal furnace at Tucurui, Para State in northern Brazil. The first 18-MV•A furnace was commissioned in 1988. A third and fourth furnace were near completion at yearend. The furnaces were manufactured by the Demag Corporation. Production from the furnaces was intended for export.

Italmagnésio SA Industria e Comércio made plans to double its existing capacity to produce 75%-grade ferrosilicon. The plan included the installation of 24-MV•A and 6-MV•A furnaces.[17]

Multisilicon, a new Brazilian company, announced a project aimed at producing 27,600–30,900 tpy of chemical and metallurgical grade silicon metal at Leopoldina, Minas Gerais.

TABLE 4

U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON			
Over 55% silicon:			
Canada	3,309	1,985	$2,486
Japan	5,042	2,948	3,846
Korea, Republic of	7,595	5,334	5,906
Mexico	2,747	1,649	2,018
Taiwan	1,935	1,194	1,870
Other (18 countries)	2,669	1,627	2,136
Total[1]	23,297	14,738	18,262
Other ferrosilicon:			
Australia	1,735	868	1,244
Canada	11,200	5,600	8,008
Japan	2,063	1,031	1,714
Mexico	1,631	815	1,189
United Kingdom	8,017	4,008	5,756
Other (25 countries)	6,114	3,057	4,668
Total[1]	30,760	15,380	22,580
Total ferrosilicon[1]	54,056	30,117	40,842
SILICON METAL			
Over 99.99% silicon:			
Denmark	46	NA	3,191
Italy	99	NA	4,190
Japan	534	NA	27,235
Korea, Republic of	30	NA	1,463
Malaysia	220	NA	35,698
Other (29 countries)	78	NA	3,490
Total[1]	1,007	XX	75,266
99.00%–99.99% silicon:			
Italy	299	NA	684
Mexico	159	NA	233
Saudi Arabia	184	NA	189
South Africa, Republic of	105	NA	116
Taiwan	106	NA	111
Other (17 countries)	452	NA	936
Total[1]	1,305	XX	2,269
Other silicon:			
Canada	570	NA	537
Mexico	548	NA	1,501
Netherlands	602	NA	709
New Zealand	287	NA	376
Venezuela	717	NA	768
Other (36 countries)	524	NA	2,648
Total[1]	3,249	XX	6,539
Total silicon metal[1]	5,561	XX	84,074

NA Not available. XX Not applicable.

[1] Data may not add to totals shown because of individual rounding of converted units.

Source: Bureau of the Census.

The project was scheduled for completion by 1991. Prior to construction, the company had obtained a 10-year sales contract with Dow Corning Corp., Midland, MI. Multisilicon intended to export the majority of its production. Initial plans called for two 18-MV•A furnaces.[18]

The Rima group was reported to have brought two silicon metal furnaces on-line in Minas Gerais state. Rima also began construction of a 50-MV•A hydroelectric plant at Rodeado. The electric plant was intended to help provide a small portion of the plant's enormous energy needs.[19]

Canada

SKW Canada Inc. shut down one of its furnaces for repair late in 1989. The furnace was not expected to return to full capacity for at least a 6-month period.

India

VBC Ferro Alloys Ltd. upgraded its ferrosilicon capacity from 11,000 to 16,500 tpy. Nav Bharat Ferroalloys Ltd. sought permission from the Indian Government for an additional 11,000 tpy of ferrosilicon capacity. Ispat Alloys Ltd. was in the process of installing a silicon metal furnace to increase its capacity to 22,000 tpy. In an effort to alleviate problems with electrical power cutbacks, several companies began projects to build captive power plants.[20]

Iran

The Iran Ferro-Alloy Co. scheduled the opening of Iran's first ferrosilicon plant for early 1991. The new facility was being constructed in Azna within the western province of Luristan. The plant was expected to produce 27,600 tpy of ferrosilicon for domestic consumption. Technical support for the project was to be provided by Elkem Technology AS.[21]

Japan

Effective in August 1989, Japanese steelmaker NKK Corp. sold its interest in the ferrosilicon producer Yakushima Denko Co. Ltd. The sale was based on a decision by the company to rely on imports for ferrosilicon. The Brazilian ferroalloy producer Ferro Ligas Assofon SA, of which NKK held a 27% portion of ownership, was expected to

fulfil a large portion of the company's ferrosilicon needs.[22]

Denal Silane Co. Ltd. completed a state-of-the-art monosilane plant at Omi. Denal was a joint venture between Denki Kagaku Kogyo KK and the L'air Liquide Group. The plant was reported to be the largest merchant producer of monosilane and was capable of producing monosilane at the parts per billion (ppb) purity level.[23]

Norway

Elkem A/S reorganized its global management structure from geographic divisions to a product based organization. In order to give the company a firmer footing in the European aluminum industry and to boost its downstream involvement, Elkem increased its share in Alcoa Nederland BV from 25% to 50%. Late in 1989, Elkem announced it would maintain its worldwide ferrosilicon production level in the coming year. Elkem also announced plans to purchase the remaining interest in Bjølvefossen AS. During 1989, Bjølvefossen operated four ferrosilicon furnaces at its facility in Ålvik.[24]

In December, Fesil KS announced plans to reduce its Norwegian ferrosilicon production by 11,000 tons to 16,500 tpy. The company planned to idle one of its furnaces at IIa og Lilleby Smelteverker and begin a furnace maintenance program at its Hafslund facility. The company delayed bringing ferrosilicon furnaces on-stream at its Mo I Rana facility.[25]

Philippines

Mindanao Ferroalloys Co. (Minfaco) was formed as a joint venture between Maria Cristina Chemicals Industries (MCCI), Sangyong Co. Ltd., Pohang Iron and Steel Co. (Posco), and Dongil Chungong Co. Ltd. The new company planned to convert a 27-MV•A carbide furnace at MCCI's plant on the island of Mindanao to producing ferrosilicon. The estimated 14,300 tpy of new capacity was scheduled for startup in mid-1991. Production from this facility was intended for export to the Republic of South Korea.[26]

Portugal

Brazilian Italmagnésio Group formed a new subsidiary in Portugal called Novos Fornas de Beira Alta Lda. (Forbel). In a 10-year rental agreement with So-

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON			
55%–80% silicon, over 3% Ca:			
Argentina	1,188	705	$1,428
Belgium	74	45	96
Brazil	16,926	10,499	20,879
France	3,125	1,908	4,354
Germany, Federal Republic of	121	78	306
Italy	808	502	1,027
Japan	207	157	439
Spain	60	35	78
Total[1]	22,510	13,929	28,607
55%–80% silicon, other:			
Argentina	9,446	7,180	7,124
Australia	22	17	14
Brazil	15,531	11,421	11,527
Canada	20,208	15,255	15,211
China	1,516	1,025	899
France	595	394	738
Germany, Federal Republic of	472	339	1,550
Iceland	13,846	10,565	7,202
Japan	78	51	205
Norway	13,632	10,347	7,803
Venezuela	28,798	21,680	19,602
Yugoslavia	3,196	2,284	1,037
Total[1]	107,341	80,557	72,912
80%–90% silicon:			
Brazil	15	12	13
France	10	9	22
Total[1]	25	21	35
Over 90% silicon:			
Brazil	2,756	2,545	2,705
China	122	112	119
Hong Kong	118	109	117
Japan	(2)	(2)	1
Total[1]	2,996	2,766	2,941
Magnesium ferrosilicon:			
Brazil	5,804	2,589	3,851
Canada	282	66	104
China	77	25	110
Germany, Federal Republic of	1,139	389	1,848
Japan	31	13	57
Total[1]	7,333	3,082	5,970

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
FERROSILICON—Continued			
Other ferrosilicon:			
Brazil	8,485	2,979	$1,967
Canada	8,282	3,740	3,186
Finland	1,126	538	573
France	464	192	465
Germany, Federal Republic of	72	21	75
Japan	37	17	69
Norway	1,003	512	375
U.S.S.R.	36,422	17,706	14,457
Total[1]	55,891	25,704	21,166
Total ferrosilicon[1]	196,096	126,059	131,631
SILICON METAL			
Over 99.99% silicon:			
China	13	NA	133
Denmark	8	NA	396
Finland	(2)	NA	1
France	33	NA	1,174
Germany, Federal Republic of	530	NA	18,686
Italy	210	NA	12,341
Japan	162	NA	2,284
Korea, Republic of	6	NA	112
Malaysia	4	NA	9
Netherlands	1	NA	7
Sweden	(2)	NA	2
United Kingdom	(2)	NA	7
Total[1]	965	XX	35,152
99.00%–99.99% silicon:			
Argentina	7,488	7,420	7,466
Brazil	12,426	12,325	12,610
Canada	7,370	7,306	6,970
China	5,042	4,996	5,172
Denmark	(2)	(2)	2
France	1,485	1,473	1,027
Germany, Federal Republic of	30	30	77
Hong Kong	1,624	1,608	1,700
Italy	100	99	56
Japan	119	118	144
Norway	19	19	38
South Africa, Republic of	853	846	838
Spain	91	90	109
Sweden	41	41	66
Taiwan	184	182	163
Total[1]	36,874	36,553	36,438

See footnotes at end of table.

ciedada Portuguesa de Electrometallurgia SA, the new company restarted ferrosilicon furnaces previously operated by Cia Portuguesa de Fornos Eléctricos S.A.R.L. The operations were capable of producing 33,000 tpy of 75%-grade ferrosilicon. However, a 19-MV•A furnace included in this capacity was being dismantled and sent to Venezuela. Italmagnésio SA Industria e Comercio, which had previously experienced antidumping problems in the European Community, hoped the new subsidiary would give the company a better sales position in the European market.[27]

Venezuelan PT Investment Alloy acquired two 19-MV•A Demag silicon metal furnaces from Portugal's Metalurgia do Norte S.A.R.L. (Milnorte). The furnaces were being dismantled and sent to Venezuela for installation.[28]

Venezuela

Work began on several major ferroalloy projects in 1989. All of the projects revolved around joint-venture agreements with the state development body Corporacion Venezolana de Guayana (CVG). The ventures planned to take advantage of Venezuela's abundant electricity available from CVG's Guri Dam near Puerto Ordaz.

Rima Electrometallurgical SA signed an agreement with CVG to set up a new silicon metal plant in Venezuela. The company reportedly was awaiting an import license from the Venezuelan Government for two new 13,200-tpy silicon metal furnaces. If approved, the furnaces were to be constructed by Rima Mecanica SA in Brazil.

Progress continued on the Guaysil project to produce chemical-grade silicon metal. The project was a Latin-American joint venture between the Rima Group, Cia Minera Autlan SA de CV, and Corporacion Venezolana de Guayana. In 1989, the project received an authorization from the Venezuelan Government for a debt swap arrangement with Venezuela's Morgan Guaranty Bank.

C.V.G. Ferrosilicio de Venezuela CA (Fesilven) started construction of a silicon metal furnace with a scheduled completion within 2 years. Fesilven also planned to install two 32-MV·A furnaces to produce 27,600 tpy of 75%-grade ferrosilicon and modernize two existing furnaces.

Central de Ferroaleacines de Venezuela CA (Cefeca), which had plans for

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY

(Short tons)

Grade and country	1989		
	Gross weight	Contained weight	Value (thousands)
SILICON METAL—Continued			
Other silicon:			
Belgium	3	3	$31
Brazil	4,590	4,498	3,945
Canada	1,028	1,010	990
China	2,970	2,915	2,534
Germany, Federal Republic of	2	2	5
Hong Kong	836	795	856
Italy	3	3	10
Japan	81	80	128
Luxembourg	55	54	57
Norway	34	32	30
Sweden	3	3	21
Taiwan	110	109	112
United Kingdom	60	59	78
Total[1]	9,775	9,560	8,798
Total silicon metal[1]	47,615	347,078	80,388

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.

TABLE 6

WORLD PRODUCTION CAPACITY FOR SILICON-CONTAINING FERROALLOYS AND SILICON METAL IN 1989

(Thousand short tons, contained silicon)

Country	Capacity
Argentina	85
Australia	40
Brazil	350
Bulgaria	(1)
Canada	105
Chile	7
China	400
Colombia	(1)
Czechoslovakia	(1)
Egypt	50
France	170
German Democratic Republic	(1)
Germany, Federal Republic of	50
Hungary	(1)
Iceland	55
India	60
Italy	94
Japan	90
Korea, North	(1)
Korea, Republic of	18
Mexico	19
Norway	457
Peru	(1)
Philippines	25
Poland	(1)
Portugal	13
Romania	(1)
South Africa, Republic of	136
Spain	79
Sweden	50
Switzerland	(1)
Taiwan	15
U.S.S.R.	650
United States	518
Uruguay	(1)
Venezuela	50
Yugoslavia	135
Other	304
Total	4,026

[1] Included with "Other."

no less than 11 new ferroalloy plants, began to purchase equipment for these operations. The Cefeca company, PT Investment Alloy, acquired two 19 MV•A Demag silicon metal furnaces from Metalurgia do Norte S.A.R.L. in Portugal. These furnaces were being dismantled and were planned for installation in 1991. An additional silicon metal furnace was acquired from Portugal's Cia. Portuguesa de Fornas Electricos. The plans called for a total of 76 MV•A of capacity, producing up to 52,900 tpy of silicon metal by 1993. The company also hoped to acquire two Nippon Denko Co. Ltd. furnaces with capacities of 22 and 33 MV•A for the production of 75%-grade ferrosilicon. These furnaces were scheduled to be brought on-line in 1994.[29]

CURRENT RESEARCH

Engine Components Inc. introduced a silicon carbide coating process for aircraft piston engines designed to expedite ring seating, reduce oil consumption, and increase cylinder service life.[30]

Silicon nitride ceramic valves were produced by the American Ceramic Engine Co., Bolingbrook, IL, for use in stockcar racing engines.[31]

The Duralcan Corp., San Diego, CA, successfully marketed its aluminum and silicon carbide metal matrix composite. The material was sold to Specialized Bicycle Corp. Specialized used the composite material to produce bicycle wheel rims that offered a 40%-higher specific stiffness than unreinforced rims. The company's San Diego pilot plant produced an estimated 100 tons per month in 1989. A 12,500-tpy plant at Jonquiere, Quebec, was under construction and scheduled for completion in 1990. In November, Duralcan cast the largest metal matrix composite (MMC) ingot ever produced. The ingot weighed 1,325 pounds and was composed of an aluminum and silicon carbide composite.

Lanxide Corp., Newark, DE, continued to develop several patented processes that were used to produce ceramic and metal matrix composites. Many of the processes were based on directed metal oxidation and were used to grow metal matrix composites through an oxidation reaction between molten metal and an

adjacent gaseous oxidant. Several of the Lanxide products used silicon carbide reinforcements.[32]

Whole-wafer integrated circuits came to fruition in 1989. Anamaric Ltd. Cambridge, United Kingdom, produced a 6-inch wafer with 202 1-megabyte (MB) dynamic random access memory chips. The success was achieved though the use of control logic to bypass defects on a wafer. The first product based on the wafer-scale integration was a 40-MB solid-state computer disk drive.[33]

Ibis Technology Corp., Danvers, MA, used a new process called Separation by Implantation of Oxygen (SIMOX) to bury oxygen ions just below the surface of a standard silicon wafer. As a result of this process, circuits printed on the SIMOX chip ran 30% faster than an ordinary silicon chip. The SIMOX process implants a layer of silicon dioxide in the chip, which insulates the circuits from stray capacitances and currents triggered by radiation or high temperatures. The SIMOX process was originally developed by Harris Semiconductor, Melbourne, FL, for military and space applications. Ibis produced SIMOX wafers for commercial applications commercially.[34]

In 1989, micromechanics emerged as a viable industry. Researchers used techniques used to produce computer chips to carve out minuscule devices only two-thirds the width of a human hair. Although these devices included mechanisms such as micromotors and microswitches, commercial success was achieved though microsensors. These sensors were the result of early research efforts by such research centers such as AT&T Bell Labs, Murray Hill, NJ; Stanford University, Stanford, CA; and Massachusetts Institute of Technology, Cambridge, MA. The largest producer of these sensors was Delco Electronics Corp, Kokomo, IN. Delco incorporated the sensors into controls and diagnostics for automobile engines and transmissions. Future applications for the sensors included antilock braking, dynamic suspension, crashbag activation, and tire pressure monitoring.[35]

Dow Corning Corp., Midland, MI, proceeded with plans to develop a process using silica sand to produce silicon metal. After the completion of a $1.1 million feasibility study, Dow made plans to construct a $42 million research facility. The facility was to include a pilot plant to allow further study of the new process. A 25 MV•A furnace producing 30 million pounds-per-year of silicon metal was scheduled for 1994 contingent upon the success of the pilot plant study. If successful, the new process was expected to significantly reduce energy costs and virtually eliminate the need for consumable electrodes normally associated with silicon metal production.[36]

Researchers at Sandia National Laboratories in New Mexico achieved a record solar to electric conversion efficiency ratio of 20.3% using a silicon-base photovoltaic concentrator module. The module consisted of 12 lenses that concentrate concentrated sunlight over several hundred times onto silicon solar cells. A commercial product using these cells was expected within three years.[37]

OUTLOOK

Demand for silicon metal is driven by the aluminum and the chemical industries. Consumption by the aluminum industry, which uses silicon as an alloying agent, is expected to undergo slow growth over the next 5 years. The increased use of aluminum in automobiles, which reached a record high in 1989, will contribute to this growth. Additionally, a trend toward the use of higher silicon content in aluminum castings is expected to continue. The chemicals industry consumes silicon metal to produce a wide variety of compounds such as silanes, silicone resins, and lubricants. In the past, this industry has shown steady growth and is expected to continue this trend.

Ferrosilicon is consumed primarily by the iron and steel industry. The industry uses ferrosilicon for both deoxidation of molten metal and as an alloying agent. The American Iron and Steel Institute studied the consumption of steel by industrialized countries and predicted an average decline of 0.1% per year from 1985-95. Subsequently, ferrosilicon consumption is not expected to grow over the next 5 years.[38] However, several factors could influence consumption of ferrosilicon by the steel industry. These factors may include possible technological advances, environmental legislation, and trade agreements.

Production cutbacks were scheduled by many producers in the latter half of 1989. These cutbacks are expected to affect moderate price increases in the coming year. However, average prices are not expected to rise appreciably over the long term because of increases in worldwide capacity.

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SILVER

By Robert G. Reese, Jr.

Mr. Reese, a physical scientist with the Branch of Nonferrous Metals, has covered silver for 8 years. Domestic survey data were prepared by Lisa Conley, Eraina Dixon, and Stephen Hays, Nonferrous Data Section. International data were prepared by Giovanni Jacarepaqua, International Data Section.

Domestic silver production increased for the third consecutive year, reaching its highest level since 1941. Higher byproduct silver production from copper, lead, and zinc mines and the opening of new mines were the primary reasons for the higher output. Most of these new mines, as has been the case for the past several years, were gold mines with byproduct silver production. Notable exceptions were the openings of two large lead, silver, and zinc mines in Alaska. World mine output of silver increased primarily in response to a more stable labor situation in Peru and to the increased U.S. production.

LEGISLATION AND GOVERNMENT PROGRAMS

The U.S. Department of the Treasury, as required by Public Law 100-440, the Treasury and Postal Service Appropriations Bill, sold a portion of its silver stocks. Pubic Law 100-440 authorized the disposal of approximately 233 metric tons of Treasury Department silver over a 3-year period. Sales of nearly 78 tons was to occur in each of fiscal years 1989-91, although the quantity of silver sold could be reduced to avoid severely disrupting the domestic silver market.

In early fiscal year 1989, officials at the Treasury Department developed criteria to determine whether a proposed sale would severely disrupt the domestic silver market. According to the criteria, a proposed sale should proceed, unless the silver price had declined in 15 of the 20 previous days, and the silver price had declined by 5% or more during that same 20-day period.

The Defense Logistics Agency (DLA), acting as sales agent for the Treasury Department, sold 78 tons of silver as required for fiscal year 1989 in two sales. The first sale occurred on May 9 and the second on July 18. The silver was sold through an auction process, marking the Government's first use of auctions for silver disposal since late 1981 when 62 tons of National Defense Stockpile (NDS) silver was sold. From 1982 until the May 9 sale, Government disposals of excess silver had been accomplished through various coinage programs. Purities of the disposed

TABLE 1

SALIENT SILVER STATISTICS

		1985	1986	1987	1988	1989
United States:						
Mine production	metric tons	1,227	1,074	1,241	1,661	2,007
Value, dollars per troy ounce-thousands		r$241,580	$188,846	r$277,063	$349,339	$354,971
Percentage derived from:						
Precious metals ores		70	63	W	W	W
Base metal ores		30	37	W	W	W
Placers		(1)	(1)	(1)	(1)	(1)
Refinery production:						
Domestic and foreign ores and concentrates	metric tons	1,674	1,319	1,415	1,474	1,718
Secondary (old scrap)	do.	866	762	810	852	735
Exports:						
Refined	do.	392	314	350	444	430
Other	do.	r368	467	493	555	850
Imports for consumption:						
Refined	do.	r4,244	3,899	2,114	2,260	3,062
Other	do.	473	607	431	497	241
Stocks, Dec. 31:						
Industry	do.	574	550	r471	r480	544
Futures exchanges	do.	5,385	5,042	5,279	5,862	7,795
Apparent demand, refined[2]	do.	r6,392	5,666	3,989	4,142	5,085
Coinage	do.	11	234	469	275	265
Price, average per troy ounce[3]		$6.14	$5.47	$7.01	$6.54	$5.50
Employment[4]		3,000	2,200	1,800	2,300	2,800
World:						
Mine production	metric tons	r13,051	r12,970	13,757	p14,167	e14,452
Consumption:[3]						
Industry and the arts	do.	r13,906	r15,399	r15,443	r16,671	17,004
Coinage	do.	r277	r526	r933	r799	1,070

e Estimated. p Preliminary. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] Less than 1/2 unit.

[2] Defined as refinery production from primary materials plus refinery production from old scrap plus imports 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.

[3] Handy & Harman.

[4] Mine Safety and Health Administration.

Treasury silver ranged from 40% to 99.9%.

For fiscal year 1990, DLA proposed selling the required 78 tons in four sales. The first sale occurred on October 31, and bids for slightly more than 19 tons were accepted.

Near mid-June, the first gold and silver coins commemorating the bicentennial of Congress were struck at the U.S. Capitol Building. The coins were authorized by Public Law 100-673, the Bicentennial of the United States Congress Commemorative Coin Act, and signed by the President on November 17, 1988. The ceremony marked the first time that official U.S. coins had been struck outside a U.S. Mint facility since 1792. Public Law 100-673 authorized the production of 1 million gold coins, 3 million silver coins, and 4 million copper clad coins. The silver coin was to contain 24 grams of silver, and the silver was to be obtained from the NDS. A surcharge added to each coin's price was to be used by the Capitol Preservation Commission to maintain and restore the capitol building.

PRODUCTION

Silver was produced from precious metal ores at 111 lode mines. Silver also was produced as a byproduct of the processing of copper, lead, and zinc ores at 51 lode mines. In 1989, 18 mines each produced more than 30 tons of silver; their aggregated production equaled 79% of total domestic production. Silver was also produced at 15 placer operations. U.S. silver production in 1989, 2,007 tons, was the largest quantity produced in any year since 1941 when 2,211 tons was produced.

Alaska

Commercial production began at the Greens Creek Mine during the first quarter of 1989. The underground mine, on Admiralty Island, used a 900-ton-per-day mill to produce gold, lead, silver, and zinc. Kennecott Corp. operated the mine. Other partners in the venture included CSX Energy Inc., Exalas Resources Corp., and Hecla Mining Co. Although Greens Creek did not achieve full production during the year, nearly 161 tons of silver was produced during the first 11 months of operation.[1]

The first concentrates were produced at the new Red Dog Mine in late November. The mine, an open pit operation 192 kilometers north of the Arctic Circle, near the Chukchi Sea, produced lead and zinc concentrates containing byproduct silver. Owing to the mine's location, concentrates can only be shipped from the area during an approximate 100-day interval in the summer. As a result, a concentrate storage facility, capable of holding 9 months of production, was constructed near the port. The first concentrates were delivered to the storage facility in December. The mine was developed by Cominco Alaska Inc., a subsidiary of Cominco Ltd. Cominco Alaska leased the property from the NANA Regional Corp., one of 13 native corporations established by the Alaska Native Claims Settlement Act of 1971.

Idaho

Production began at the Champagne Mine, an open pit, heap-leach operation. The mine, near Arco, was owned by Bema Gold Corp. (85%) and Glamis Gold Ltd. (15%).

Mining and milling resumed at the Copper Cliffs Mine in June. The open pit mine, closed since 1981, produced copper concentrates containing byproduct silver. Copper Cliffs was operated by Alta Gold Co., a company formed in late November following the merger of Silver King Mines Inc. and Pacific Silver Corp. Known reserves at the mine were expected to be depleted in 1990.

A heap-leach facility was constructed at the Yellow Pine gold-silver mine in Valley County. During 1989, approximately 84,000 tons of ore was mined and stockpiled at Yellow Pine in preparation for the resumption of processing in 1990.

Michigan

Callahan Mining Corp. announced the indefinite closure of the Ropes gold-silver mine in late September. Ground control problems near the mine's main production shaft and low gold prices were cited as the reasons for the closure. The mine, located near Ishpeming, has had a history of ground control problems since its opening in late 1985. A number of methods for transporting ore to the surface were investigated during the remainder of the year. Among the methods examined were trucking the ore directly from the mine, trucking the ore to the mine's 900-foot level and then using existing facilities to hoist the ore to the surface, and installation of a steel and concrete liner in a portion of the shaft. Company officials stated, however, that regardless of the method chosen to transport the ore, the mine would not reopen until the gold price recovered.

Metall Mining Corp. acquired the Copper Range Co. in May. The principal assets of Copper Range were the White Pine Mine, mill, and smelter. Copper Range was formed in 1985 when the employees and management of White Pine reached an agreement to purchase the facilities from Echo Bay Mines Ltd. White Pine, the State's largest silver producer, recovered silver as a byproduct of its copper operations.

Montana

In June, Pegasus Gold Inc. acquired Pangea Resources Ltd., an Australian mining company with interests in the United States. As a result of the acquisition, Pegasus became the owner of the Basin Creek Mine. Basin Creek was an open pit, heap-leach, gold-silver producer located near Helena.

In Silver Bow County, commercial production began at the Beal Mountain Mine during May. Beal Mountain was an open pit operation owned by Pegasus. Ore from the mine was crushed, agglomerated, and placed on impermeable pads for heap leaching. During 1989, the mine produced nearly 1.2 tons of gold and 0.25 tons of silver.[2]

ASARCO Inc. acquired a 49.9% interest in the Continental Mine in June. Asarco reportedly acquired the holding from Montana Resources Inc. as part of its strategy to change from being primarily a custom smelter and refiner to being a fully integrated producer. The Continental Mine was an open pit copper-molybdenum-silver producer located near Butte.

American Copper and Nickel Co., a subsidiary of Inco Ltd., officially began production at the underground Mineral Hill gold-silver mine in September. Mineral Hill, a 50-50 joint venture of American Copper and Nickel and Homestake Mining Co., was located in Park County, adjacent to Yellowstone National Park. Owing to the site's environmental sensitivity, the

companies went to unusual lengths to minimize the mine's visual and environmental impacts. Among the steps taken were complete containment of the mine and mill water systems, limiting surface excavations as much as possible, using only existing roads, and the initiation of special procedures for tailings disposal. The mine received the Greater Yellowstone Ecosystem Bald Eagle Working Group Award, recognizing its environmental commitment and efforts to ensure the well-being of bald eagles near its property. Ore from the mine was processed by a 400-ton-per-day mill located on-site.

Nevada

Mining operations at the Alligator Ridge Mine were suspended near mid-December, owing to the exhaustion of identified ore reserves. The mine, a joint venture of NERCO Minerals Co. (50%) and Kennecott Corp. (50%), processed ore using both heap-leach and carbon-in-leach facilities. Ore treatment and metal production were expected to continue into 1990.

Mining was halted at the Austin Mine in November. The decision was attributed in part to low ore grades and reserves. The mine was operated by WESTGOLD Inc., in partnership with FMC Gold Co. Reclamation of the site was begun and was expected to be completed by late 1990.

Two projects to enhance production capabilities were completed in June and September at the Big Springs and Jerritt Canyon Mines, respectively. The main components of both projects were the installation of ore roasting circuits at the mills. These new facilities operated independent of the older mill circuits and allowed treatment of refractory ores as well as ores previously considered subeconomic. At Jerritt Canyon, the new roasters were designed to treat about 3,200 tons of ore per day. Total ore throughput at Jerritt Canyon following installation of the roasters was estimated to be about 6,400 tons per day.

Mining was completed at the Borealis Mine. Echo Bay, the mine's owner, expected leaching operations to continue through 1990. Reclamation of the mine site was begun.

The first gold-silver doré bar was poured at the Bullfrog Mine in late July. The mine, located near Beatty, was wholly owned by Bond International Gold Inc. Ore from the pit was processed through a modified carbon-in-leach circuit. Construction of the mine and mill was completed in less than a year.

In late October, U.S. Gold Corp. sold its 29.3% interest in the Dee Mine to its principal partners, Corona Corp. and Rayrock Yellowknife Resources Inc. After the sale, Corona and Rayrock each had a 44% interest in the mine with the remaining 12% privately held. Dee, an open pit operation in Elko County, used both milling and heap leaching to recover gold and byproduct silver.

The Golden Butte Mine, located about 80 kilometers north of Ely, began production in June. The mine, an open pit operation, recovered gold and a small quantity of silver using heap leaching. Golden Butte was operated by Alta Bay Venture, a joint venture of Alta Gold (60%) and Echo Bay (40%).

Heap leaching was completed at Alta Bay's Illipah Mine. Mining at the site had ended in 1988.

Milling operations began at the Marigold Mine in September. The new open pit mine used a 1,100-ton-per-day mill to produce gold and a small quantity of byproduct silver. Heap leaching was expected to begin during the first quarter of 1990. The mine was owned by Corona, Placer Dome U.S. Inc., Rayrock, and Santa Fe Pacific Mining Corp.

At the McCoy/Cove Mine, a new 6,800-ton-per-day mill began commercial operation in July. The new mill processed high-grade oxide ore from both the McCoy and Cove pits. Lower grade oxide ore continued to be heap leached. Ramps were driven into the sulfide ore beneath both pits, and underground mining began beneath the Cove pit in December. The sulfide ore produced underground was also processed by the new mill. Ground water problems reduced the expected underground mining rate to about 540 tons per day. As a result, in December Echo Bay, the mine's owner, initiated a program to increase the surface mining rate from 118,000 tons per day to 150,000 tons per day. An extensive core drilling program undertaken in 1989 resulted in a reduction of proven and probable reserves at McCoy and Cove by 11%, to about 390 tons and about 4,000 tons of contained gold and silver, respectively.[3] Contamination of earlier drill samples owing to the nature of the host rock, combined with the presence of ground water and the high-water flow rates associated with reverse circulation drilling were cited by Echo Bay as the reasons for the reserve revision.

Ore at the Preble Mine, an open pit operation in Humboldt County, was exhausted during the third quarter. Heap leaching was expected to continue until the second quarter of 1990. In the future, the facilities were expected to be used to process ore from the Kramer Hill deposit, about 20 kilometers southwest of Preble.

Pegasus commenced reclamation of the Relief Canyon Mine. Mining operations were completed, and the loading of ore on the pads for heap leaching ended in late 1989. Leaching operations and gold-silver recovery were expected to end in 1990.

A program begun in 1987 to increase the production capacity of the Round Mountain Mine was completed in 1989. The new plant consisted of a large gyratory primary crusher, an intermediate ore storage and reclaim system, secondary and tertiary cone crushers and screens, a conveyor system to transport the ore, and an automated stacking system for the leach pad. With the new facilities, Round Mountain was expected to be capable of processing 41,000 tons of ore per day.

In April, Amax Gold Inc. began commercial operations at its Wind Mountain Mine in Washoe County. The open pit, heap-leach operation reportedly produced about 1 ton of gold and more than 10 tons of silver from May through December.[4] The mine used the Merrill-Crowe process to produce precious metal precipitates. The precipitates were subsequently processed to produce doré at Amax Gold's Sleeper Mine. Notable was the fact that the mine began production 84 days after the first concrete pour at the site.

Mining was completed at the Wood Gulch Mine, a small heap-leach operation owned by Homestake Mining Co. Leaching and precious metal recovery were expected to continue through 1990.

Other States

The Royal Mountain King Mine in Calaveras County, CA, began produc-

tion in late February. An open pit operation, the mine used a 2,300-ton-of-ore-per-day mill and produced gold and silver doré. The mine was developed by Meridian Minerals Co. and Mother Lode Gold Mines Consolidated.

Mining was halted at the Sixteen-to-One Mine in October. The mine, a joint venture of Royal Gold Inc. and Lucky Chance Mining Co., was located in Sierra County, CA. Sixteen-to-One was an underground operation that produced gold and byproduct silver. Royal Gold officials attributed the decision to temporarily suspend mining operations to the low gold price.

At the end of August, Nerco acquired Texasgulf Minerals & Metals Inc. Texasgulf and its joint-venture partner, Golden Cycle Gold Corp., used heap leaching to process previously mined material in the Cripple Creek Mining District near Victor, CO. After the acquisition, Texasgulf was renamed Pikes Peak Mining Co.

CONSUMPTION AND USES

Apparent U.S. demand for silver in 1989, calculated as refinery production from primary materials and from old scrap plus net imports of refined bullion, was 4,967 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, photo-offset printing plates, and in some other minor light-sensitive products. Photographic materials are produced by depositing thin layers of silver salts, gelatin, and dyes onto a support material. Silver salts, although not extremely sensitive to light when first exposed to illumination, produce a greatly intensified image when subsequently treated with photographic chemical developers. The developer reduces a portion of each silver salt grain to metallic silver, depending on the intensity of the light to which the grain was exposed. The resulting gray to black metallic silver forms a negative image of the original object.

Silver is used in electrical and electronic products because of its high electrical and thermal conductivity and its resistance to corrosion. Silver has the highest thermal and electrical conductivity of any known substance. 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 1989 increased by more than 1,700 tons over the previous year owing to a significant increase in Commodity Exchange Inc., (COMEX) held stocks. Analysts attributed the larger COMEX stocks to the movement of unreported bullion stocks to New York depositories from depositories and warehouses outside the State, in response to the abolition of New York's precious metals sales tax. As reported to the Bureau of Mines, refiner, fabricator, and dealer stocks remained essentially unchanged from the previous year.

The quantity of Government-held silver continued to decline. The U.S. Mint used NDS silver stocks for various coinage programs, and a portion of excess Treasury Department stocks were sold through Government-sponsored auctions in May and July.

PRICES

The domestic silver price as quoted by Handy & Harman remained in a relatively narrow range throughout 1989. The price began the year at $6.07 per troy ounce and was $5.18 at yearend. Throughout the year, there were no significant upward price movements; rather, the price gradually drifted lower toward $5.00 per troy ounce. In mid-November, the price rallied briefly, reaching $5.84 on November 22 before resuming a downward trend. Factors that analysts believed to have affected the silver price during the year included: the value of the U.S. dollar in terms of certain foreign currencies; expectations of no more than a moderate U.S. inflation rate; a lower demand for bullion by investors; and increased U.S. interest rates.

As with the domestic price, the London spot price was quoted within a relatively narrow range throughout the year. The U.S. dollar equivalent of the London spot price, as published in Metals Week, began 1989 at $6.07 and ended the year at $5.22. The high price for the year, $6.21, occurred on January 24. The low price for the year, $5.05, occurred on September 1 and again on October 11. The average for 1989 was $5.51.

The amount of silver represented by the future contracts traded on the COMEX decreased in 1989 to 680,640 metric tons. At the Chicago Board of Trade (CBT), the quantity of silver corresponding to the futures trading volume decreased from 15,626 tons to 8,295 tons in 1989. Silver futures trading volume on the Mid-America Commodity Exchange (Mid-Am), at 422 tons, remained essentially unchanged from the previous year.

FOREIGN TRADE

U.S. silver exports increased in 1989 for the fifth 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 135 tons and 123 tons, respectively. In the case of both Canada and Japan, most of the increased shipments were in the form of silver-bearing waste and scrap materials. The largest decrease in U.S. silver exports from the previous year was in shipments of waste and scrap materials to France—approximately 59 tons.

U.S. silver imports for consumption increased, probably owing in part to the stronger U.S. dollar in terms of foreign exchange rates. The countries with the largest increases of silver exports to the United States were Mexico, with an increase of more than 541 tons; Canada, with a 98 ton increase; and Uruguay, with a 61 ton increase. For all three countries, the increased exports were primarily refined bullion.

WORLD REVIEW

The data in table 13 were rated production capacity in mines as of December 31, 1989. 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 judgement of the author, can be brought into production within a short period of time with minimum capital expenditure.

World mine production of silver increased slightly in 1989. Increased production of copper, lead, and zinc resulted in increased byproduct silver production. Other reasons for the higher production included a more stable labor situation with fewer strikes in Peru and the opening of a number of new gold mines, many of which produce byproduct silver. Although gold continued to be the primary metals exploration target during the year, the higher prices for copper, lead, and zinc encouraged exploration for these metals also. Most copper, gold, lead, or zinc deposits contain some silver. Oceania and countries bordering the Pacific Ocean continued to be the most active exploration areas.

Before 1989, Handy & Harman, in its annual review, estimated silver production and consumption for market economy countries only. However, in response to the year's geopolitical developments, Handy & Harman began making world production and consumption estimates. In its 1989 review, Handy & Harman estimated world silver consumption at about 18,100 tons, an increase of more than 600 tons over the revised 1988 figure.[5] Of the total, approximately 17,000 tons was used in industrial applications, a 333-ton increase over the 1988 level. The quantity of silver used for coinage increased from about 800 tons in 1988 to about 1,100 tons in 1989.

Canada

Mine production resumed at the Heath Steele lead-zinc-copper-silver underground mine in June. The Heath Steele Mine in New Brunswick had been inactive since 1984. Partners in the mine were Noranda Inc. (75%) and Brunswick Mining and Smelting Corp. Ltd. Operations at the new Stratmat Mine, adjacent to the Heath Steele Mine, began in July. Stratmat, consisting of both open pit and underground operations, produced lead, zinc, copper, and silver. Noranda and Brunswick Mining each had a 50% interest in the Stratmat Mine.

Near mid-December, shareholders of Dumagami Mines Ltd. voted to merge Dumagami with Agnico-Eagle Mines Ltd. Dumagami's principal asset was the LaRonde Mine, an underground gold-silver-copper operation located in Quebec. In 1989, during its first full year of operation, the LaRonde Mine produced 2.6 tons of gold and 4 tons of silver.[6]

Cominco Ltd. completed construction of its new lead smelter near Trail, British Columbia, near yearend. The new plant was expected to result in significantly lower sulphur, lead, and particulate emissions through the use of an oxygen smelting process. Although the first lead bullion was produced by the plant in late December, mechanical problems and metallurgical process difficulties prevented the plant from achieving normal operations by yearend. At its Trail facility, Cominco produced more than 350 tons of refined silver during 1989.[7]

At the Valley Mine in British Columbia, Highland Valley Copper Co. completed the renovation and expansion of its milling facilities. Two mills formerly owned by Highmont Mining Co. were

moved to a site adjacent to the Lornex mill, and an older nearby mill was closed. The new facility, called the Highland mill, can process more than 130,000 tons of ore per day. Near mid-October, a 2-year agreement was reached with the mine's workers, ending a 15-week strike.

An 8-year legal battle for ownership of the Williams Mine ended in August. The Supreme Court of Canada ruled that the mine, in the Hemlo District of Ontario, belonged to Corona Corp. The decision upheld earlier rulings that LAC Minerals Ltd., developer of the mine, had used confidential information supplied by Corona's predecessor company to acquire the property where the Williams Mine was later located. The mine, which recovers some byproduct silver, was Canada's largest gold producer. After the ruling, Corona split the mine's ownership with Teck Corp. in return for Teck's paying 50% of the related legal costs. Included in the legal costs was approximately C$213 million to reimburse LAC for its expenditure to develop the mine.

In September, Noranda and Trelleborg AB acquired control of Falconbridge Ltd. Falconbridge, a Canadian copper, gold, nickel, silver, and zinc producer, was expected to increase Noranda's silver production by 40% in 1990. Following the acquisition, Noranda and Trelleborg each had a 50% interest in Falconbridge's assets, including 11 mines and 5 metallurgical plants.

Other Countries

In March, Battle Mountain Gold Co. acquired 33.3% of the stock of Inti Raymi S.A., a Bolivian gold-silver producer. In July, Battle Mountain acquired an option to increase its equity interest in Inti Raymi to 51%. Inti Raymi operated the Kori Kollo Mine, a heap-leach operation in Western Bolivia near Oruro. For 1989, Kori Kollo produced about 6 tons of silver.[8]

In November, the initial pour of gold-silver bullion was made at the Crixas Mine, an underground operation in the Brazilian State of Goiàs. The mine was a joint venture of Mineraçáo Morro Velho S.A. (50%) and two Brazilian subsidiaries of Inco Ltd. Included at the mine site was a 1,000-ton-per-day mill.

In November, Freeport McMoRan Inc. announced that it and three affiliates would restructure their operations by selling what were regarded as nonstrategic assets and businesses. Proceeds from the sale of these assets were to be used for debt reduction and the development of Freeport's two new mineral discoveries, one of which was the Grasberg copper-gold-silver deposit in Indonesia on the western half of the island of New Guinea. By yearend, Freeport had sold a number of its oil and gas assets and reportedly was seeking buyers for others.

Development work began at the Grasberg deposit with the prestripping of waste material. Ore from Grasberg was expected to be processed at the mill serving Freeport's other mines in the area. In February, Freeport began a program to increase the mill's processing rate to 32,000 tons of ore per day. In August, Freeport's board of directors approved expanding the mill's capacity to 52,000 tons of ore per day by 1992. In the fourth quarter, a fourth ball mill became operational, allowing the mill to process up to 32,000 tons of ore per day.

Control of Consolidated Gold Fields PLC was acquired by Hanson PLC, a British conglomerate, in early August. The acquisition ended a nearly yearlong battle for Gold Fields, an international mining company with gold and silver operations in Australia, the Republic of South Africa, and the United States. Gold Fields became an acquisition target when Minorco S.A., a Bermuda-based investment company with ties to the Republic of South Africa, made a hostile bid for all of the Gold Field shares that it did not already own. Hanson's winning bid, made in July, valued Gold Fields at more than $5.5 billion, making the acquisition the largest in British history. It was widely believed that Hanson would attempt to recover part of the purchase price by selling some of Gold Fields' assets. In mid-August it was announced that Hanson had sold a 30% stake in Gold Fields South Africa, a gold and byproduct silver producer. The sale reduced the original Gold Fields holding in the South African company to 8%.

CURRENT RESEARCH

Silver-related research and development was extensive in 1989. Numerous reports on silver-related research were summarized in New Silver Technology, a publication published under the auspices of The Silver Institute.[9]

OUTLOOK

The recent increase in domestic silver production was due in part to significant operating cost reductions at many mines, which allow these operations to remain profitable at silver prices as low as those in 1989. Another factor in the higher domestic production is that silver is often recovered as a byproduct of other nonferrous metals. Extensive exploration and development during the past decade has resulted in the opening of a large number of new, low-cost gold mines, most of which produce some byproduct silver. More recently, the prices of such nonferrous metals as copper, lead, and zinc have increased, stimulating an increase in the production of these commodities. As is the case with gold mines, most of these other nonferrous mines also produce some byproduct silver. In either case, the byproduct silver is either concentrated when the ore is processed or recovered with the principal product. Because the additional cost of recovering the silver is relatively low, its production is not dependent on the demand for silver; rather, its production is dependent on the demand for and resultant production of the principal product. Therefore, assuming that domestic economic conditions remain similar to those of 1989 and that the price of commodities such as copper, gold, lead, and zinc do not decline significantly, it is expected that the domestic silver supply will remain near 2,000 tons per year during the 1990–92 period.

Worldwide, the silver supply is also expected to remain near the 1989 level of 14,500 tons. It is assumed that labor unrest in countries such as Peru does not increase significantly and that local population concern about mining operations, such as in Papua New Guinea, does not spread.

Future industrial demand for silver is harder to forecast owing to the lack of data. Some analysts believe that the domestic industry demand for silver is

growing at a rate of perhaps 5% per year. Other analysts believe that in 1989, U.S. industrial demand for silver declined. It is believed that during 1990–92, industrial silver demand will grow slightly, primarily because of its lower cost. Worldwide, demand for silver is expected to grow at a slightly higher rate than in the United States, primarily because political events such as those in Eastern Europe should open new markets for products containing silver.

BACKGROUND

Silver has played an important role in peoples' lives since ancient times. Early man 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 to meet both industrial demand and 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 1964–67. 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 to 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 Bolivia, Mexico, and Peru, silver production shifted from Europe to these countries. 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 1989.

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 silver 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 a minimum of 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, strip and foil, are available in widths of up to almost 2.1 meters and as thin as 0.01 millimeters. 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 are the main components account for the remaining one-third of total world reserves and resources. U.S. silver resources are estimated to be about 190,000 tons.[10] 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 ($Ag_{16}Sb_2S_{11}$), prousite (Ag_3AsS_3), pyrargyrite (Ag_3SbS_3), stephanite (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 inches to 8 feet 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. Currently, the United States is experiencing extensive exploration for precious metal deposits, most of which is being conducted in the Rocky Mountain States. It is likely that if major new reserves are discovered, the deposits will be located 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 located above each other and are vertically separated by as much as 200 feet 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 predominatly 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 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 pure silver strips or graphite are 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 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 often 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, some mines appear capable of producing silver at a cost of less than $160,000 per ton while other mines require a silver price in excess of $260,000 per ton to be profitable. Underground mining is, in general, more expensive than surface mining.

U.S. silver-producing companies are permitted 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 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 silver is not a toxic substance in other than very large doses, a standard has been established for worker exposure to airborne silver. The Occupational Safety and Health Administration currently requires that worker exposure to either silver metal or soluble silver compounds be less than 0.01 milligram per cubic meter of ambient air.

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 groundwater, nearby water courses, 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.

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TABLE 2

MINE PRODUCTION OF RECOVERABLE SILVER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1985	1986	1987	1988	1989
Alaska	W	W	(1)	1	W
Arizona	152	140	114	152	171
California	4	5	4	15	21
Colorado	17	20	27	27	W
Idaho	586	349	W	340	439
Michigan	W	W	W	W	W
Missouri	51	45	37	45	53
Montana	125	148	185	192	194
Nevada	154	199	379	608	625
Oregon	—	—	W	W	W
South Carolina	W	W	W	W	W
South Dakota	2	W	W	3	4
Other[2]	137	167	496	279	500
Total[3]	1,227	1,074	1,241	1,661	2,007

W Withheld to avoid disclosing company proprietary data.
[1] Less than 1/2 unit.
[2] Includes Illinois, New Mexico, New York, Tennessee, Utah, and 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	1985	1986	1987	1988	1989
January	107	115	99	116	143
February	95	101	97	114	139
March	105	102	105	131	166
April	100	99	103	126	160
May	104	90	99	129	176
June	100	86	101	142	174
July	100	84	110	142	175
August	104	81	107	152	185
September	91	82	109	152	179
October	120	82	105	157	168
November	97	74	100	150	170
December	102	78	106	150	173
Total[1]	1,227	1,074	1,241	1,661	2,007

[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 1989, 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	Rochester	Pershing, NV	Coeur Rochester Inc.	Do.
5	Candelaria	Mineral, NV	NERCO Metals Inc.	Do.
6	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Co.	Copper ore.
7	Troy	Lincoln, MT	ASARCO Incorporated	Silver-copper ore.
8	Galena	Shoshone, ID	do.	Silver ore.
9	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold ore.
10	Coeur	Shoshone, ID	ASARCO Incorporated	Silver ore.
11	Lucky Friday	do.	Hecla Mining Co.	Lead-zinc ore.
12	DeLamar	Owyhee, ID	Nerco DeLamar Co.	Gold-silver ore.
13	Tyrone	Grant, NM	Phelps Dodge Corp.	Copper ore.
14	Escalante	Iron, UT	Hecla Mining Co.	Silver ore.
15	Sierrita	Pima, AZ	Cyprus Sierrita Corp.	Copper ore.
16	Mission Complex[1]	do.	ASARCO Incorporated	Do.
17	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Gold ore.
18	White Pine	Ontonagon, MI	Copper Range Co.	Copper ore.
19	Continental	Silver Bow, MT	Montana Resources Inc.	Do.
20	Trinity	Pershing, NV	U.S. Borax & Chemical Corp.	Silver ore.
21	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Copper ore.
22	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Co.	Do.
23	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
24	Wind Mountain	Washoe, NV	Amax Gold Corp.	Gold ore.
25	Ray	Pinal, AZ	ASARCO Incorporated	Copper 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[1]

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
1985	(2)	24,392,566	51	946,969	63	3,903,328	747
1986	(2)	38,931,526	120	788,434	56	5,040,027	493
1987	1	62,044,114	221	W	W	7,944,696	432
1988	(2)	108,310,781	r372	W	W	9,573,505	674
1989:							
Alaska	W	W	W	—	—	—	—
Arizona	(2)	134,536	3	—	—	—	—
California	W	17,045,563	20	—	—	—	—
Colorado	W	W	5	—	—	—	—
Idaho	—	W	1	W	W	W	W
Illinois	—	—	—	—	—	—	—
Michigan	—	W	W	—	—	—	—
Missouri	—	—	—	—	—	—	—
Montana	—	13,290,968	12	—	—	W	W
Nevada	W	104,766,110	454	32,173	11	W	W
New Mexico	—	W	W	—	—	—	—
New York	—	—	—	—	—	—	—
Oregon	W	—	—	—	—	—	—
South Carolina	—	W	W	—	—	—	—
South Dakota	—	4,173,944	3	—	—	—	—
Tennessee	—	—	—	—	—	—	—
Utah	—	4,440,675	7	W	W	292,175	51
Washington	—	W	W	—	—	—	—
Total	W	153,826,050	528	W	W	4,450,703	524
Percent of total silver	(2)	XX	26	XX	W	XX	26

	Lode				Total	
	Copper ore		Other[3 4]			
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1985	140,304,031	300	11,170,326	64	180,717,219	1,227
1986	[5]133,060,395	[5]345	5,484,734	59	183,305,115	1,074
1987	201,434,248	477	W	W	279,753,709	1,241
1988	r222,306,768	485	W	W	r350,639,851	1,661
1989:						
Alaska	—	—	W	W	W	W
Arizona	141,811,972	165	W	W	142,036,494	171
California	—	—	W	W	17,171,602	21
Colorado	—	—	W	W	1,554,668	W
Idaho	W	W	W	W	3,958,757	439
Illinois	—	—	—	W	—	W
Michigan	W	W	—	—	W	W
Missouri	—	—	6,834,189	53	6,834,189	53
Montana	W	W	W	W	35,319,986	194
Nevada	W	W	—	—	108,459,275	625
New Mexico	29,415,333	77	—	—	W	W
New York	—	—	W	W	W	W
Oregon	—	—	—	—	—	W
South Carolina	—	—	—	—	W	W

See footnotes at end of table.

TABLE 5—Continued

SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE[1]

	Lode				Total	
	Copper ore		Other[3 4]			
	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1989—Continued						
South Dakota	—	—	92	1	4,174,035	4
Tennesse	—	—	W	W	W	W
Utah	W	W	—	—	W	W
Washington	—	—	—	—	W	W
Total	230,558,082	529	W	W	405,732,025	2,007
Percent of total silver	XX	26	XX	W	XX	100

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.
[1] Data may not add to totals shown because of independent rounding.
[2] Less than 1/2 unit.
[3] Includes lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.
[4] Includes silver recovered from tungsten and fluorspar ores.
[5] Includes copper-zinc ore and silver recovered from copper-zinc ore.

TABLE 6

SILVER PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

Year	Leaching in vats, tanks, and closed containers[2 3]		Leaching in open heaps or dumps[4]	
	Ore treated (metric tons)	Silver recovered (metric tons)	Ore treated (metric tons)	Silver recovered (metric tons)
1985	13,990,519	212	13,494,706	84
1986	17,481,228	233	25,057,030	113
1987	[r]17,942,079	280	45,256,274	254
1988	26,603,455	302	86,870,554	456
1989	37,031,057	226	117,836,833	564

[r] Revised.
[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

Year and State	Amalgamation		Cyanidation		Smelting of concentrates			Smelting of ore		Total ore processed[1 2] (metric tons)	Total silver recovered[2] (metric tons)
	Ore treated (metric tons)	Silver recovered (metric tons)	Ore treated (metric tons)	Silver recovered (metric tons)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Silver recovered (metric tons)	Ore smeltered (metric tons)	Silver recovered (metric tons)		
1985	—	—	37,485,225	296	152,997,656	4,103,779	912	234,339	18	180,717,219	1,226
1986	682,585	(3)	42,538,258	346	139,899,530	3,542,557	717	184,742	9	183,305,115	1,074
1987	W	W	r63,198,353	534	211,446,971	4,459,843	696	W	W	r279,753,709	1,240
1988	1,512	(3)	113,474,009	758	r236,925,134	r4,943,949	884	239,195	19	r350,639,851	1,661
1989:											
Alaska	—	—	W	W	W	W	W	—	—	W	W
Arizona	—	—	W	W	141,807,608	2,398,289	165	102,188	W	142,030,089	[4]171
California	W	W	14,988,930	19	W	W	W	—	—	17,171,602	[4]21
Colorado	1,613	(3)	W	W	W	W	W	W	W	1,554,668	W
Idaho	—	—	3,007,878	59	950,879	60,780	381	—	—	3,958,757	439
Illinois	—	—	—	—	—	—	W	—	—	—	W
Michigan	—	—	W	W	W	W	W	181	(3)	W	W
Missouri	—	—	—	—	6,834,189	577,356	53	—	—	6,834,189	53
Montana	—	—	W	W	22,042,908	221,251	183	W	W	35,319,986	194
Nevada	—	—	108,154,153	623	W	W	W	W	W	108,459,275	[4]625
New Mexico	—	—	—	—	W	W	W	W	W	W	W
New York	—	—	—	—	W	W	W	—	—	W	W
South Carolina	—	—	W	W	—	—	—	—	—	W	W
South Dakota	—	—	4,173,944	3	—	—	—	92	1	4,174,035	4
Tennessee	—	—	—	—	W	W	W	—	—	W	W
Utah	—	—	4,732,850	58	W	W	W	W	W	W	W
Washington	—	—	W	W	W	W	W	—	—	W	W
Total	W	W	154,867,890	790	248,846,222	5,164,847	1,195	188,566	W	405,725,620	2,007

r Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[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.

[4] Includes some placer production to avoid disclosing company proprietary data.

TABLE 8

U.S. REFINERY PRODUCTION OF SILVER

(Metric tons)

Raw material	1985	1986	1987	1988r	1989
Concentrates and ores:					
Domestic and foreign	1,674	1,319	1,415	1,474	1,718
Old scrap	866	762	810	852	735
New scrap	1,389	1,448	1,316	1,505	1,495
Total[1]	3,928	3,529	3,541	3,832	3,948

r Revised.

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

TABLE 9

YEAREND STOCKS OF SILVER IN THE UNITED STATES

(Metric tons)

	1985	1986	1987	1988	1989
Industry	574	550	r471	r480	544
Futures exchanges	5,385	5,042	5,279	5,862	7,795
Department of the Treasury	1,015	1,052	1,229	1,201	997
Department of Defense	14	78	75	81	81
National Defense Stockpile	4,277	3,960	3,517	3,310	2,973

r Revised.

TABLE 10

U.S. SILVER PRICES

(Dollars per troy ounce)

Period	Low		High		Average
	Price	Date	Price	Date	
1985	5.57	Mar. 12	6.74	Mar. 27	6.14
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:					
January	5.82	Jan. 31	6.17	Jan. 23	5.97
February	5.80	Feb. 13	6.00	Feb. 23	5.89
March	5.76	Mar. 30	6.14	Mar. 14 and 21	5.93
April	5.65	Apr. 28	5.88	Apr. 12 and 13	5.79
May	5.20	May 30	5.66	May 1 and 2	5.45
June	5.15	June 30	5.44	June 8	5.28
July	5.13	July 31	5.38	July 6	5.24
August	5.07	Aug. 31	5.24	Aug. 2 and 22	5.18
September	5.02	Sept. 15	5.29	Sept. 26	5.13
October	5.06	Oct. 10	5.25	Oct. 4	5.13
November	5.17	Nov. 1	5.84	Nov. 22	5.47
December	5.14	Dec. 29	5.71	Dec. 12	5.53
Average and date	5.02	Sept. 15	6.17	Jan. 23	5.50

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)
1985	8,394	$1,651	321,147	$67,884	r38,112	$9,551	392,246	$81,746	r759,899	$160,832
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:										
Argentina	—	—	—		—	—	1,875	375	1,875	375
Australia	—	—	90	54	—	—	—	—	90	54
Austria	—	—	289	51	—	—	351	62	640	113
Belgium	114	26	79,030	18,440	—	—	236	42	79,380	18,508
Brazil	—	—	80	22	407	109	—	—	487	131
Canada	316	91	139,213	26,765	1,681	309	80,791	14,538	222,001	41,703
China	—	—	80	22	—	—	—	—	80	22
Dominican Republic	—	—	1,183	209	—	—	—	—	1,183	209
France	—	—	162,580	30,111	2,007	358	1,886	332	166,473	30,800
Germany, Federal Republic of	—	—	24,730	5,086	2,490	444	16,134	3,153	43,354	8,683
Hong Kong	—	—	1,201	233	187	33	101	18	1,489	284
Israel	—	—	51	9	—	—	—	—	51	9
Italy	55	16	13,030	1,108	3	2	346	61	13,434	1,187
Japan	—	—	174,383	20,117	2,892	521	186,540	33,332	363,815	53,970
Korea, Republic of	—	—	279	52	—	—	18,277	3,547	18,556	3,598
Lebanon	—	—	—	—	—	—	1,900	336	1,900	336
Mexico	—	—	1,479	249	—	—	292	63	1,771	312
Netherlands	68	18	—	—	—	—	—	—	68	18
Panama	—	—	72	13	—	—	—	—	72	13
Singapore	—	—	82	15	349	62	52	16	483	92
South Africa, Republic of	—	—	1,135	201	—	—	—	—	1,135	201
Sweden	—	—	25,919	4,648	—	—	—	—	25,919	4,648
Switzerland	—	—	19,842	4,808	58,436	11,738	2,732	497	81,010	17,043
Taiwan	—	—	1,724	307	7,922	1,415	2,231	417	11,878	2,139
Thailand	35	10	—	—	—	—	452	107	487	117
United Kingdom	—	—	121,114	32,244	2,290	487	115,756	20,890	239,161	53,621
Venezuela	—	—	3,074	544	—	—	—	—	3,074	544
Other	19	5	131	33	—	—	158	27	308	66
Total[2]	607	166	770,788	145,340	78,664	15,478	430,110	77,812	1,280,169	238,797

r Revised.

[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)
1985	109,892	$20,180	55,076	$10,854	307,919	$65,364	r4,244,107	r$849,471	r4,716,995	r$945,869
1986	171,556	30,926	58,066	10,372	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	2,545,065	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:										
Argentina	—	—	—	—	—	—	13,973	2,811	13,973	2,811
Australia	—	—	8	34	—	—	4,219	764	4,227	798
Bolivia	79	17	—	—	—	—	442	81	521	98
Brazil	—	—	—	—	—	—	3,001	666	3,001	666
Canada	1,741	550	38,832	23,307	311	59	1,157,141	217,820	1,198,025	241,736
Chile	284	129	250	370	1,561	275	22,529	4,482	24,624	5,256
China	—	—	53	680	—	—	—	—	53	680
Dominican Republic	—	—	91	74	24,660	4,937	402	100	25,153	5,111
Ecuador	—	—	—	—	4,959	985	1,841	382	6,800	1,366
El Salvador	—	—	384	13	—	—	—	—	384	13
Germany, Federal Republic of	—	—	6	89	—	—	10,023	1,635	10,029	1,724
Haiti	—	—	80	100	—	—	—	—	80	100
India	—	—	8,807	550	—	—	—	—	8,807	550
Israel	—	—	5,000	169	—	—	—	—	5,000	169
Italy	—	—	24	5	8	2	395	51	427	58
Japan	—	—	329	99	—	—	—	—	329	99
Korea, Republic of	—	—	84	150	—	—	—	—	84	150
Malaysia	—	—	4,200	435	—	—	6,219	1,097	10,419	1,532
Mexico	4,011	1,457	2,587	1,015	108,687	21,236	1,656,634	316,705	1,771,919	340,413
Netherlands Antilles	—	—	—	—	—	—	365	70	365	70
Panama	—	—	18	35	—	—	42	9	60	44
Peru	—	—	916	224	722	124	85,883	14,910	87,521	15,258
Philippines	—	—	121	72	—	—	170	30	291	102
Singapore	—	—	939	135	—	—	—	—	939	135
South Africa, Republic of	—	—	—	—	1,069	195	1,473	295	2,542	489
Sweden	880	145	967	11,427	—	—	—	—	1,847	11,572
Switzerland	13	1	5,694	54,438	—	—	—	—	5,707	54,440
Taiwan	—	—	719	1,537	—	—	—	—	719	1,537
Tanzania	—	—	—	—	399	70	—	—	399	70
Thailand	—	—	80	13	—	—	—	—	80	13
United Kingdom	—	—	20,469	680	—	—	(4)	2	20,469	682
Uruguay	—	—	—	—	—	—	60,886	10,662	60,886	10,662
Venezuela	—	—	—	—	—	—	1,368	245	1,368	245
Yugoslavia	—	—	—	—	—	—	34,540	5,964	34,540	5,964
Zaire	—	—	—	—	363	60	—	—	363	60
Other	5	3	96	603	—	—	—	—	101	606
Total[2]	7,013	2,301	90,753	96,254	142,739	27,943	3,061,548	578,781	3,302,054	705,278

r Revised.

[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.

[4] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 13

WORLD ANNUAL SILVER PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(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]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	4	4	4	4	4
Argentina	68	66	60	79	78
Australia	1,086	1,023	1,119	1,118	1,000
Bolivia	111	95	142	232	[3]267
Brazil[e 4]	32	46	50	59	60
Bulgaria[e]	29	28	28	28	28
Burma	18	16	26	9	8
Canada	1,197	1,088	1,375	1,371	[3]1,285
Chile	517	500	500	507	507
China[e]	80	90	[r]100	110	125
Colombia[5]	5	6	5	[e]7	7
Costa Rica[e]	([6])	([6])	([6])	([6])	([6])
Czechoslovakia[e]	([r 6])	([r 6])	([r 6])	([r 6])	([6])
Dominican Republic	50	41	36	40	[3]23
Ecuador[e]	([6])	([6])	([6])	([6])	([6])
Fiji	([6])	1	1	1	1
Finland	31	37	44	[e]31	32
France	26	26	25	22	20
German Democratic Republic	41	41	41	40	39
Germany, Federal Republic of	[r]38	28	31	31	31
Ghana[e]	([6])	([6])	1	1	1
Greece	51	54	52	[e]53	53
Greenland	10	12	13	14	15
Honduras	86	54	23	58	60
India	25	[r]35	38	44	[3]34
Indonesia	38	47	50	58	[3]74
Ireland	9	8	7	6	7
Italy[5 7]	72	56	82	92	93
Japan	339	351	281	252	[3]156
Korea, North[e]	50	50	50	50	50
Korea, Republic of	124	157	209	227	[3]239
Malaysia	16	14	15	11	11
Mexico	[r]2,153	[r]2,303	2,415	2,359	[3]2,306
Morocco	85	49	[e]44	226	225
Namibia	106	108	75	117	100
Nicaragua	1	[e]1	1	[e]1	1
Papua New Guinea	46	56	61	70	70
Peru	1,811	1,926	2,054	1,552	1,840
Philippines	[r]54	[r]54	52	52	[3]48
Poland	831	829	831	1,063	1,060
Portugal	1	1	1	1	1
Romania[e]	25	25	23	23	25
Saudi Arabia[e]	—	—	—	4	11
Solomon Islands	—	—	—	([6])	([6])
South Africa, Republic of	208	222	208	200	[3]178
Spain	367	327	350	353	350
Sweden	231	235	215	193	195
Taiwan	11	13	10	8	[3]6
Tunisia	1	2	[e]2	[e]2	2

See footnotes at end of table.

TABLE 14—Continued

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Turkey[e]	7	7	9	[r]23	18
U.S.S.R.[e 5]	1,490	1,500	1,500	1,490	1,490
United States	1,227	1,074	1,241	1,661	[3]2,007
Yugoslavia[5]	156	177	165	139	140
Zaire	[r]43	34	37	24	20
Zambia	19	27	30	29	29
Zimbabwe	25	26	25	22	[3]22
Total	[r]13,051	[r]12,970	13,757	14,167	14,452

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Recoverable content of ores and concentrates produced unless otherwise specified. Table includes data available through June 20, 1990.

[2] In addition to the countries listed, Botswana produces silver 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 metric tons, are identified as placer silver (the balance being silver content of other ores and concentrates): 1985—14 (estimated); 1986—20 (estimated); 1987—20 (estimated); 1988—22 (estimated); and 1989—22 (estimated).

[5] Smelter and/or refinery production.

[6] Less than 1/2 unit.

[7] Includes production from imported ores.

SLAG—IRON AND STEEL

By Judith F. Owens

Ms. Owens, a physical scientist with 3 years Bureau of Mines experience, has been the commodity specialist for iron and steel slag since 1988.

Notable events in the iron and steel slag industry during 1989 included the acquisition of one of the Nation's largest slag companies and a major international concrete conference on natural pozzolans in which slag played an integral role. The Federal Environmental Protection Agency (EPA) continued to assess iron and steel slags as potential Bevill exclusion candidates under the Resource Conservation and Recovery Act (RCRA). The Bevill exclusion temporarily exempts certain high-volume, low-hazard wastes from hazardous waste regulation.

Research during the year pertaining to slag utilization included studies such as slag in the manufacture of asphaltic concrete, road base pavements, glass, concrete, mine backfill, and ceramics.

Domestically, consumption of both iron and steel slag combined showed a moderate increase when compared with that of 1988, with continuing imports of granulated blast furnace slag entering into the west coast of the United States. Steel slag consumption increased significantly for the second consecutive year in a row, with substantial gains in the marketing of steel slag as the aggregate in asphaltic concrete.

DOMESTIC DATA COVERAGE

Sales, use, and transportation data for iron and steel slag are developed by the Bureau of Mines from a voluntary survey of U.S. processors. Of the 86 operations canvassed, 86 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.

LEGISLATION AND GOVERNMENT PROGRAMS

On September 25, 1989, the EPA conditionally proposed the retention of iron and steel slags under the exemption afforded by the Bevill exclusion of RCRA, pending further evaluation of hazard data.[1]

The Bevill exclusion, section 3001(b)(3)(A)(ii) of RCRA, exempts from hazardous (subtitle C) regulation high-volume, low-hazard wastes generated from the extraction and beneficiation of ores and minerals, pending the evaluation of EPA studies on these wastestreams as mandated under RCRA section 8002. The EPA had been under a court-imposed deadline to narrow the scope and definition of the Bevill exclusion. The general criteria for the Bevill exemption were as follows:

1. Nonliquid mineral processing wastes were generated at an average annual rate greater than 45,000 metric tons per year per facility during any year between 1983 and 1988.

2. Wastes had to pass both a mobility test (Method 1312) and toxicity test (i.e., Method 1310), and the pH of the mineral processing wastestream could not have been less than 1.0 or greater than 13.5.

The specific iron and steel slags retained under the Bevill exemption are iron blast furnace, basic oxygen furnace, and open-hearth furnace. Electric arc furnace slags did not qualify for the exemption because the percentage of nonminerals (scrap) used in the charge of the furnace was greater than 50%.

It was expected that these iron and steel slags would be permanently retained under the Bevill exclusion of RCRA once the EPA finalized the list of wastes by mid-January 1990. If so retained, they would then be

TABLE 1

Iron and steel slags sold or used[1] in the United States

(Thousand short tons and thousand dollars)

Year	Blast furnace slag								Steel slag		Total slag[2]	
	Air-cooled		Granulated		Expanded		Total iron slag[2]					
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1985	13,363	62,588	(3)	(3)	1,742	24,290	15,106	86,878	5,972	17,472	21,078	104,351
1986	13,501	58,899	(3)	(3)	1,879	33,851	15,380	92,750	5,689	17,883	21,068	110,633
1987	14,447	65,943	(3)	(3)	1,774	33,750	16,221	99,693	5,013	15,787	21,234	115,480
1988	14,242	69,415	(3)	(3)	1,658	32,139	15,900	101,554	5,714	18,058	21,614	119,614
1989	13,783	66,574	(3)	(3)	1,706	29,143	15,489	95,717	7,376	24,056	22,865	119,772

[1]Value based on selling price at plant. Includes estimated value data for several operations.

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

[3]Included with "Expanded" to avoid disclosing company proprietary data.

subject to a study for Congress, which would be issued by about late July 1990. A final regulatory determination on all Bevill exempted wastestreams, i.e., whether subtitle C or the nonhazardous subtitle D regulation was warranted, was anticipated by late January 1991.

The Bureau of Mines continued to support the position of the domestic iron and steel slag industry by publicly submitting comments to the EPA that basically stated that those slags that were processed and sold as commercial products were not, and should not be, regulated as solid wastes.

PRODUCTION

The Standard Slag Co., one of the Nation's top slag processors based in Youngstown, OH, was sold in September 1989 with six other affiliates for an undisclosed sum to the Lafarge Corp. based in Reston, VA.[2] Included in the sale were the Duquesne Slag Products Co., Pittsburgh, PA, and the St. Louis Slag Products Co., Granite City, IL. Also acquired from the Standard Slag Holding Co. were Standard Aggregates Inc., Cleveland Builders Supply Co., Standard Materials Inc., and the Portsmouth Trucking Co. Lafarge, a major producer of aggregates and construction materials in North America, bought these companies to expand its Construction Materials Group in the United States. This acquisition represents a growing U.S. trend toward vertical integration by some cement, concrete, and aggregate companies to lock up sufficient minerals reserves for the future.

Edward C. Levy Co., Detroit, MI, another of the country's top slag processors, entered into a joint venture with Queensland Cement Ltd. and Cleary Brothers to form Australian Mill Services Pty.[3] Australian Mill Services will process and market the slag from Broken Hill Properties (BHP) Port Kembla complex; included are air-cooled, expanded, and granulated slag.

International Mill Service Inc., a wholly owned subsidiary of EnviroSource Inc. headquartered in Stamford, CT, acquired the Waylite Corp., Bethlehem, PA, in January 1989. Waylite processed blast furnace slag into both air-cooled and lightweight (expanded) aggregate and primarily marketed the slag as cement and cement-based products throughout the Northeastern United States.

Domestic production of iron and steel slag, which is not reported to the Bureau of Mines, apparently remained essentially unchanged from that of 1988 according to U.S. iron and steel production figures of the American Iron and Steel Institute. However, sales and uses of iron and steel slag, when combined, increased 6% when compared with the level of the previous year.

Production and consumption of iron slag in this chapter refer only to those slags that are generated in a blast furnace. Depending on how the molten slag is cooled and solidified, three different types of blast furnace slags can be produced. In the United States, those types are as follows: air cooled, expanded, and granulated. Steel slag in this country, however, is not processed in any special manner and, for all practical purposes, is essentially air cooled. The different types of steel slag are solely dependent on the furnaces that generate them, which are open hearth, basic oxygen, or electric arc.

CONSUMPTION AND USES

Historically, iron and steel slags have effectively replaced natural aggregates such as crushed stone and sand and gravel in many end uses, owing to slag's relatively lower cost, proven superior performance in many applications, and/or shortages of natural aggregates in certain regions.

Sales of slag products generally reflect demand from the construction industry. According to the U.S. Department of Commerce, total new construction in 1989 remained essentially unchanged from that of 1988.[4] Private nonresidential construction also remained at the level of the prior year, whereas new road and bridge construction decreased 5%.

Air-cooled blast furnace slag continues to be the predominant form of iron slag processed in the United States, accounting for more than 89% of the blast furnace slag sales in 1989. The most significant increases from 1988 in end uses for air-cooled slag were as the aggregate in asphaltic concrete and for use in roofing, either built-up or in shingles. The increases were 61% and 31%, respectively.

Granulated and expanded blast furnace slag accounted for the remainder of the iron slag sold or used in the United States in 1989. Consumption of combined expanded and granulated slag increased slightly from that of 1988 to 1,706,000 tons valued at $29,143,000. Grand totals and specific end-use information for both the expanded and granulated slag had to be withheld to not disclose individual company proprietary information. Granulated slag was predominantly used in the manufacture of cement, and expanded slag was utilized in the manufacture of lightweight concrete blocks. Total end uses for 1989 were as follows:

	Expanded slag	Granulated slag
Cement manufacture		X
Lightweight concrete aggregate	X	
Road base		X
Soil conditioning		X

Steel slag consumption increased 29% over that of 1988. The most significant increase in end-use consumption for steel slag was as the aggregate in asphaltic concrete.

TRANSPORTATION

Historically, high transportation cost is one of the major factors affecting the delivered price of construction aggregates such as crushed stone and sand and gravel. Because slag is a relatively high-volume, low-value commodity, nearly all of it is marketed locally. Most slag is shipped by truck because hundreds of customers are widespread geographically and generally require a more flexible and rapid delivery system than is offered by rail or barge.

Of all the iron and steel slag products sold in 1989, 87% traveled by truck with an average marketing range of 27 miles; 3% traveled by waterway with an average range of 245 miles; and 5% traveled by rail with an average range of 210 miles. The remaining 5% was used at the plant where it was processed.

PRICES

The average price, f.o.b. plant, for all blast furnace slag sold decreased slightly from that of 1988 to $6.18 per ton. The price of air-cooled blast furnace slag remained essentially unchanged from the level of the previous year at $4.83 per ton. Granulated and expanded slag price information was withheld to avoid disclosing

company proprietary data. The unit value for steel slag increased 3% from that of 1988 to $3.26 per ton.

FOREIGN TRADE

Statistics developed by the U.S. Department of Commerce, Bureau of the Census, indicated that 109,854 tons of granulated blast furnace slag valued at $4,533,227 was imported into the country during 1989. The breakdown was as follows: 40,014 tons from Japan, valued at $336,719; 23,149 tons from Switzerland, valued at $240,660; and 46,691 tons from Canada, valued at $3,955,848. It should be noted that the Canadian imports may be, in fact, expanded or pelletized slag. Verification by the Census Bureau of the type and actual value of the Canadian imports was not completed by the time of publication. The Japanese imports entered into the country through the port of Los Angeles, CA, and the Switzerland imports reportedly entered through Cleveland, OH. Canadian imports reportedly entered into the country primarily through Detroit, MI, Cleveland, OH, and Baltimore, MD.

WORLD REVIEW

Australia

A joint project between the University of Newcastle, New South Wales, and industry was undertaken to construct and test road pavement sections incorporating iron and steel slags.[5] The main objective of the study was to monitor and determine whether steel mill slags could be suitable as road base materials. The companies involved in the study were BHP Rod and Bar Products Div., Newcastle, BHP Slab and Plate Products Div., Port Kembla, and Boral Resources, Sydney. The test sections were made from various blends and mixtures of the following materials: air-cooled blast furnace slag; granulated blast furnace slag; basic oxygen furnace steel slag; fly ash; and a high-quality natural aggregate, dacite. Control samples were made with the natural aggregate. The test sections were constructed on a road that was subject to heavy industrial traffic on the approaches to a weigh bridge at BHP's Newcastle Works. The performance of the test sections was monitored both in the field and laboratory. Pavement stiffness, assessment of deformation, and surface skid resistance were among the factors studied. Researchers concluded in part that the use of iron and steel slags as a road pavement base performed as well as or even better than the test sections constructed with the natural aggregate. The one blend that performed outstandingly well as a bound base material contained air-cooled blast furnace slag, basic oxygen furnace slag, granulated slag, and fly ash in the following proportions: 50:20:20:10.

A joint venture between Queensland Cement Ltd., Cleary Bros., and the Edward C. Levy Co. of Detroit, MI, was formed in 1989 to process and market blast furnace and basic oxygen furnace slag from BHP's Port Kembla complex. The consortium was awarded a long-term contract. The blast furnace slag will be processed into three different types: air-cooled, expanded, and granulated. Queensland Cement's wholly owned subsidiary, North Australia Cement Ltd., will produce a portland blast furnace slag cement at its Townsville plant from the granulated blast furnace slag.

Canada

Mining companies in the Sudbury Basin region of Ontario have been interested in a low-cost viable alternative to portland cement as the binding agent for cementing mine backfill. Research on ground granulated blast-furnace slag as a potential binder in the backfill was undertaken by the Canadian Centre for Mineral and Energy Technology of the Energy, Mines and Resources of Canada.[6] The main objective of the study was to determine the compressive strength of mine backfills constructed with slag in both a laboratory and a field test. A slag granulating system was constructed at Algoma Steel Corp.'s Sault Ste. Marie plant. Forty-six metric tons of granulated slag was produced and shipped for grinding down to the appropriate fineness. Samples were then constructed with varying proportions of granulated slag and portland cement Type 10 (Canadian Standards Association) as the binders and tailings from four different mines as the aggregate. Control samples were made with 100% portland cement. Laboratory test results found that when the slag was used, the compressive strength of the mine backfill was either comparable with or even greater than the compressive strength of the control sample. A field test was designed to test the physical properties of the cemented mine backfill. The performance in the field of the mixtures incorporating slag was considered satisfactory.

Egypt

Researchers at Zagazig University, Zagazig, Egypt, studied the hydration effects of hydrothermally hardened granulated blast-furnace-slag-alite pastes in the presence of quartz.[7] Granulated slag is widely used as a raw material source for the manufacture of cement because of its relatively low price and savings in fuel energy. The relationships between the hydration characteristics of various slag-alite-quartz mixtures and the compressive strength of the final hardened products were determined experimentally. Investigations of the hydration kinetics, such as the free lime content, were also studied. Researchers concluded that the addition of quartz to the slag-alite-quartz mixture increased the strength of the final product. They also discovered that the higher the alite content, the higher the compressive strength.

Germany, Federal Republic of

Traditionally, ground granulated blast furnace slags have been used as an integral component in cement. Steel slag historically has not been used in such a confined application because of its inherent capability to expand owing to its relatively high free lime content. Recently, however, researchers have undertaken a closer examination of the possibility that steel slag could be used in the manufacture of cement. One such study was undertaken by researchers at the University of Dortmund, Dortmund, Federal Republic of Germany.[8] Researchers observed the hydration of five different basic oxygen furnace (bof) steel slag pastes. They were interested in determining the effect different activators would have on hydration and if a correlation between the mineralogical and chemical composition of the different steel slags and the rate of hydration existed. Methods used in the analysis included thermogravimetric, loss on ignition, and powder X-ray diffraction. Mortar specimens were also constructed utilizing various blends and proportions of granulated blast furnace slag, steel slag, and portland cement clinker. The goal was to study the performance characteristics, such as the strength and porosity, of the various cement blends. Methods employed in the analysis of the mortar specimens included mercury porosimetry. The study concluded in part that the steel slags hydrated in the presence of water were comparable to portland cement rather than granulated slag. In the beginning, sodium

hydroxide acted as an accelerator, and the sodium was not incorporated in the slag hydrate phases. The results of the analysis of steel slag as a cement binder revealed that the high free lime content did not result in unsoundness when blended with either portland cement or blast furnace slag. No clear correlation between the different bof slags' chemical and mineralogical components and mortar strength diminution was found. Based on the analysis of the porosity and compressive strength of the mortars made with blast furnace slag, bof slag, and portland cement, the researchers concluded that the cement would be acceptable for practical use on specific occasions according to German standards.

Japan

Researchers at NKK Corp.'s Steel Research Center, Kawasaki City, Japan, have developed a low-cost amenity ceramic based on granulated blast furnace slag.[9] The material has strong growth potential in the construction industry as a low-cost replacement for wood and artificial wood products in buildings. The material is considered a wet ceramic because the composite mixture can be molded and dried without the need for expensive sintering. A typical composition of the material is: 85% to 95% ground granulated blast-furnace slag mixed with water and alkali, 5% to 10% polymer binding, and 3% to 5% glass fibers. Some of the amenity ceramic's properties are as follows: specific gravity of 0.5; fire resistant; does not physically change in response to water or dry air; easily cut and colored; and is hygroscopic.

Figures released by Japan's Steel Slag Association revealed that the production of blast furnace slag in 1989 was 25,215,000 tons, of which 60%, or 15,129,000 tons, was utilized in the production of cement.[10] Steel slag production during the year was 12,448,000 tons, of which only 31%, or 3,858,000 tons, was utilized in road construction.

NKK, in conjunction with another Japanese company, Okutana Kogyo, began marketing a ground solidifying material based on slag.[11] The material is prepared by mixing soil with powderized slag which in turn stabilizes the ground for construction work to be undertaken in such difficult areas as harbors and rivers.

Taiwan

The National Chen University, Taiwan, conducted research on the suitability of blast furnace slag as the major raw material in the production of glass containers.[12] Batches were prepared with 40% to 50% slag by weight, powdered quartz sand (SiO_2), and varying amounts of reagent-grade chemicals such as lithium oxide, zirconium oxide, and sodium sulfate. The slag glasses produced were amber to yellow-green in color. Experimental results demonstrated that the slag glasses were very effective in absorbing ultraviolet (UV) radiation owing to the presence of both ferrous and ferric ions. The researchers concluded that containers made from slag glass would be suitable for liquids that require protection from UV rays, such as beer, wine, and citrus-flavored drinks.

United Kingdom

The Building Research Establishment in England published the results of a 24-year special investigation on the effect of blast furnace slag aggregate in concrete on the embedded steel reinforcing bars.[13] In 1962, chloride-free concrete prisms were constructed using ordinary portland cement, a sulfate-resisting portland cement, and four types of commercially available air-cooled blast furnace slag products. Control samples were also constructed utilizing a Thames Valley River gravel aggregate. The steel reinforcement was of a commercially bright mild steel stock. The concrete prisms were then placed outside in an industrial environment for 24 years and were removed in 1986 and destructively examined. The reinforced steel bars revealed no cracking nor indication of corrosion and were judged to be in nearly perfect condition. No observed differences between the steel bars embedded in the slag aggregate concrete and those embedded in the natural aggregate concrete were found. The researchers concluded that the concrete made with the slag aggregate had provided almost complete protection for the reinforcing steel in chloride-free conditions, and the performance was comparable with the dense concretes made with natural aggregate.

The Building Research Establishment also published the results in 1989 of a 22-year study on the durability of slag aggregate concretes stored in sulfate solutions.[14] Six different air-cooled blast furnace slags were examined. All but one complied with British Standards 1047. Numerous concrete cubes were made with slag as the coarse aggregate, river sand as the fine aggregate, and either ordinary portland cement or sulfate-resisting portland cement (SRPC) as the cementing medium. Control samples were constructed similar to those above but with river gravel substituted as the coarse aggregate. The concrete cubes were then immersed in four different aggressive sulfate solutions for more than 20 years. The solutions consisted of strong and weak solutions of magnesium sulfate and sodium sulfate. Some of the conclusions reached after 22 years included the following: those blast furnace slag aggregate concretes complying with British Standards 1047 performed satisfactorily in terms of sulfate resistance; performance of the slag aggregate concretes in corrosive sulfate solutions was broadly similar to that of the natural aggregate concretes; slag aggregate concretes made with SRPC in strong sulfate solutions deteriorated at a rate similar to the gravel aggregate concretes; slag aggregate concretes in SRPC performed as well as the natural aggregate concretes in weak sodium sulfate, but were marginally worse in weak magnesium sulfate.

CURRENT RESEARCH

A third major international conference entitled "Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete," was held in Trondheim, Norway, June 18-23, 1989.[15] The conference was sponsored by the American Concrete Institute, Detroit, MI; the Canadian Centre for Mineral and Energy Technology of the Energy, Mines and Resources of Canada; the Norwegian Institute of Technology; and several other organizations in Canada and Norway. More than 11 sessions were held on slag, specifically granulated blast furnace slag. Topics included durability, curing, activation, characterization and reactions, mechanical properties, waste containment, and various other topics.

Steel slag usage has steadily increased worldwide, particularly in the application of asphalt surface mixtures. Research conducted as part of an investigation for the Indiana Department of Transportation (INDOT) attempted to further evaluate steel slag's suitability as an aggregate in bituminous pavement surface layers.[16] The findings were presented at the January 1990 annual meeting of the Transportation Research Board in Washington, DC. The study was conducted on samples made from various combinations of steel slag and natural sand aggregates. The research, in addition to a comprehensive literature search, included field and laboratory testing. Six different combinations of varying

proportions of steel slag as the coarse aggregate, natural sand as the fine aggregate, and an AC-20 asphalt cement were made. Between 1979-81, these steel slag asphalt mixtures were used to construct thick surface layers for several Indiana roadways. A pavement performance history of these test sections was compiled and included the results of skid resistance measurements, visual inspections, and even pavement surface temperatures. Marshall mix design procedures such as unit weight, percent air voids, flow values, and Marshall stability were conducted in the laboratory. Indirect tensile tests and the effects of freezing and thawing cycles were also studied as part of the investigation. Some of the conclusions reached were as follows: pavement surfaces that used steel slag aggregate in the asphalt surface mixtures may provide good skid resistance; steel slag in the asphalt paving mixtures displayed exceptionally high stability, which may also be rut resistant; and the use of natural sand as the fine aggregate in combination with the steel slag as the coarse aggregate provided among other attributes good stability for the mixture.

OUTLOOK

Production of iron and steel slags is directly related to the production of iron and steel. Consumption of slag is solely dependent on supply and demand. In certain regions in the United States, demand for slag products exceeds supply. For iron and steel production and outlook, please refer to the Bureau of Mines Minerals Yearbook chapter on Iron and Steel.

In the United States, there has been only a slight variation in the markets for iron slag occurring over the past 100 years, and there is very little indication that this will change in the future. However, there will be a gradual change over the next 5 to 10 years in the type of iron slag produced in this country. Some iron slag that is currently processed as air cooled will be replaced by the granulated type. It is expected that the capacity for granulated slag in the United States will effectively double in the future.

Steel slag has not yet achieved the full market potential that iron-blast- furnace slag has in this country, in part, owing to steel slag's capability to expand upon the hydration of its calcium and magnesium oxides. However, the market for steel slag should continue to grow in the future, particularly if research continues to demonstrate its market potential.

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[15]Malhotra, V. M. (ed.). Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete. Proceedings of the Third International Conference sponsored by CANMET and ACI, Trondheim, Norway, June 18-23, 1989, 1714 pp.

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TABLE 2

BLAST FURNACE SLAGS SOLD OR USED[1] IN THE UNITED STATES, BY REGION AND STATE

(Thousand short tons and thousand dollars)

Region and State	1988				1989			
	Air-cooled, screened and unscreened		Total, all types		Air-cooled, screened and unscreened		Total, all types	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
North Central:								
Illinois, Indiana, Michigan	W	W	W	W	W	W	W	W
Ohio	2,324	W	W	W	2,818	15,728	W	W
Total	W	W	8,466	42,507	W	W	8,819	41,572
Middle Atlantic:								
Maryland, New York, West Virginia	1,319	7,107	W	W	1,351	7,324	W	W
Pennsylvania	2,220	13,000	W	W	2,591	14,999	W	W
Total	3,539	20,107	W	W	3,942	22,323	W	W
West: Colorado, Texas, Utah	W	W	W	W	W	W	W	W
South: Alabama and Kentucky	W	W	W	W	W	W	W	W
Pacific: California	591	2,303	591	2,303	—	—	—	—
Grand total[2]	14,242	69,415	15,900	101,554	13,783	66,574	15,489	95,717

W Withheld to avoid disclosing company proprietary data; included in "Total" and "Grand total."

[1]Value based on selling price at plant.

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

TABLE 3

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1989

Company	Plant location	Slag source				Blast furnace slag type
		Iron	Steel			
		Blast furnace	Basic oxygen furnace	Open hearth	Electric arc furnace	
American Aggregates	Middletown, OH	X				Air-cooled.
Do.	New Miami, OH	X				Do.
Blue-Circle Atlantic Inc.	Sparrows Point, MD	X				Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
Dunbar Slag Co. Inc.	Wheatland, PA	X	X	X		Do.
Duquesne Slag Products Co.	West Alliquippa, PA	X	X	X		Do.
Do.	West Mifflin, PA	X	X	X		Do.
Do. (Brown Reserve)	West Mifflin, PA	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		Do.
Heckett Co.	Emeryville, CA				X	Do.
Do.	Fontana, CA		X			—
Do.	Bourbonnais, IL				X	—
Do.	Chicago, IL	X				Air-cooled.
Do.	Sterling, IL				X	—
Do.	Indiana Harbor, IN		X			—
Do.	Ashland, KY	X	X			Air-cooled.
Do.	Coalton, KY				X	—
Do.	Owensboro, KY				X	—
Do.	Kansas City, MO				X	—
Do.	Jackson, MS				X	—
Do.	Charlotte, NC				X	—
Do.	Canton, OH				X	—
Do.	Mansfield, OH				X	—
Do.	Warren, OH		X		X	—
Do.	Butler, PA				X	—
Do.	Fairless Hills, PA			X	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.	Jacksonville, FL				X	—
Do.	Tampa, FL				X	—
Do.	Atlanta, GA				X	—
Do.	Cartersville, GA				X	—
Do.	Alton, IL				X	--
Do.	Chicago, IL	X				Air-cooled and expanded.
Do.	Granite City, IL		X			—
Do.	Gary, IN		X		X	—
Do.	Laplace, LA				X	—
Do.	Baltimore, MD				X	—

TABLE 3

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1989 (Continued)

Company	Plant location	Slag source				Blast furnace slag type
		Iron	Steel			
		Blast furnace	Basic oxygen furnace	Open hearth	Electric arc furnace	
International Mill Service	Jackson, MI				X	—
Do.	Monroe, MI				X	—
Do.	Kansas City, MO				X	—
Do.	St. Paul, MN				X	—
Do.	Perth Amboy, NJ				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.	Patton, PA		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			—
Edward C. Levy Co.	Detroit, MI	X	X		X	Air-cooled and expanded.
The Levy Co. Inc.	Burns Harbor, IN	X	X			Do.
Do.	East Chicago, IN	X				Air-cooled.
Do.	Gary, IN		X			—
Maryland Slag Co.	Baltimore, MD	X				Air-cooled.
Sheridan Corp.	Lebanon, PA	X				Do.
The Standard Slag Co.	Cleveland, OH	X				Do.
Do.	Lordstown, OH	X				Granulated.
Do.	Mingo Junction, OH	X				Air-cooled.
Do.	Warren, OH	X				Do.
Do.	Weirton, WV	X				Do.
Stein, Inc.	Cleveland, OH		X		X	—
Do.	Lorain, OH		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 Co. (Div. IMS)	Bethlehem, PA	X				Do.

TABLE 4

SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1989, BY METHOD OF TRANSPORTATION

Method of transportation	Quantity (thousand short tons)
Truck	19,835
Waterway	667
Rail	1,108
Not transported (used at plant site)	1,256
Total	22,865

TABLE 5

AIR-COOLED BLAST FURNACE SLAG SOLD OR USED[1] IN THE UNITED STATES, BY USE

(Thousand short tons and thousand dollars)

Use	1988		1989	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	1,042	6,511	1,673	8,771
Concrete aggregate	1,752	9,325	1,394	8,043
Concrete products	383	2,505	412	2,586
Fill	1,410	4,643	1,651	5,119
Glass manufacture	115	W	W	W
Mineral wool	542	3,830	510	3,285
Railroad ballast	W	W	248	1,285
Road base	8,095	36,858	7,276	32,981
Roofing, built-up and shingles	70	689	92	1,027
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other[2]	834	5,052	527	3,474
Total[3]	14,242	69,415	13,783	66,574

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Value based on selling price at plant.
[2]Includes snow and ice control, miscellaneous uses, and data indicated by symbol W.
[3]Data may not add to totals shown because of independent rounding.

TABLE 6

STEEL SLAG SOLD OR USED[1] IN THE UNITED STATES, BY USE

(Thousand short tons and thousand dollars)

	1988		1989	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	654	2,976	969	3,835
Fill	1,451	4,039	1,374	5,057
Railroad ballast	W	W	213	670
Road base	2,630	7,647	3,141	9,169
Other[2]	980	3,398	1,679	5,325
Total	5,714	18,058	7,376	24,056

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Value based on selling price at plant.
[2]Includes snow and ice control, blast furnace feed, miscellaneous uses, and data indicated by symbol W.

TABLE 7

AVERAGE VALUE AT THE PLANT FOR IRON AND STEEL SLAGS SOLD OR USED IN THE UNITED STATES

(Dollars per short ton)

Year	Blast furnace slag				Steel slag	Total slag
	Air-cooled	Granulated	Expanded	Total iron slag		
1984	4.33	W	11.49	5.09	3.28	4.66
1985	4.68	W	11.00	5.75	2.93	4.95
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

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 SLAGS IN THE UNITED STATES IN 1989, BY USE

(Dollars per short ton)

Use	Blast furnace slag						Steel slag	
	Air-cooled		Granulated		Expanded			
	Average	Range	Average	Range	Average	Range	Average	Range
Asphaltic concrete aggregate	5.24	2.44-8.50	—	—	—	—	3.96	3.05-5.33
Cement manufacture	W	W	W	W	—	—	—	—
Concrete aggregate	5.77	2.00-8.50	—	—	—	—	—	—
Concrete products	6.27	4.00-8.50	—	—	—	—	—	—
Fill	3.10	1.46-8.50	—	—	—	—	3.68	1.05-8.96
Glass manufacture	W	W	—	—	—	—	—	—
Lightweight concrete aggregate	—	—	—	—	W	W	—	—
Mineral wool	6.44	4.32-11.70	—	—	—	—	—	—
Railroad ballast	5.18	4.00-7.50	—	—	—	—	3.14	1.96-6.58
Road base	4.53	2.56-8.50	W	W	—	—	2.92	0.85-6.17
Roofing, built-up and shingles	11.22	4.00-22.00	—	—	—	—	—	—
Sewage treatment	W	W	—	—	—	—	—	—
Soil conditioning	W	W	W	W	—	—	—	—
Other	3.27	1.88-6.56	—	—	W	W	3.17	1.00-6.50

W Withheld to avoid disclosing company proprietary data.

SODA ASH

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 11 years 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, International Data Section.

The U.S. soda ash industry operated at 97% of rated capacity to produce a record 9.9 million short tons. The increase in production was because of the strength of export sales, which also was a record, and moderate growth in certain domestic markets, such as in soaps and detergents and pulp and paper. Although consumption in these two domestic markets was higher than in the previous year, total domestic consumption declined. Most of the decrease was attributed to certain sectors that switched back to using caustic soda when prices and availability became favorable by midyear.

The high operating rate of the domestic soda ash industry prompted an increase in the offlist price of the material as supplies became tight. Several consumers, concerned about future availability, negotiated new contracts at higher prices. The strong world demand for soda ash also made U.S. exports grow 18% over the previous year. The environmental and political events in the world, which began to occur in 1989, should provide excellent opportunities for U.S. soda ash in the future.

DOMESTIC DATA COVERAGE

Domestic production data for soda ash are developed by the 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 table 1.

TABLE 1

SALIENT SODA ASH STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Production[1]	8,511	8,438	8,891	9,632	9,915
Value[1]	$622,253	$553,517	$593,685	$644,973	$764,146
Production, Wyoming trona	11,823	13,237	13,869	15,116	16,286
Exports[2]	1,747	2,049	2,224	2,467	2,919
Value[2]	$173,937	$241,238	$253,200	$286,945	$365,469
Imports for consumption	56	106	150	133	142
Value	$8,089	$15,023	$18,334	$15,999	$17,396
Stocks, Dec. 31: Producers'	r392	294	259	r288	243
Consumption:					
Apparent	6,750	6,593	6,852	7,269	7,183
Reported	NA	NA	6,724	7,159	7,131
World: Production	r32,111	r32,367	33,332	p34,234	e34,910

eEstimated. pPreliminary. rRevised. NA Not available.

[1]Includes natural and synthetic for 1985 and 1986; natural only thereafter. Soda liquors and mine waters converted to soda ash equivalent in 1987 and thereafter; 69,963 tons in 1987, 80,871 tons in 1988, and 104,749 tons in 1989.

[2]Export data for 1985-1988 were adjusted by the Bureau of Mines to reconcile data discrepancies among the Bureau of the Census, the American Natural Soda Ash Corp, and Statistics Canada.

ISSUES

Environmental concerns of emissions of chlorine-based compounds, such as those used in chlorofluorocarbons (CFC's) and in paper bleaching, have reduced chlorine demand and production of coproduct caustic soda since 1988. As a result, caustic soda prices increased while supplies became tight. Certain chemical consumers, such as the pulp and paper, chemical, and alumina industries, began switching to less expensive soda ash. However, after mid-1989, many customers reverted to caustic soda as prices and availability became balanced. Because of the discovery of trace amounts of carcinogenic dioxin (2,3,7,8-TCDD) and furan (2,3,7,8-TCDF) from paper bleaching, many paper mills stayed with soda ash.

The international awareness of environmental problems is growing, and the effects of chlorinated compounds are under investigation. If the demand for chlorine, which cannot be easily stored, continues to decline while the demand for caustic soda remains strong, soda ash demand may soar. One soda ash producer announced plans to make caustic soda directly from trona rather than the traditional route of using salt as the feedstock. Some chlorine and caustic soda manufacturers reportedly are also evaluating the possibilities of producing caustic soda directly. The future outlook for this scenario depends on the production economics of making caustic soda from trona and the transportation costs from Green River, WY, to caustic soda markets.

Another environmental issue that has growing national importance is recycling. Glass containers, the preferred packaging medium for many years, have undergone years of strong competition from plastic materials, especially in the beverage container sector. Public con-

cern regarding the problems of nonbiodegradable landfill waste accumulation have prompted more glass recycling. Various plastics do not degrade easily, and few are easily recyclable. Glass has the advantage in terms of recyclability. Unfortunately, more recycling will require less soda ash used in new batch mixtures.

Other important issues confronting the growth of U.S. soda ash are the political events in China and Eastern Europe, both regions which have tremendous potential for increased soda ash consumption. The export opportunities are favorable, pending a peaceful resolution to the political and economic problems.

PRODUCTION

Domestic production of natural soda ash from California and Wyoming reached a record 9.9 million tons; that quantity had been expected, based on production forecasts in the Bureau of Mines 1985 Mineral Facts and Problems. About 105,000 tons of soda ash equivalent from soda liquors and mine waters were 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.

FMC Wyoming Corp. resumed its longwall mining operation at its Green River, WY, trona mine after being idle for several years. It reportedly was the only noncoal longwall activity in the United States.[1] The new longwall shearing unit, which was built in the Federal Republic of Germany, incorporated changes obtained from FMC's previous experiences with longwall technology. The new unit has greater horsepower to cut the tough trona ore, thereby increasing mine output and feed to the refinery. The company anticipates the longwall's high extraction rate will offset production losses from its suspension of soda ash solution mining operations. Some solution mining will occur, but only to feed sodium carbonate solutions to the new sodium cyanide facility.[2]

Tenneco Minerals Co. finished the first of two projects in March that added 75,000 tons of incremental nameplate capacity, raising total capacity to 1.15 million tons. The second phase will add another 100,000 tons in 1990.[3]

Cominco American Inc.'s subsidiary, Lake Minerals Corp., and Vulcan Materials Co. conducted a feasibility study to construct and operate a 500,000-ton-per-year soda ash facility at Owens Lake, CA. The engineering, environmental, and marketing study was expected to take 6 months to complete. The project was slated to come on-stream in 1991, pending the outcome of the study.[4]

NaTec Ltd., a partnership among CRS Sirrine, Industrial Resources Inc., and Church & Dwight Co., successfully completed a full-scale demonstration of its dry nahcolite (natural sodium bicarbonate) injection technology for reducing SO_2 and NO_x emissions from coal-fired power utilities. The test was conducted at a 575-megawatt facility in Texas.[5] NaTec also was chosen to provide equipment, technical service, and solution-mined sodium bicarbonate to Western Slope Refining Co. at its Fruita, CO, power facility.[6]

CONSUMPTION AND USES

Based on reported industry sales, the manufacture of glass represented about 51% of domestic soda ash consumption, with the container sector comprising 30% of this end use; flat, 14%; fiber, 4%; and specialty, 3%. The other end uses include chemicals (primarily sodium bicarbonate, sodium chromates, sodium phosphates, and sodium silicates), 22%; soap and detergents, 12%; distributors, 6%; fluegas desulfurization and miscellaneous, 3%

FIGURE 1

U.S. PRODUCTION OF SODA ASH—NATURAL VERSUS SYNTHETIC

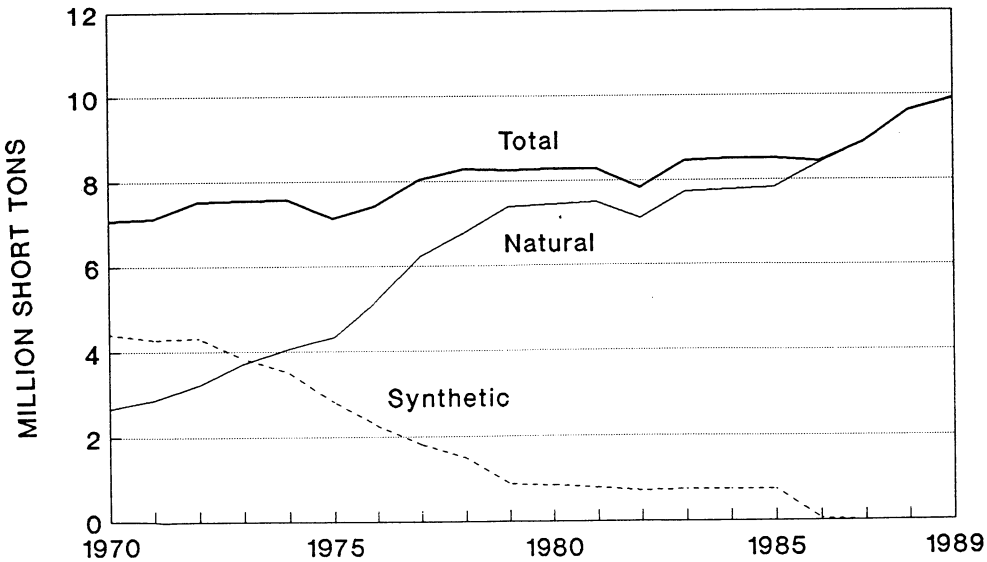


TABLE 2

U.S. PRODUCERS OF SODA ASH IN 1989

Company	Plant nameplate capacity (thousand short tons)	Plant location	Source of sodium
FMC Wyoming Corp	2,850	Green River, WY	Underground trona.
General Chemical (Soda Ash) Partners[1]	2,200	do.	Do.
Kerr-McGee Chemical Corp.—Argus plant	1,300	Trona, CA	Dry lake brine.
Rhone-Poulenc of Wyoming[2]	1,960	Green River, WY	Underground trona.
Tenneco Minerals Co.	1,150	do.	Do.
T.g. Soda Ash Inc.[3]	1,100	Granger, WY	Do.
Total	10,560		

[1] A joint venture between General Chemical Corp. and Australian Consolidated Industries International, which owns 49% of the soda ash operation.
[2] Joint venture between Rhone-Poulenc Basic Chemicals Co., formerly Stauffer Chemical Co., and Union Pacific Resources Co.
[3] Owned by Texasgulf Inc. of Societe Nationale Elf Aquitaine. Acquired permits to operate at 1.3 million tons of capacity.
NOTE: Nameplate capacities may differ from total shown in table 9 for rated capacity.

each; pulp and paper, 2%; and water treatment, 1%.

Domestic demand for soda ash remained strong during the first half of 1989, following the trend that started in late 1988. The rise in demand was primarily caused by the substitution of high-priced caustic soda for less expensive soda ash by chemical consumers in the pulp and paper, chemical, and alumina industries. The crossover reduced soda ash availability, which increased the market price of soda ash by about $10 per ton over the previous year. Although many consumers came back to caustic soda by yearend, soda ash for pulp and paper manufacture continued to show increased sales due to the environmental concerns raised by the studies that found minute quantities of dioxins and furans in various bleached-paper products that used chlorine-based bleaches.

Although the quantity of glass containers manufactured increased in 1989, less soda ash was used because of the increased use of cullet. Sales to the flat-glass sector rose, mainly due to use in industrial building construction, which consumes about 57% of all flat glass made. Automotive glass represented 25%, and the remainder went to specialty flat-glass products.

The third largest use of soda ash directly is 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. Because phosphatic detergents contribute to the environmental problems of eutrophication, many regions of the nation have adopted phosphate limitations or bans. About 33% of the U.S. population resides in the areas that have adopted restrictions. In response to the environmental issue, detergent manufacturers began reformulating their detergents by switching from 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 also require more soda ash as a direct addition. From 1988 to 1989, soda ash sales to the soap and detergent industry rose approximately 9% because of these changes. This was encouraging because liquid detergents, which do not contain any soda ash, commanded 40% of the household laundry detergent market. Liquid detergents were only 15% in 1978.

STOCKS

Yearend stocks of dense soda ash in plant silos, warehouses, terminals, and on teamtracks amounted to 243,131 tons. Producers indicate that a potential supply problem could exist when inventories fall below 200,000 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.

PRICES

An announcement was made on April 15 by General Chemical Corp., and later by Tenneco Minerals Co., to raise the list price of soda ash by $12 per ton, the offlist price by $15 per ton, and bagged price by $17 per ton. However, the increases were not unanimously supported by all the producers and the effort to raise the list price was abandoned by June. The strong domestic demand caused by the substitution of high-priced caustic soda for the less-expensive soda ash during the first half of 1989, and the rise in export sales caused soda ash supplies to become very tight. In anticipation of possible supply shortages, several high-volume soda ash contracts were renegotiated for higher prices than in the previous year. The result was that the annual soda ash value increased to $77.07 per ton, for bulk, dense natural soda ash, f.o.b. Green River, WY, and Searles Valley, CA.

FOREIGN TRADE

U.S. soda ash exports have increased each year since 1976, growing more than 325% between 1976 and 1989, when exports reached a record high of 2.9 million tons, or about 29% of production. Exports to 46 countries, on a regional basis, were: Asia, 51%; South America, 20%; North America, 15%; Africa, 7%; Oceania, 3%; Europe, 2%; and the Caribbean and Central America, 1% each. Exports to the Middle East were negligible.

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, 1990, 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

TABLE 3

SODA ASH SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand short tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION										
United States	8,275	8,281	7,819	8,467	8,511	8,511	8,438	8,891	9,632	9,915
Rest of world	22,972	22,599	21,731	22,278	23,714	23,600	23,929	24,441	24,602	24,995
Total	31,247	30,880	29,550	30,745	32,225	32,111	32,367	33,332	34,234	34,910
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
U.S. production capacity	9,620	10,360	11,160	11,160	11,160	11,160	10,560	10,485	10,485	10,560
Wyoming trona ore production	12,906	12,457	10,831	11,510	11,704	11,823	13,237	13,869	15,116	16,286
Domestic sources	8,275	8,281	7,819	8,467	8,511	8,511	8,438	8,891	9,632	9,915
Imports	18	12	18	20	17	56	106	150	133	142
Industry stocks, Jan.1[2]	68	133	263	324	307	322	392	294	259	288
Total U.S. supply	8,361	8,426	8,100	8,811	8,835	8,889	8,936	9,335	10,024	10,345
Distribution of U.S. supply:										
Industry stocks, Dec. 31[2]	133	263	324	307	322	392	294	259	288	243
Exports	1,094	1,051	1,109	1,636	1,648	1,747	2,049	2,224	2,467	2,919
Industrial demand[3]	7,134	7,112	6,667	6,868	6,865	6,750	6,593	6,852	7,269	7,183
U.S. DEMAND PATTERN[4]										
Glass	3,851	3,700	3,500	3,450	3,400	3,400	3,475	3,685	3,737	3,631
Container	2,773	2,627	2,500	2,400	2,300	2,200	2,150	2,322	2,346	2,162
Flat	616	555	500	575	600	700	750	905	939	1,000
Fiber	193	260	220	230	250	275	300	275	272	265
Other	269	258	280	245	250	225	275	183	180	204
Chemicals	1,426	1,420	1,300	1,400	1,550	1,500	1,300	1,364	1,593	1,557
Soaps and detergents	499	500	500	620	600	600	650	754	791	860
Pulp and paper	250	210	275	200	250	350	200	69	122	126
Water treatment	250	250	230	230	300	300	250	79	121	102
Flue gas desulfurization	NA	NA	NA	NA	300	175	200	202	220	230
Distributors	NA	NA	NA	NA	NA	NA	NA	385	412	419
Other[5]	856	1,032	862	968	464	425	715	186	163	206
Total U.S. consumption	7,132	7,112	6,667	6,868	6,864	6,750	6,790	6,724	7,159	7,131
Undistributed[6]	2	—	—	—	1	—	−197	128	109	52
Total U.S. primary demand	7,134	7,112	6,667	6,868	6,865	6,750	6,593	6,852	7,269	7,183
VALUES[7]										
Average annual value—natural soda ash (Dollars per ton, f.o.b.)	89.85	91.19	88.35	76.95	67.00	67.82	65.29	66.78	66.96	77.07

[e] Estimated. NA Not available; included in "Other."

[1] Natural and synthetic except where noted.

[2] Natural soda ash only in 1980 and 1987–89; natural and synthetic from yearend 1981–1986.

[3] Also known as apparent consumption (production + imports − exports + / − stock changes) and is equal to Total U.S. primary demand.

[4] Estimated consumption for 1980–1986 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.

[6] Represents the amount of discrepancy between "Total U.S. consumption" (obtained from estimated and reported consumption surveys) and "Total U.S. primary demand," which is the calculated quantity of soda ash available for consumption. The discrepancy is because of the fluctuating balance of inventory in transit from plants to domestic or export destinations.

[7] 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, bulk, f.o.b. plant. The value may or may not be synonymous with the posted list prices of the commodity.

Source: Bureau of Mines.

TABLE 4

SODA ASH YEAREND PRICES

		1988	1989
Sodium carbonate (soda ash):			
Dense, 58%, Na_2O 100-lb:			
Paper bags, carlot, works, f.o.b.	per ton	$141.00	$146.00
Bulk, carlot, same basis tons	do.	93.00	93.00
Light 58%, 100-lb:			
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.235, No.1, Dec. 30, 1988, p. 33; and v. 237, No. 1, Jan. 1, 1990, p. 39.

soda ash are listed in the appropriate trade tables in this report.

Officials of the antidumping directorate of the European Community Commission (ECC) made a surprise visit to the corporate offices and plants of six West European synthetic soda ash producers to obtain information about alleged anticompetitive practices in the European Community (EC) market.[7] The companies were Solvay et Cie. of Belgium, Akzo N.V. of the Netherlands, Imperial Chemical Industries PLC 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 Germany. The combined output of these producers represented about 20% of world soda ash production. The Commission had reason to believe that all six producers conspired to prevent competition in the EC soda ash market by blocking U.S. imports in the early 1980's, when antidumping duties were levied. The current duty is 67.5 European Currency Units (ECUs), about $67.13 per short ton. ECC investigators also investigated U.S. producers at yearend and indicated that a decision would be forthcoming in early 1990. European soda ash consumers would prefer to have an alternate source of soda ash, namely the United States. With two Wyoming soda ash plants co-owned by French companies, the U.S. soda ash industry is hopeful that the investigation will result in reduced or eliminated duties, which would increase U.S. export sales to Europe.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF SODA ASH

Year	Disodium carbonate[1]	
	Quantity (short tons)	Value[2] (thousand dollars)
1985[3]	56,202	8,089
1986[3]	105,965	15,023
1987[3]	150,103	18,334
1988[3]	132,948	15,999
1989	141,967	17,396

[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] Customs, Insurance, and freight (c.i.f.) value at U.S. ports.
[3] Also contains hydrated sodium carbonate, and sesquicarbonate.

Source: Bureau of the Census.

TABLE 6

U.S. EXPORTS OF SODA ASH

(Thousand short tons and thousand dollars)

Year	Disodium carbonate[1]	
	Quantity	Value[2]
1985[3]	1,747	173,937
1986[3]	2,049	241,238
1987[3]	2,224	253,200
1988[3]	2,467	286,945
1989	2,919	365,469

[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] Free alongside ship (f.a.s.) value at U.S. ports.
[3] Adjusted by the Bureau of Mines to account for discrepancies in data.

Source: Bureau of the Census, as adjusted by the Bureau of Mines.

For the previous several years, international tariffs on imports of soda ash from the United States have blocked U.S. efforts to increase export sales. In 1989, however, an easement of these trade barriers began with the announcement that Taiwan was reducing the import tariff from 12.5% to 10%, which equals a $5.90 per short ton savings for Taiwanese consumers. Reducing the tariff could result in greater overseas trade as well as better trading relationships.[8]

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 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, which require consumer products made with soda ash. The developing nations tend to have greater soda ash demand and higher rates of growth.

Capacity

World soda ash production capacity is about 38.3 million tons, divided among 35 countries. Approximately 72% of world capacity is synthetic soda ash, 28% natural. The United States represents 27% 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 Wyoming Corp. of the United States is the second largest with 2.85 million tons of capacity.

The data in table 9 are rated capacities for mines and refineries 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 operat-

TABLE 7

REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS IN 1989

(Short tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Atlantic:											
Baltimore, MD	—	—	110	—	29	—	—	—	—	139	—
Charleston, SC	—	74	—	—	3	—	—	—	—	77	—
Miami, FL	—	—	2	206	—	—	—	—	—	208	—
New York, NY	36	—	18	—	21	22	—	119	—	216	—
Philadelphia, PA	—	—	469	—	—	—	—	—	—	469	—
Savannah, GA	—	—	—	65	—	—	—	—	—	65	—
Gulf:											
Galveston, TX	—	—	2	40	—	—	14	28	—	84	—
New Orleans, LA	—	10	226	20	—	—	18	—	—	274	—
Port Arthur, TX	—	7,799	357,205	19,029	—	—	85,281	—	—	469,314	16
Pacific:											
Anchorage, AK	7,811	—	—	—	—	—	—	—	—	7,811	—
Los Angeles, CA	—	8,925	123,022	—	17,032	—	27,558	456,188	—	632,725	22
San Diego, CA	6,032	—	—	—	—	—	—	—	—	6,032	—
San Francisco, CA	—	—	—	—	—	—	—	47	—	47	—
Seattle, WA	8,968	—	—	—	—	—	—	117	—	9,085	—
Portland, OR	—	—	96,717		46,217		93,240	1,045,926	98,762	1,380,862	47
North Central:											
Detroit, MI	190,490	—	—	—	—	—	—	—	—	190,490	7
Duluth, MN	17	—	—	—	—	—	—	—	—	17	—
Great Falls, MT	60,968	—	—	—	—	—	—	—	—	60,968	2
Pembina, ND	9,802	—	—	—	—	—	—	—	—	9,802	—
Northeast:											
Buffalo, NY	410	—	—	—	5	—	—	—	—	415	—
Ogdensburg, NY	22	—	—	—	—	—	—	—	—	22	—
St. Albans, VT	80	—	—	—	—	—	—	—	—	80	—
Southwest:											
Laredo, TX	150,106	—	—	—	—	—	—	—	—	150,106	5
Nogales, AZ	94	—	—	—	—	—	—	—	—	94	—
Total	434,836	16,808	577,771	19,360	63,307	22	206,111	1,502,425	98,762	2,919,402	100
Percent of total	15	1	20	1	2	—	7	51	3	100	

Source: Bureau of the Census.

ing 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.

Natural soda ash mine capacity assumes two daily mine shifts and one daily maintenance shift per 5-day work week. Considerations were made for operations that mine underground trona, surface sodium salts, and sodium carbonate-bearing brines. Natural and synthetic soda ash refining capacities are based on 360 working days per year with scheduled short-term maintenance periods once or twice per year, depending on the physical characteristics of the plant.

The U.S. soda ash industry rated capacity was derived by averaging each producer's third and fourth highest months of output during the past year. These months were used because the first and second highest months were not realistic for sustained production rates. The range between each producer's third and fourth highest months were close and probably more indicative of what each plant can effectively sustain on a monthly basis, given favorable market conditions. The calculated averages were aggregated and annualized. Individual rated capacities may or may not be synonymous with plant nameplate capacities.

Australia

ICI Australia Operations Pty. Ltd. sold its Osborne synthetic soda ash plant, salt fields, quarry, a bulk terminal, and bagging facilities to Penrice Pty. for $35 million.[9]

TABLE 8

SODA ASH: WORLD PRODUCTION, BY COUNTRY[1]

(Short tons)

Country	1985	1986	1987	1988[p]	1989[e]
Albania[e]	34,200	35,300	34,000	33,100	33,100
Australia[e]	330,000	330,000	330,000	330,000	330,000
Austria[e]	165,000	165,000	165,000	160,000	165,000
Belgium	492,164	530,934	493,804	417,731	420,000
Brazil	197,000	222,000	187,000	203,300	220,000
Bulgaria	1,142,695	1,162,070	1,179,679	[e]1,210,000	1,210,000
Canada[e]	385,000	385,000	360,000	360,000	360,000
China[e]	2,220,000	2,310,000	2,610,000	2,855,000	[3]3,285,000
Colombia	124,791	124,473	128,820	125,759	128,000
Czechoslovakia	123,459	124,561	[e]121,000	[e]121,000	121,000
Denmark[2]	126	129	[e]130	[e]130	130
Egypt	54,132	[e]55,000	[e]55,000	52,592	52,000
France[e]	1,500,000	1,375,000	1,400,000	1,400,000	1,430,000
German Democratic Republic	974,442	975,544	984,000	1,008,000	992,000
Germany, Federal Republic of	1,556,462	1,589,531	1,596,000	1,548,000	1,655,000
Greece[e]	1,100	1,100	1,100	1,100	1,100
India	896,839	962,978	1,068,800	[e]1,058,000	1,100,000
Italy[e]	680,000	650,000	675,000	675,000	680,000
Japan	1,165,254	1,125,292	1,210,849	1,193,935	1,235,000
Kenya[4]	251,062	261,964	252,043	242,500	260,000
Korea, Republic of	276,559	291,245	318,016	[e]309,000	309,000
Mexico[e 5]	[3]504,205	500,000	475,000	[r]475,000	475,000
Netherlands[e]	420,000	420,000	420,000	420,000	430,000
Pakistan	130,169	144,286	147,051	147,826	143,000
Poland	1,035,069	1,061,252	1,025,000	1,003,200	1,003,000
Portugal[e]	165,000	170,000	[r]175,000	[r]170,000	165,000
Romania[e]	[3]921,531	940,000	950,000	950,000	880,000
Spain[e]	610,000	580,000	610,000	620,000	620,000
Switzerland[e]	50,000	48,000	25,000	—	—
Taiwan	123,479	147,002	140,359	139,804	138,000
Turkey	[e]331,000	[e]365,000	415,000	418,000	425,000
U.S.S.R.[6]	5,418,956	5,546,824	5,566,000	5,618,000	5,400,000
United Kingdom[e]	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000
United States[7]	8,511,055	8,438,192	8,890,746	9,632,031	[3]9,914,966
Yugoslavia	220,053	229,245	222,158	235,774	230,000
Total	[r]32,110,802	[r]32,366,922	33,331,555	34,233,782	34,910,296

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 27, 1990. Synthetic unless otherwise specified.

[2] Production for sale only; excludes output consumed by producers.

[3] Reported figure.

[4] Natural only.

[5] Includes natural and synthetic. In 1988 and 1989, Mexico allegedly produced an estimated 180,000 metric tons per year of natural soda ash.

[6] Excludes potash for 1985–87.

[7] Includes natural and synthetic for 1985–86, natural only thereafter.

Botswana

In June, financing of the Sua Pan soda ash project was finalized in an agreement among Soda Ash Botswana Ltd., three South African shareholders, and a consortium of South African banks. The agreement includes commercial loans at the 17.5% South African prime rate and lower interest rate export credits. The principal engineering contractors have been chosen with completion scheduled for mid-1991.[10]

Mexico

Vitro S.A. of Monterrey, the largest glass and raw material for glass manufacturing company in Mexico, acquired for $265 million Anchor Glass Container Corp. and Latchford Glass Co. in the United States.[11] The buyout involved more than 20 glass container plants. The acquisition made Vitro the largest glass container manufacturer in the United States and probably the largest single consumer of soda ash in North America.

OUTLOOK

Although world demand for soda ash has grown about 2.4% per year since the early 1970's, the environmental, energy, and economic issues of the 1980's reduced the international growth rate of soda ash to slightly more than 1% per annum. 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 consumer preferences, all of which have an adverse affect on soda ash usage. These issues will be of greater importance in the 1990's. Lesser developed 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 consumption since the 1973 energy crisis, which changed the operating factors between competing natural and synthetic soda ash industries, to the present has been less than 1%. The forecast of 1.2% made in the 1985 Mineral Facts and Problems did not fully anticipate the inroads made by plastic bottles, cullet, and liquid deter-

TABLE 9

WORLD SODA ASH ANNUAL PRODUCTION CAPACITY,[1] DEC. 31, 1989

(Thousand short tons)

	Natural	Synthetic	Total
North America: 200			
Canada	—	495	495
Mexico	300	240	540
United States	10,200	—	10,200
Total	10,500	735	11,235
South America:			
Brazil	—	220	220
Colombia	—	120	120
Total	—	340	340
Europe, Western:			
Austria	—	195	195
Belgium	—	440	440
France	—	1,650	1,650
Germany, Federal Republic of	—	1,800	1,800
Italy	—	775	775
Netherlands	—	420	420
Portugal	—	140	140
Spain	—	775	775
Turkey	—	365	365
United Kingdom	—	1,100	1,100
Total	—	7,660	7,660
Europe, Eastern:			
Albania[e]	—	30	30
Bulgaria	—	1,900	1,900
Czechoslovakia	—	150	150
German Democratic Republic	—	990	990
Poland	—	1,100	1,100
Romania	—	1,100	1,100
U.S.S.R.	30	[2]5,895	5,925
Yugoslavia	—	290	290
Total	30	11,455	11,485
Africa:			
Chad	NA	—	NA
Egypt	—	45	45
Kenya	330	—	330
Sudan	NA	—	NA
Total	330	45	375
Asia:			
China	11	3,289	3,300
India	—	1,135	1,135
Iran	—	66	66
Japan	—	1,565	1,565
Korea, North	—	110	110
Korea, Republic of	—	350	350
Pakistan	—	160	160
Taiwan	—	150	150
Total	11	6,825	6,836

See footnotes at end of table.

gents. Although U.S. production was close to what was forecast by 1990, the export market grew greater than anticipated, mainly through the efforts of the industry's export association.

Exports

The outlook for soda ash is excellent. Export opportunities are favorable, particularly to new regions such as the Middle East and Western and Eastern Europe. If the ruling in the EC antidumping investigation is favorable to the United States, additional U.S. soda ash may be exported to Western Europe in the near future. The changes in the political situation in the U.S.S.R. and the East European countries 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 environmental problems in Eastern Europe are critical. Inefficient and polluting synthetic soda ash plants may be targeted for shutdown in order to resolve some of the pollution problems. These problems are similar to those that adversely affected several U.S. synthetic facilities in the late 1970's and finally led to their closures. Any changes in East Europe's soda ash production capacity could signal opportunities for the U.S. soda ash industry.

The future of U.S. exports to China is uncertain. China has been debottlenecking several synthetic soda ash plants and constructing new ones but production cannot keep pace with demand. China was forced to reduce its soda ash consumption by limiting imports because of economic problems. Although Bulgaria had supplied some of China's requirements, future shipments could be curtailed in order to satisfy the East European countries' needs, thereby reducing Bulgaria's level of exports. This could allow the United States the opportunity to continue to export to China, pending the availability of U.S. product. Despite these obstacles, total U.S. exports could grow by several hundreds of thousands of tons in the next several years.

Glass

Although glass is the largest end use of soda ash, domestic consumption in

TABLE 9-Continued

WORLD SODA ASH ANNUAL PRODUCTION CAPACITY,[1] DEC. 31, 1989

(Thousand short tons)

	Natural	Synthetic	Total
Oceania:			
Australia	—	385	385
Total	—	385	385
World total	10,871	27,445	38,316

[e] Estimated. NA Not available, although production is known to occur.

[1] From natural sources of trona and sodium carbonate-bearing brines and from the manufacture by the Solvay, ammonium chloride, and caustic carbonation processes.

[2] Includes soda ash obtained as a byproduct of aluminum processing from nepheline-bearing ore at at least four locations.

the glass container sector is declining because of the increasing use of cullet; the national interest in recycling; and the continuing competition with polyethylene terephthalate (PET) plastic containers.

The glass container shipments were higher in 1989 than in previous years, mainly because ethylene feedstock shortages for plastic resin caused prices of plastics to increase, thereby increasing glass usage. This situation is temporary. However, the public's perception that glass is completely recyclable compared with plastics will raise the quantity of cullet now being consumed. This trend will probably be short-lived as plastic manufacturers develop biodegradable materials, such as polyhydroxybutyrate-hydroxyvalerate (PHBV), which completely decompose into inert compounds. Aside from the problems with plastics' recyclability, the public also is concerned about the dioxin emissions from incineration of polyvinyl chloride (PVC) bottles.

Municipal landfills are a growing national problem. Glass reportedly accounts for 8.4% of disposable household waste. The U.S. Environmental Protection Agency has a goal of reducing the nation's waste by 25% by 1992. It is probable that new taxes will be placed on items manufactured at the source of production to encourage greater use of recycled products. Rebates would be given for every ton of recycled material utilized. It is also likely that domestic glass container manufacturers will strive to add more cullet in new batch mixtures, which will reduce the amount of soda ash consumption, in order to use most of the collected glass.

The glass container industry is changing. Two facilities closed in 1989 and Vitro S.A. of Mexico bought Anchor Glass Container Corp. and Latchford Glass Co. There reportedly are plans to close more plants, thereby reducing domestic capacity and improving industry operating rates. As plants operated at higher rates, production costs decreased. Soda ash sales for glass containers should remain at the same levels despite the closures.

Soda ash for flat glass and fiber glass is expected to decline in the automotive industries. Consumption will probably be the same in the building construction sector. Strong demand is not anticipated until the mid-1990's.

Soap and Detergents

The world consumes about 10 million tons of laundry detergents annually, which are composed of many active and inert chemical ingredients. Household liquid detergents and phosphate-free detergents are considered environmentally safe products. More soda ash has been added as a phosphate-replacement builder in various detergent formulations in order to meet regional phosphate discharge requirements.

The environmental movement in Europe has also prompted foreign detergent manufacturers to consider changing formulations to reduce phosphate content. In the Federal Republic of Germany, consumption of phosphates in detergents dropped from 276,000 tons in 1975 to 80,000 tons in 1987.

Consumer preferences may ultimately decide 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 uncertain, despite the current level of sales.

Pulp and Paper

The U.S. pulp industry is growing at about 2.75% per year. Amid this prosperous outlook, 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-based chemicals for nonchlorine pulping and bleaching agents, such as oxygen and hydrogen peroxide. About 1.8 million tons of chlorine are used in pulp bleaching annually. Industry sources estimate a 25% to 30% reduction in chlorine consumption by 1995. If this forecast is accurate, coproduct caustic soda, which is used to delignify wood pulp, could be in short supply. This situation could result in additional quantities of soda ash being used instead of caustic soda, although it would take 1.3 tons of soda ash to have the same chemical effect of 1.0 ton of caustic soda. FMC Wyoming Corp. and Tenneco Minerals Co. have announced plans to produce caustic soda from their Green River, WY, 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; however, assertive strategic planning by one or more chlorine-caustic soda producers to produce their own caustic soda from trona could alter this outlook.

Flue Gas Desulfurization

With changes to the Clean Air Act, the nation's powerplants will be required 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-based compounds are located, sodium-based sulfur dioxide removal agents, such as trona and nahcolite, have opportunities for commercial development in the West.

In 1989, nearly 0.5 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-based agents. The addition of some sodium minerals removes additional sulfur and a substantial amount of the nitrogen materials. Eastern powerplants will probably use low-sulfur coal rather than use trona or nahcolite resources found in the West. As Western powerplants retrofit older facilities with dry-injection scrubbing equipment to conserve water, demand for soda ash will increase.

BACKGROUND

Soda ash is the eleventh largest inorganic chemical in terms of production of all inorganic and organic chemicals, excluding petrochemical feedstocks. In 1989, soda ash represented about 2.4% of the total $32 billion nonfuel mineral industry that was surveyed by the Bureau of Mines. The average U.S. citizen consumes about 40,000 pounds of new minerals in the form of consumer goods each year. Based on the 1989 U.S. population of nearly 248 million, the 1989 per capita consumption of soda ash was 58 pounds, compared with copper, 20 pounds; aluminum, 45 pounds; salt, 345 pounds; cement, 742 pounds; and iron and steel, 863 pounds. An infant born in 1988 would require 4,344 pounds of soda ash in a lifetime, based on an average life expectancy 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 around 3500 B.C. to make ornamental glassware, as evidenced by many of the early Egyptian glass artifacts. The Egyptians also mixed lime and soda ash to make caustic soda. The caustic soda was combined with silicate minerals obtained from the Sinai desert. This made a soluble silica that was added to aluminum-rich Nile River silt, producing a silica-aluminate cement mortar with superior bonding properties. Soda ash was also used in the mummification process. Natural soda ash was placed on the deceased to dry out the body, which was then wrapped in cloth for 70 days.

In the Old Testament, soda ash was referred to as neter; it has also been known as natrium, kali, trona, and natron. Until the 18th century, soda ash was obtained mainly by burning seaweeds and marine plants, leaching the soluble material from the ashes, and evaporating the solutions to dryness. About 13 tons of ash yielded 1 ton of sodium carbonate and 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; his patent and factory were confiscated, and he received only token compensation. Napoleon returned the factory to Leblanc who, unable to raise enough capital to reopen it, 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 were in operation by 1939 in the United States and, ironically, the last one to close. The Solvay process gained in popularity over the years and is now the basic method used throughout the world for making synthetic soda ash.

The site of the first commercial production of natural soda ash in the United States was from two deposits known as the Soda Lakes near the present town of Fallon, NV. Asa L. Kenyon acquired title to Little Soda Lake in 1855 and sold it to Higgins and Duffy in 1868, when the first 300 tons of natural soda ash was produced. Production at adjacent Big Soda Lake began in 1875 and reached its peak in 1887. The brines became diluted when 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 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.

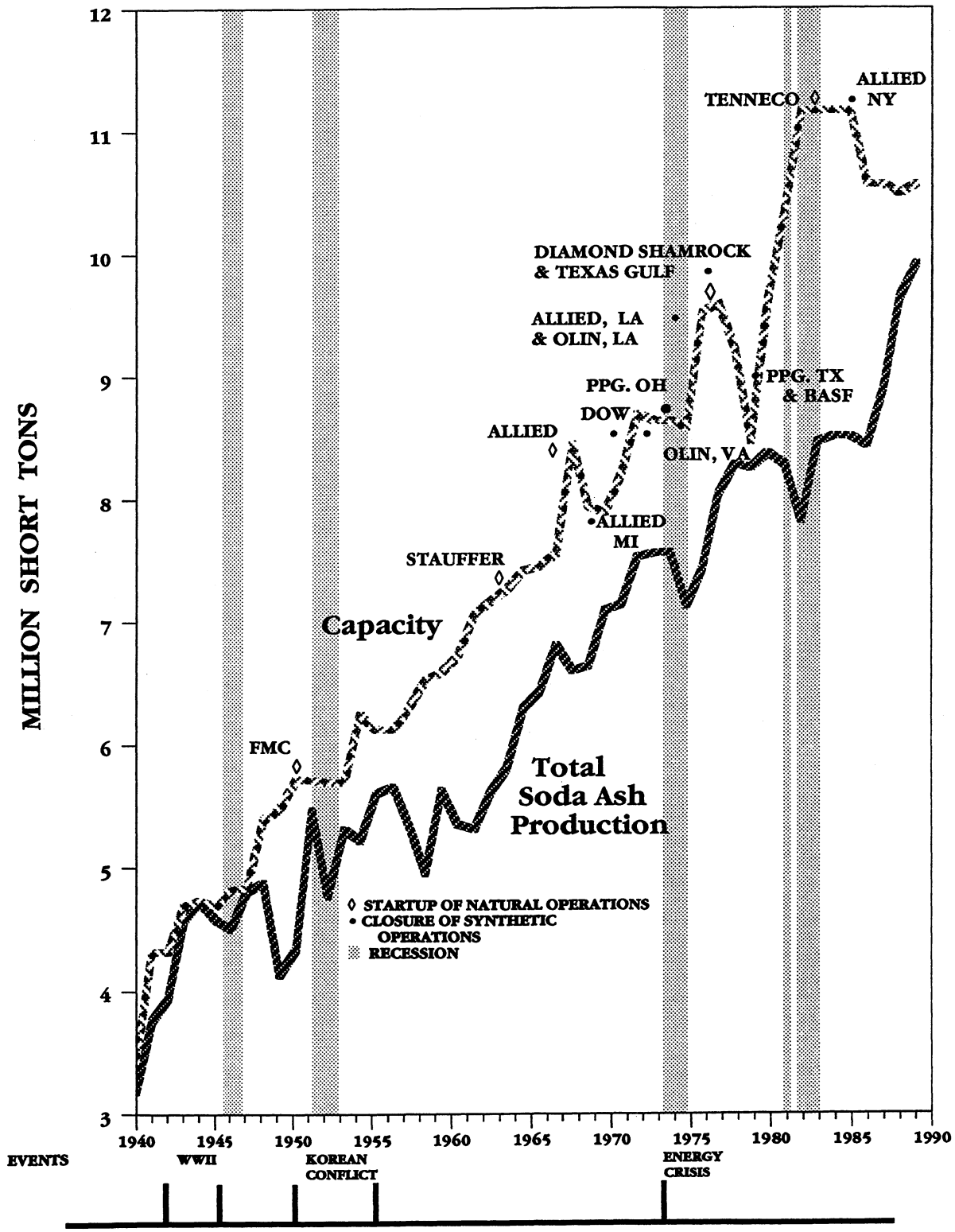
Light Soda Ash.—Has a bulk density of 32 to 39 pounds per cubic foot. It is produced by calcining the sodium sesquicarbonate precipitate recovered from the carbonation towers or vacuum crystallizers.

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

FIGURE 2

HISTORICAL CHRONOLOGY OF U.S. SODA ASH ACTIVITIES



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 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 are 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 detergents 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 comprised 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 30% in 1989. Three of the six U.S. companies have either Australian or French partners.

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, which is 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 10 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 3 feet or more. Eleven of these exceed 6 feet in thickness and cover an area of more than 1,200 square miles. The trona beds were deposited about 50 million years ago in the early to middle Eocene epoch in an ancient freshwater lake, named "Lake Gosiute" by Clarence King in 1878. The sodium and carbonate constituents of trona owe their respective origins to the leaching of the extensive pyroxene-andesite volcanic ash layers and the seasonal influxes of carbonate-rich sediments into the local depositional basin. In addition, subterranean thermal springs contributed a significant quantity of dissolved alkaline carbonates as well as sodium, calcium, silica, and bicarbonate ions. Trona can precipitate only in the presence of abundant carbon dioxide, which probably was supplied from the atmosphere and/or the biogenic decay of Eocene plant and aquatic remains. For 4 million years, Lake Gosiute went through many stages of filling and evaporation, thereby depositing over 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 52 billion tons of identified soda ash resources could be obtained from the 62 billion tons of bedded trona and the 52 billion tons of interbedded or intermixed trona and halite that are in beds greater than 4 feet thick. Approximately 37 billion tons of reserve base soda ash could be obtained from the 40 billion tons of halite-free trona and the 27 billion tons of interbedded or intermixed trona and halite in beds more than 6 feet thick. Although about 16 million tons of trona are presently being mined there annually, Wyoming could supply all domestic requirements for more than 3,100 years at the 1989 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 over 5,100 years. With Wyoming reserves estimated at 22 billion tons, the United States, through this one deposit, could provide the supply needed to meet the

current annual world soda ash 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 located 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 evaporite minerals found in California comprise the second largest reserves of sodium carbonate in the United States. Subsurface sodium carbonate-bearing brines and crystalline material comprise the resource at Searles Lake, which is a nearly dry playa 9 miles long by 7 miles wide with an area of about 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 900 million 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 32 billion tons of nahcolite and 19 billion tons of dawsonite, equivalent to 20 billion tons and 7 billion 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 caliché layers at a depth of 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 200 million 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.

Mining.—Commercial mining of Wyoming trona began in 1950. Between 1950 and 1989, more than 230 million tons of trona (equal to about 128 million tons of soda ash) have been mined. Only about 0.6% of the 40 billion 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; the remaining 40% stays in-place as pillars for structural integrity and is 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 vehi-

TABLE 10

WORLD NATURAL SODA ASH RESERVES AND RESERVE BASE

(Million short tons)

	Reserves	Reserve base[1]
North America:		
United States:		
California[2]	900	1,400
Colorado[3 4]	2,600	4,300
Wyoming[3]	22,000	37,000
Total	25,500	42,700
Mexico	200	500
Total	25,700	43,200
Europe:		
Turkey	216	260
Africa:		
Botswana	400	NA
Chad	8	NA
Kenya[5]	56	NA
Uganda	18	NA
Total	482	NA
Asia:		
China[6]	232	232
World total[7]	26,600	43,700

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] Includes Owens Lake and Searles Lake.

[3] 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. When solution mining of trona and nahcolite is commercially used, a 30% extraction efficiency rate is expected.

[4] The sodium carbonate content of nahcolite reserves and reserve base are 0.8 billion tons and 1.26 billion tons, respectively. The sodium carbonate content of dawsonite reserves and reserve base are 1.82 billion tons, and 3.0 billion, tons respectively.

[5] Annual leaching of volcanic rocks replenishes the resources at Lake Magadi.

[6] Proven reserves in Inner Mongolia, 100 million tons; Tongbai, Henan, 132 million tons.

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

Note.—There are at least 62 identified natural sodium carbonate depósits in the world, some of which have been quantified. The countries and number of deposits include Australia (1), Bolivia (2), Botswana (1), Brazil (1), Canada (3), Chad (9), China (9), Egypt (1), Ethiopia (1), India (2), Kenya (3), Mexico (1), Namibia (1), Niger (1), Pakistan (1), the Republic of South Africa (1), Tanzania (5), Turkey (1), Uganda (1), the U.S.S.R. (4), the United States (20), and Venezuela (1).

TABLE 11

SODIUM CARBONATE-BEARING MINERALS

Mineral	Composition	Percent Na_2CO_3 [1]
Themonatrite (monohydrate)	$Na_2CO_3 \cdot H_2O$	85.5
Trona (sesquicarbonate)	$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$	70.4
Nahcolite (sodium bicarbonate)	$NaHCO_3$	63.1
Bradleyite	$Na_2PO_4 \cdot MgCO_3$	47.1
Pirssonite	$Na_2CO_3 \cdot CaCO_3 \cdot H_2O$	43.8
Northupite	$Na_2CO_3 \cdot NaCl \cdot MgCO_3$	40.6
Tychite	$2MgCO_3 \cdot 2Na_2CO_3 \cdot Na_2SO_4$	42.6
Natron (sal soda or washing soda)	$Na_2CO_3 \cdot 10H_2O$	37.1
Dawsonite	$NaAl(CO_3)(OH)_2$	35.8
Gaylussite	$NaCO_3 \cdot CaCO_3 \cdot 5H_2O$	35.8
Shortite	$Na_2CO_3 \cdot 2CaCO_3$	34.6
Burkeite	$Na_2CO_3 \cdot 2Na_2SO_4$	27.2
Hanksite	$2Na_2CO_3 \cdot 9Na_2SO_4 \cdot KCl$	13.6

[1] Includes bicarbonate converted to carbonate.

cles 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. (formerly Allied Chemical Co.), and is now used by FMC Wyoming Corp. Adopted from coal mining use, the longwall method uses a special track-mounted shearer that moves in front of a hydraulic-operated roof support system.

FMC has pioneered the use of solution mining to dissolve and recover deeply buried trona. Using an array of injection and recovery wells, a solvent, dilute sodium hydroxide, is introduced under pressure to dissolve the underlying trona. This technique has had moderate success since its first commercial debut in 1985.

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 workforce, and increased the quantity of ore mined per shift. Companies have also been considering eliminating conventional mining but retaining other mining methods, sometime in the foreseeable future, in order to further reduce labor, safety, and other operating costs.

Subterranean brines between 50 and 350 feet below the surface at Searles Lake in California are extracted using an array of injection and recovery wells 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, 220 feet to 310 feet below the surface. Solar concentration ponds are used to aerate and concentrate the brine to improve processing efficiency.

Beneficiation.—Crushed trona is calcined in a rotary kiln at 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 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 100° F and centrifuged to produce a pure product, which has uses as such. The sesquicarbonate can be further calcined at 400° F to produce anhydrous soda ash of light to intermediate density.

The complex brines of the lower level of Searles Lake are first treated with carbon dioxide gas in carbonation towers to convert the sodium carbonate in solution to sodium bicarbonate, which will precipitate under these conditions. The sodium bicarbonate is separated from the remainder of the brine by settling and filtration and is then calcined to convert the product back to soda ash. The decarbonated brine is cooled to recover borax and Glauber's salt. A second dissolving, precipitating with carbon dioxide, filtering, and calcining the light soda ash to dense, refines the product to better than 99% sodium carbonate.

At Owens Lake in California, crude soda ash has been mined and processed by Lake Minerals Corp., by simply digging perimeter channels allowing the interstitial fluids to drain. The surface was tilled to promote evaporation to reduce moisture content, followed by harvesting with front-end loaders.

At Lake Magadi, Kenya, crude trona is dredged from surface crusts, crushed, washed, and calcined to convert the sodium sesquicarbonate to soda ash. At Lake Texcoco in Mexico, underground brines are recovered and sent to a surface spiral concentrator to promote the solar concentration of the sodium carbonate in solution. On the Kola Peninsula in the U.S.S.R., soda ash is recovered from processing nepheline-bearing rocks. Nepheline, a sodium-potassium-aluminum silicate is calcined in rotary kilns to yield alumina, potash, and soda ash. The alumina content of the rocks is about

one-half 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 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 is not 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 Kerr-McGee in California. In Wyoming, only value-added products, such as sodium bicarbonate, sodium hydroxide, 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.

Sodium hydroxide (caustic soda) 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 influences 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 Bureau of Mines. The 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. plant basis. This value may or may not necessarily correspond to the posted list prices.

TABLE 12

TIME-VALUE RELATIONSHIPS FOR SODA ASH

	Average annual value (dollars per ton)	
	Natural soda ash	
Year	Actual value[1]	Based on constant 1989 dollars[2]
1970	21.03	63.24
1971	21.21	60.33
1972	22.28	60.52
1973	25.36	64.71
1974	33.87	79.22
1975	42.20	89.88
1976	49.70	99.48
1977	54.19	101.70
1978	54.51	95.35
1979	64.55	103.72
1980	89.85	132.42
1981	91.19	122.52
1982	88.35	111.59
1983	76.95	93.54
1984	67.00	78.57
1985	67.82	77.24
1986	65.29	72.46
1987	66.78	71.84
1988	66.96	69.72
1989	77.07	77.07

[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 bulk soda ash sold, f.o.b. plant. The average annual value may not necessarily correspond to posted list prices for soda ash.
[2] From final 1989 implicit price deflators for Gross National Product, by the Council of Economic Advisors. Based on 1982 = 100.

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) is imposed on any U.S. soda ash sold on the continent.

Taxes.—The total effective tax rate on the Wyoming trona industry is

about 12.64% and comes from two major taxes. The trona severance tax of 5.5% is a State excise tax on minerals as they are removed from the ground, and is applied as a percentage of assessed valuation. The collected taxes are disbursed to the Permanent Wyoming Mineral Trust Fund (2.0%), the General Fund (2.0%), and the Capital Facilities Revenue Account (1.5%). The property, or ad valorem, tax is about 7.14% of the assessed value of trona produced from the mines. The ad valorem taxes on trona are higher than any other Wyoming minerals, including oil, gas, and coal. Other ad valorem taxes are placed on the assessed value of real property (buildings and equipment), and State sales and use taxes on equipment and facilities.

Royalties.—Soda ash mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides royalty payments to the United States Government. The Federal royalty is 5% of the quantity or gross value of the output of the product at the point of shipment to market. Each Federal lease also has other costs, such as bonds, acreage rental fees, sodium prospecting permit application fees, and permit bonds.

In Wyoming, the soda ash deposit within the Known Sodium Leasing Area is under the jurisdiction of the U.S. Government (administered by the Bureau of Land Management), the State, and the Union Pacific Railroad, which was given alternate 1-square-mile sections north and south of the railway that was constructed in the 1860's. Of the nearly 915,000 total acres of sodium mineral estate, the Federal ownership is 55.7%; Union Pacific owns 38.1%, and the State, 6.2%. Sixteen lessees hold 53 active and inactive Federal leases, having a total of 75,783 acres. In order to prevent a possible land monopoly, no lessee may hold more than 15,360 acres of Federal land but may lease more private or State land. The State royalty rate is tied to the Federal rate of 5%; however, the private royalty rate varies. One-half of all Federal royalties collected by the Minerals Management Service is disbursed back to Wyoming for various State and local programs.

In California, the Federal Government maintains 33 sodium mineral leases having 26,799 acres. The major lessee is Kerr-McGee Chemical Corp., 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 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 potential of hydrogen (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 fowls' 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 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 governments 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 12.9 million tons of trona. In 1989, 2,939 people were employed, of which 1,199 underground workers produced 16.2 million tons of ore. From 1980 through 1989, the underground workforce was reduced about 34%, while the quantity of trona increased 26%. This represented a 90% increase in the amount of ore mined per worker per year; 7,100 tons in 1980 and 13,511 in 1989.

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 that U.S. natural soda ash has maintained its competitiveness in the world market.

An early 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 Kerr-McGee 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 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 nevertheless 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 Shoshone. Of the nearly 9 million tons of soda ash produced in Wyoming, Bonneville trucks about 850,000 tons out of Green River. Other trucking companies have started similar operations with the Southern Pacific (shipping over 250,000 tons per year) and Denver & Rio Grande Railroads to compete with Union Pacific.

The railroads have been involved in establishing soda ash bulk loading terminals at ports to handle large volumes of material for export. Kansas City Southern Railroad's terminal at Port Arthur, TX, has a railcar unloading capacity of about 1,000 tons per hour. Material is conveyed to a ship loader spout for transfer to bulk cargo ocean vessels. Port Arthur was the third largest port of the 24 ports that shipped soda ash in 1989, most of which was shipped to South America. Longview, WA, which is in the Portland, OR, customs district, has a bulk loading terminal that transferred the most soda ash, 47%, in 1989.

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SODIUM SULFATE

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 11 years 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, International Data Section.

The U.S. sodium sulfate industry rebounded slightly in 1989 as demand increased in the detergent and pulp and paper sectors. After years of stagnant growth, domestic producers were encouraged at the positive trend but were aware the trend may be short lived because of environmental changes occurring throughout the Nation, which may affect domestic consumption. Additional imports from neighboring countries contributed to domestic supplies of sodium sulfate in response to a decline in U.S. production capacity. Although the United States continued to be one of the largest producers of natural and synthetic sodium sulfate, world production has grown only 1% per year since 1985.

ISSUES

The pulp and paper industry, which consumes about 28% of domestic sodium sulfate supplies, has been under investigation for discharging carcinogenic wastewater effluents into the environment. Although dioxin investigations have been conducted since 1983, 104 bleached pulp mills were studied 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,-TCDF) released by the processes. Dioxins are toxic synthetic compounds that have been identified as carcinogenic to some animals but their effect on humans is controversial. The issue is whether or not the quantity of dioxin that has migrated from milk carton stock into milk and from other paper products, such as paper towels, coffee filters, disposable diapers and sanitary paper products, is harmful. If pulp mills convert from chlorine-base bleaching chemicals to oxygen-base chemicals that are environmentally safe, less sodium sulfate will be used in the pulping process. This change in processing technology will have an adverse effect on future sodium sulfate consumption.[1]

PRODUCTION

Domestic production of sodium sulfate decreased about 5% in 1989 primarily because of the closure 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 85,000 tons. The company encountered economic and environmental problems at its facility beginning in late 1988. Because the facility manufactured special carbonized rayon fabric for the U.S. Department of Defense and for the National Aeronautics and Space Administration, the Federal Government and private contractors intervened with sufficient funding to temporarily avert the closure. By September 1989, problems with carbon disulfide and polychlorinated biphenyl (PCB) emissions forced State and Federal regulatory agencies to demand a cessation of contaminated water discharges.[2] In November, the company abandoned its efforts to counter the mounting criticism of its operations and permanently closed the facility. In order to prevent possible supply disruptions, several sodium sulfate consumers relied upon imports to meet their anticipated supply needs.

Ozark-Mahoning Co., the Nation's second largest natural sodium sulfate producer, was included in the sale of its parent organization, Pennwalt Corp., to Atochem S.A. Atochem is the chemical sector of Société Nationale Elf Aquitaine of France. The reorganization of Atochem's U.S. chemical enterprises

TABLE 1

SALIENT SODIUM SULFATE STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Production[1]	r811	r841	r799	r817	776
Value[2]	r$74,766	r$72,419	r$69,289	r$64,388	$64,447
Exports	119	111	122	85	68
Value	$11,899	$10,183	$10,554	$8,737	$6,241
Imports for consumption	195	188	138	150	190
Value	$14,492	$13,829	$10,363	r$11,962	$13,990
Stocks, Dec. 31: Producers'	31	72	55	59	26
Apparent consumption	r904	r877	r832	r878	931
World: Production	r4,970	r5,057	r5,163	p5,182	e5,217

e Estimated. p Preliminary. r Revised.

[1] Includes natural and synthetic. Total production data for synthetic sodium sulfate, obtained from the Bureau of the Census, was revised in 1988, MA28A Inorganic Chemicals, Current Industrial Reports.

[2] The value for synthetic sodium sulfate is based upon the average value for natural sodium sulfate.

TABLE 2

PRODUCERS OF NATURAL AND SYNTHETIC SODIUM SULFATE IN 1989

Product and company	Plant nameplate capacity (thousand short tons)	Plant location	Source
Sodium sulfate, natural:			
Great Salt Lake Minerals & Chemicals Corp.	50	Ogden, UT	Salt lake brine.
Kerr-McGee Chemical Corp., Westend plant	240	Trona, CA	Dry lake brine.
Ozark-Mahoning Co.[1]	155	Seagraves, TX	Do.
Total	445		
Sodium sulfate, synthetic:			
Avtex Fibers Inc.	(2)	Front Royal, VA	Rayon manufacture.
BASF	38	Lowland, TN	Rayon manufacture.
North American Rayon Corp.	15	Elizabethton, TN	Rayon manufacture.
Climax Chemical Co.	50	Hobbs, NM	Hydrochloric acid manufacture.
Courtaulds North America Inc.	50	La Moyne, AL	Rayon manufacture.
Cyprus Specialty Metals	18	Kings Mountain, NC	Lithium carbonate.
W. R. Grace & Co. Organic Chemicals Div.	9	Nashua, NH	Chelating agents.
Green Bay Packaging	11	Green Bay, WI	Byproduct.
Hoffman-La Roche Inc.	15	Belvidere, NJ	Ascorbic acid manufacture.
J.M. Huber	35	Etowah, TN	Silica pigment.
Do.	15	Havre de Grace, MD	Silica pigment.
Indspec	39	Petrolia, PA	Resorcinol manufacture.
Lithium Corp. of America	45	Bessemer City, NC	Lithium carbonate.
Occidental Chemical Corp.	120	Castle Hayne, NC	Sodium dichromate manufacture.
Public Service of New Mexico	7	Waterflow, NM	Fluegas desulfurization.
Teepak, Inc.	7	Danville, IL	Cellulose manufacture.
Texaco Chemical Co.	3	Delaware City, DE	Fluegas desulfurization.
Total	477		
Grand total	922		

[1] Ozark's Brownfield plant, owned by Atochem North America (formerly Pennwalt), was placed on standby in Sept. 1987; 70,000 tons of capacity is not included in total industry capacity.
[2] Closed in Nov. 1989. Facility had a capacity of 85,000 tons per year; not included in total.

was scheduled to be effective January 1, 1990, and to be called Atochem North America, Inc.[3]

The United States was the largest producer of natural and synthetic sodium sulfate, representing about 15% of the world total, followed by Spain and the U.S.S.R. with 13% each; Mexico, 10%; 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

U.S. consumption of sodium sulfate rose about 6% after several years of stagnation. Although production declined, imports of anhydrous sodium sulfate, primarily from Canada and

TABLE 3

SYNTHETIC AND NATURAL SODIUM SULFATE[1] PRODUCED IN THE UNITED STATES

(Thousand short tons and thousand dollars)

Year	Synthetic and natural[2] (quantity)			Natural	
	Lower purity[3] (99% or less)	High purity	Total[4]	Quantity	Value
1985	375	436	811	389	35,860
1986	362	479	841	396	34,102
1987	344	r456	r799	382	33,086
1988	342	r475	r817	398	31,377
1989	330	447	776	375	31,104

r Revised.
[1] All quantities converted to 100% Na_2SO_4 basis.
[2] Current Industrial Reports, Inorganic Chemicals, Bureau of the Census. Revisions from 1988 Annual (Preliminary), MA28A, Nov. 1989, p. 11.
[3] Includes Glauber's salt.
[4] Data may not add to totals shown because of independent rounding.

Mexico, increased in order to meet do mestic demand requirements.

Approximately 60% of the total sodium sulfate consumed in the United States is for use as a filler in powdered laundry detergents. Because phosphatic detergents contribute to the environmental problems of eutrophication, many areas in the country have adopted phosphate bans or limitations. These areas represent about 33% of the U.S. population. In response to the environmental issue, detergent manufacturers began 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.[4] These reformulations used more sodium sulfate as filler, which was beneficial to the sodium sulfate industry.

Sodium sulfate consumption also 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 1989. 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 26,285 tons. The material stockpiled was anhydrous sodium sulfate and Glauber's salt. Synthetic sodium sulfate was marketed mainly through major chemical distributors, which have separate storage facilities from the producers.

PRICES

The increase in domestic consumption and tightness in supply caused the prices of bulk and bagged sodium sulfate to also increase. The average value rose from $78.81 per ton in 1988 to $83.05 per ton in 1989 for bulk sodium sulfate, f.o.b. mine or plant. Increased bagging costs raised the price of 100 pound bags to $7. Prices in the East are $113 to $114 per ton; $90 to $100 in the Gulf; and $117 per ton in the West. Salt cake prices are about $62 per ton.[5]

TABLE 4

SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand short tons)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION										
United States	1,139	1,111	864	855	872	811	841	799	817	776
Rest of world	3,856	4,071	3,679	3,645	3,980	4,159	4,216	4,364	4,365	4,441
Total	4,995	5,182	4,543	4,500	4,852	4,970	5,057	5,163	5,182	5,217
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Domestic sources	1,139	1,111	864	855	872	811	841	799	817	776
Imports	230	275	394	343	265	195	188	138	150	190
Industry stocks, Jan. 1[2]	29	33	66	30	48	59	31	72	55	59
Total U.S. supply	1,398	1,419	1,324	1,228	1,185	1,065	1,060	1,009	1,022	1,025
Distribution of U.S. supply:										
Industry stocks, Dec. 31[2]	33	66	30	48	59	31	72	55	59	26
Exports	129	124	111	91	76	119	111	122	85	68
Industrial demand	1,236	1,229	1,183	1,089	1,050	915	877	832	878	931
U.S. DEMAND PATTERN[e]										
Glass	74	68	60	55	54	53	53	45	40	37
Pulp and paper	593	560	540	512	500	490	482	490	525	560
Soaps and detergents	482	480	470	468	400	350	324	290	280	261
Other[3]	87	121	113	54	96	22	18	7	33	73
Total U.S. primary demand	1,236	1,229	1,183	1,089	1,050	915	877	832	878	931
VALUES[4]										
Average annual value	$62	$71	$83	$93	$92	$92	$86	$87	$79	$83

[e] Estimated using data from "Chemical Profile" issues on sodium sulfate by Chemical Marketing Reporter for 1971, 1975, 1978, 1980, 1983, 1986, and 1989.

[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 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 sulphide, sodium silicate, and sodium aluminum sulfate), feed supplements, printing inks, sulphonated oils, textile dyeing, veterinary medicines, and viscose sponges.

[4] Dollars per ton for natural sodium sulfate, f.o.b. mine or plant.

FIGURE 1

U.S. SUPPLY-DEMAND OF SODIUM SULFATE

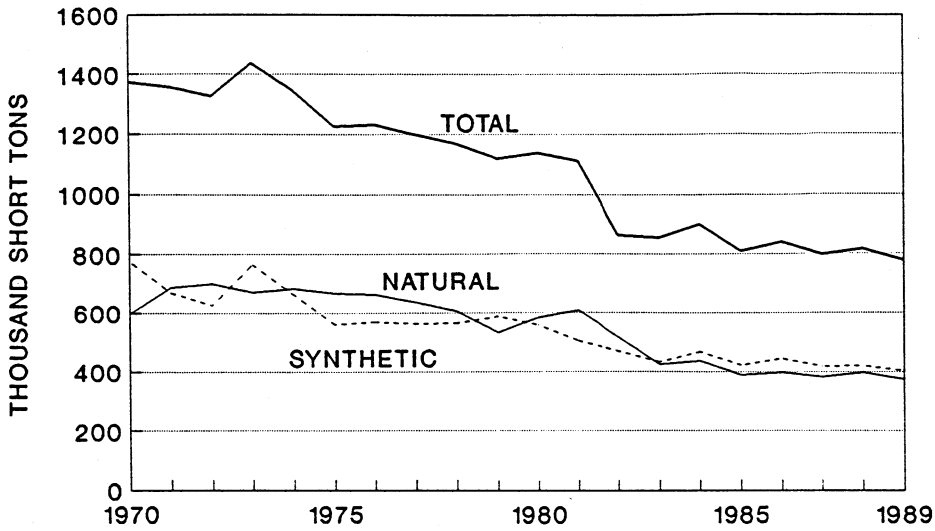
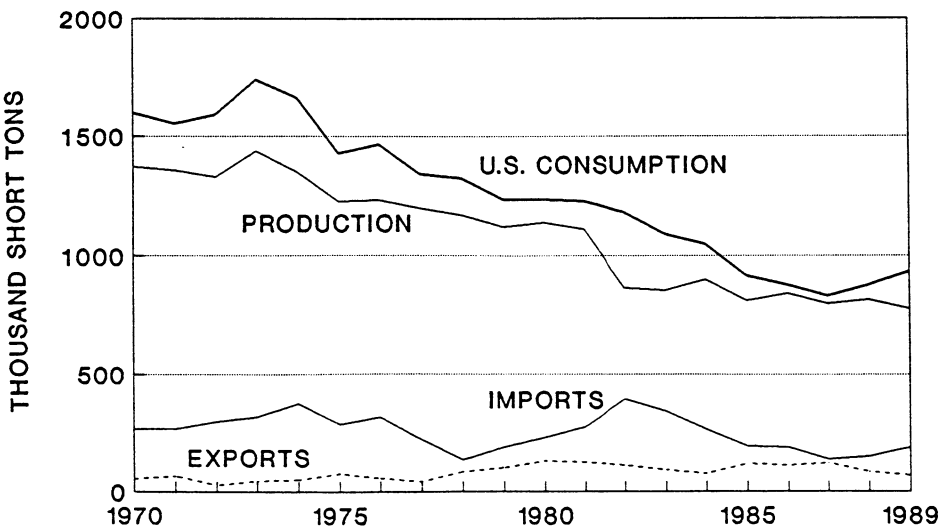


FIGURE 2

PRODUCTION OF NATURAL AND SYNTHETIC SODIUM SULFATE



FOREIGN TRADE

Canada and Mexico represented about 84% and 13%, respectively, of the total U.S. imports of sodium sulfate, and the United Kingdom imported 4% of the total. Although the United States has a net import reliance of about 13%, most imports are less expensive than products from domestic sources, especially when overland shipping costs are considered.

U.S. exports of 68,000 tons were less in 1989 than in the previous year. About 54% of the total quantity was shipped to Australia; New Zealand received 12%; Thailand, 10%; Indonesia, 9%; and Colombia, 7%. Most was in the form of low-purity salt cake.

WORLD REVIEW

Industry Structure

Approximately 47% of the world sodium sulfate industry is from natural sources; the remainder is represented by synthetic sodium sulfate recovered from various chemical and manufacturing processes. Although the Bureau of Mines collects data from 29 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 9 are rated capacities for mines and refineries 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 natural sodium sulfate is derived from available company data on ore throughput to the refinery.

TABLE 5

SODIUM SULFATE YEAREND PRICES

		1988	1989
Sodium sulfate (100% Na_2SO_4):			
East, bulk, carlot, works, frt. equaled	per ton	$113.00-$114.00	$113.00-$114.00
Gulf, bulk, carlot, same basis	do.	90.00- 96.00	90.00- 100.00
West, bulk, carlot, same basis	do.	90.00- 101.00	117.00 —
Salt cake (100% Na_2SO_4):			
East, bulk, f.o.b. works	do.	65.00- 98.00	65.00- 98.00
West, same basis	do.	90.00- 99.00	90.00- 99.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 235, No. 1, Dec. 30, 1988, p. 33; and v. 237, No. 1, Jan. 1, 1990, p. 39.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF SODIUM SULFATE

(Thousand short tons and thousand dollars)

Year	Disodium sulfate, salt cake[1 2]		Disodium sulfate, other[3]		Total[2]	
	Quantity	Value[4]	Quantity	Value[4]	Quantity	Value[4 5]
1985	40	2,549	155	11,943	195	14,492
1986	32	1,885	156	11,944	188	13,829
1987	37	2,189	101	8,173	138	10,363
1988	30	r1,930	120	r10,034	150	r11,962
1989	45	3,350	145	10,641	190	13,990

r Revised.

[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: 1985—none; 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 beginning in 1989; TSUSA No. 4214400 for prior years.

[4] C.i.f. value at U.S. port.

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

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF SODIUM SULFATE

(Thousand short 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]
1985	106	8,816	13	3,083	119	11,899
1986	106	8,218	5	1,965	111	10,183
1987	106	8,882	16	1,672	122	10,554
1988	68	5,128	16	3,609	85	8,737
1989	67	5,409	2	832	68	6,241

[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] C.i.f. value at U.S. port.

Source: Bureau of the Census.

The ore refers to mined crystalline sodium sulfate, harvested precipitate, or sodium sulfate-bearing brines. Refinery capacity for natural sodium sulfate pertains to the total amount of anhydrous sodium sulfate that the plant is capable of processing from the ore. Synthetic (also known as byproduct) sodium sulfate-refining capacity is dependent on the production capabilities of the primary industry and the sodium sulfate recovery rates. The footnotes in table 9 list the various primary industries associated with synthetic sodium sulfate.

Canada

The owner of Saskatchewan Minerals, Kam-Kotia Mines Ltd., terminated its relationship with its U.S. distributor. Low prices and the strength of the Canadian dollar were cited as reasons for the decision.

Mexico

Industrias Penoles S.A. de C.V., Mexico's largest producer of natural sodium sulfate, negotiated with Nepras of Tulsa, OK, which will act as import agent for the Mexican firm. Imports from Mexico may increase to displace the amount of supplies lost due to the closure of Avtex in 1989.

OUTLOOK

Production and consumption of sodium sulfate have decreased about 42% since 1970. This represents an annual rate of decline of about 2.7% per year. These declines are attributed to changes in the recovery operations of consuming industries mandated by environmental legislation requiring reductions in sulfate emissions. Although production has been relatively flat since about 1982, domestic consumption of sodium sulfate is rising slightly but is not expected to grow appreciably in the next several years. Less expensive imports from neighboring countries will continue to serve a part of the needs of the domestic detergent and pulp and paper industries.

Detergents

Sodium sulfate consumption is related to the changes in detergent formulation by the various manufacturers. The increased use of sodium sulfate as

TABLE 8

SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Natural:					
Argentina	23	35	30	17	16
Canada[e]	[3]403	409	377	342	350
Chile[4]	1	5	14	18	15
China[e 5]	10	15	20	30	30
Egypt	74	21	47	[e]47	47
Iran[e]	13	14	14	14	14
Mexico[e 6]	434	502	506	[r]474	500
Netherlands[e]	20	20	24	24	24
South Africa, Republic of	(7)	1	(7)	(7)	(7)
Spain	530	497	524	[e]496	496
Turkey	120	161	[e]165	[e]165	165
U.S.S.R.[e 8]	385	380	400	413	400
United States (sold by producers)	389	396	382	398	[3]375
Total	2,402	[r]2,456	2,503	2,438	2,432
Synthetic:					
Austria[e]	55	61	120	130	132
Belgium[e]	287	292	287	281	281
Brazil[e]	10	10	10	10	10
Chile[9]	[r]57	[r]60	53	70	72
Finland[e]	39	39	39	39	39
France[e]	138	121	127	170	171
German Democratic Republic	190	200	197	198	190
Germany, Federal Republic of	153	180	181	[e]185	190
Greece[e]	[r]10	[r]9	8	8	8
Hungary[e]	11	10	10	10	10
Italy[e]	88	83	88	140	145
Japan	305	279	281	272	295
Netherlands[e]	17	17	17	17	17
Pakistan[e]	1	1	1	1	1
Portugal[e]	55	57	61	60	61
Spain[e 10]	165	165	182	182	182
Sweden[e]	110	110	110	110	110
Turkey[e]	25	30	30	30	30
U.S.S.R.[e 8]	[r]285	[r]285	[r]285	[r]295	295
United Kingdom[e]	[r]100	[r]100	[r]100	[r]100	100
United States[11]	422	445	432	390	[3]402
Yugoslavia	45	47	41	46	44
Total	[r]2,568	[r]2,601	2,660	2,744	2,785
Grand total	[r]4,970	[r]5,057	5,163	5,182	5,217

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through Apr. 18, 1990.

[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] Reported figure.

[4] Natural mine output, excluding byproduct output from the nitrate industry, which is reported separately under "Synthetic" in this table.

[5] Byproduct sodium sulfate is known to be recovered but reliable data are not available; not included under "Synthetic."

[6] Series reflects output reported by Industrias Penoles S.A. de C.V., Mexico's principal producer, plus an additional 30,000 metric tons (estimated) by a smaller producer.

[7] Less than 1/2 unit.

[8] Conjectural estimates based on 1968 information on natural sodium sulfate and general economic conditions.

[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).

a filler appears to have peaked in 1989. Major detergent producers apparently were reformulating to make concentrated detergent products rather than the traditional large boxes filled with bulk detergents containing up to 20% sodium sulfate as filler. Although a new powdered detergent plant was under construction in Cartersville, GA, the future outlook for increased sales of sodium sulfate in detergents is not optimistic. In addition, liquid laundry detergents, which do not contain any sodium sulfate, make up about 40% of the home laundry market. Because of the loss of 85,000 tons of production capacity in 1989, domestic supplies of natural and synthetic sodium sulfate are not sufficient to meet demand requirements; therefore, imports of anhydrous sodium sulfate for detergent use will continue in the future unless new domestic production capacity is brought on-stream or brought back into operation, such as Ozark's Brownfield plant.

Pulp and Paper

Because of environmental concerns regarding sulfur emissions, many Kraft pulpers are installing pollution control equipment to reduce sulfur losses in the pulping process. This may adversely affect the demand for sodium sulfate in the near future. The use of sodium chlorate and hydrogen peroxide as a pulp bleaching chemical may further lessen the demand for sodium sulfate because the process yields byproduct sodium sulfate in the pulp liquor.[6] These losses in sodium sulfate consumption may be partially offset with possible gains in sodium sulfate sales if caustic soda prices continue to increase, as many industy analysts forecast.

BACKGROUND

Natural sodium sulfate reportedly 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 77 pounds per cubic foot.

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.

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.

Sodium sulfate made from natural brine usually contains less than 0.5% total impurities, but that produced as a byproduct of other manufacturing may contain much larger quantities. The material meeting U.S. Pharmacopeia (U.S.P.) specifications and that in-

TABLE 9

WORLD SODIUM SULFATE ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand short tons)

	Natural	Synthetic	Total
North America:			
Canada	538	28	566
Mexico	510	5	515
United States	[2]445	477	922
Total	1,493	510	2,003
South America:			
Argentina	18	NA	18
Brazil	—	10	10
Chile[e]	70	—	70
Total	88	10	98
Europe, Western:			
Austria[e]	—	130	130
Belgium[e]	—	[3]350	[2]350
Finland[e]	—	39	39
France	—	180	180
Germany, Federal Republic of	—	220	220
Greece[e]	—	8	8
Italy	—	140	140
Netherlands[e]	24	17	41
Portugal	—	65	65
Spain[e]	615	100	715
Sweden	—	138	138
Turkey	160	33	193
United Kingdom	—	110	110
Total	799	1,530	2,329
Europe, Eastern:			
German Democratic Republic	—	165	165
Hungary[e]	—	10	10
U.S.S.R.[e]	704	176	880
Yugoslavia	—	45	45
Total	704	396	1,100
Asia:			
China	55	NA	55
Iran[e]	20	—	20
Japan	—	300	300
Pakistan	—	1	1
Total	75	301	376
Africa:			
Egypt	50	—	50
South Africa, Republic of	5	—	5
Total	55	—	55
World total	3,214	2,747	5,961

[e] Estimated. NA Not available, although production and recovery are known to occur.

[1] Includes capacity at operating plants as well as at plants on standby basis. Production capacities of sodium sulfate are based on processing of solid minerals or sodium sulfate-bearing brines. Synthetic (byproduct) sodium sulfate capacities can fluctuate depending on the production capabilities of the primary industry (e.g., ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, pharmaceuticals, rayon, resorcinol, and silica pigments) and the sulfate recovery rates.

[2] Does not include Ozark's Brownfield, TX, idle facility.

[3] The Tessenderloo hydrochloric acid plant reportedly has 1 million tons of byproduct sodium sulfate capacity, most of which is diverted to potassium sulfate production. About 300,000 tons of sodium sulfate routinely can be recovered.

tended 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 salt content may be between 1.5% and 2.0%, and its iron content between 60 and 100 parts per million.

Industry Structure

Naturally derived sodium sulfate produced by three companies operating a total of three plants in California, Texas, and Utah supplied about one-half of the total output of domestic 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 in the Midwest and Mid-Atlantic regions. Total rated production capacity in 1989 was 922,000 tons, and the industry operated at 84% 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 postglacial age. Sodium sulfate is widespread in occurrence and is a common component of seawater and many saline or alkaline lakes. Economic reserves of natural sodium sulfate are estimated at 3.6 billion tons worldwide. With world production of natural sodium sulfate averaging nearly 3 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 industry recovering byproduct sulfate.

Origin.—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 is a hydrous form of sodium sulfate that 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, the 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 also can be 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 various chemical processes involves various techniques.

TABLE 10

WORLD NATURAL SODIUM SULFATE RESERVES AND RESERVE BASE

(Million short tons)

	Reserves	Reserve base[1]
North America: 500		
Canada	92	300
Mexico	182	250
United States	945	1,500
Total	1,219	2,050
Europe:		
Spain	200	300
U.S.S.R.	2,000	2,500
Total	2,200	2,800
Africa:		
Botswana	207	250
World total	[2]3,600	5,100

[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.

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

TABLE 11

SODIUM SULFATE-BEARING MINERALS

Mineral	Composition	Percent Na_2SO_4
Thenardite (anhydrous)[1]	$2Na_2SO_4$	100
Hanksite	$2Na_2CO_3 \cdot 9Na_2SO_4 \cdot KCl$	81.7
Sulphohalite	$2Na_2SO_4 \cdot NaCl$	73.9
Glauberite	$Na_2SO_4 \cdot CaSO_4$	51.1
Loeweite	$2Na_2SO_4 \cdot 2MgSO_4 \cdot 5H_2O$	46.3
Ferronatrite	$3Na_2O_4 \cdot Fe_2(SO_4)_3 \cdot 6H_2O$	45.6
Mirabilite (Glauber's salt)	$2Na_2SO_4 \cdot 10H_2O$	44.1
Bloedite	$Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	27.2
Tychite	$2Na_2CO_3 \cdot 2MgCO_3 \cdot Na_2SO_4$	42.5
Aphthitalite	$(Na,K)_2SO_4$	21-38
Tamarugite	$Na_2SO_4 \cdot Al_2(SO_4)_3 \cdot 12H_2O$	20.3
Mendozite	$Na_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	15.5

[1] Salt cake is anhydrous sodium sulfate with a purity lower than 98%.

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 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.

Beneficiation.—At Searles Lake, the brine is first cooled at about 60° F to precipitate borax crystals, which are removed from the system for subsequent further processing for sale. A second cooling to about 40° F precipitates the sodium sulfate in the form of Glauber's salt. These crystals are separated from the rest of the brine on a rotating drum filter. They are then redissolved in fresh water in a vacuum evaporator. 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. 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.

Manufacturers of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments produce sodium sulfate as a byproduct of the process. The sodium sulfate is considered a waste product but has marketability.

Economic Factors

Prices.—Producers of natural sodium sulfate tend to market and sell their own product, but synthetic producers use major chemical distributors. The principal product made and sold by the synthetic sodium sulfate producer is the primary economic factor. Because the sodium sulfate is a waste product, it will be sold at whatever price in order to dispose of it. 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 Bureau of Mines. The value represents the combined amount of total revenue of domestic natural sodium sulfate sold at list prices, spot prices, long-term contracts, discounts, and export divided by the aggregated quantity of sodium sulfate sold. The published value does not necessarily correspond to the posted list price.

Tariffs.—Import tariffs serve to protect the interests of domestic producers for particular products. For sodium sulfate, a 32.5 cents per ton tariff is imposed on imported anhydrous sodium sulfate from countries having most favored nation (MFN) status and $2.95 per ton from those with non-MFN status. There are no import tariffs on imported salt cake, regardless of the country of origin.

Royalties.—Sodium sulfate mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides for royalty payments to the United States

TABLE 12

TIME-VALUE[1] RELATIONSHIPS FOR SODIUM SULFATE

Year	Average annual value, dollars per ton	
	Natural sodium sulfate	
	Actual value	Based on constant 1989 dollars[2]
1970	18.28	54.97
1971	16.00	45.51
1972	16.26	44.16
1973	17.26	44.04
1974	23.99	56.11
1975	41.48	88.35
1976	49.25	98.58
1977	46.09	86.50
1978	46.06	80.57
1979	55.69	89.49
1980	62.42	91.99
1981	71.03	95.44
1982	83.00	104.83
1983	93.30	113.41
1984	92.16	108.08
1985	92.19	104.99
1986	86.11	95.57
1987	86.72	93.29
1988	78.81	82.06
1989	83.05	83.05

[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 1989 implicit price deflators for gross national product, by the Council of Economic Advisors. Based on 1982 = 100.

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 that has any Federal leases. Because of the variety of the brine constituents, the operator has a commingling agreement with the U.S. Government to compute royalties.

Depletion Provisions.—Legislation passed by the U.S. Government provides an allowance for the depletion of natural resources, notably timber and minerals. The depletion allowance is an important inducement for companies willing to accept the risk and high cost of mining development. The concept of depletion allowances for minerals is similar to the depreciation of other assets. Although cost depletion and percentage depletion are two methods used to compute depletion deductions, most companies prefer to use the latter. About 100 mineral categories are entitled to percentage depletion. The rates range between 5% and 22% of the gross income from the mineral property, depending on the mineral and location (foreign or domestic), and are subject to a limitation of 50% of the net income of the property. The mineral depletion allowance for natural sodium sulfate is 14% for U.S. companies mining from domestic or foreign sources.

Operating Factors

Operating factors are different for mining companies producing natural sodium sulfate compared with manufacturing facilities recovering byproduct sodium sulfate. The quantity of synthetic sodium sulfate recovered is directly associated with the production capabilities of the primary industry (e.g., rayon, lithium carbonate, etc.) and the sulfate recovery rates.

Environmental Requirements.—Land usage may become a problem when sodium sulfate is obtained by solar evaporation, as in the case of the Great Salt Lake brines. Large areas of relatively flat land are required to allow for adequate concentration and evaporation. When land values are high, the capital required for land acquisition may increase operating costs. Disposal of the waste liquors from which sodium sulfate was extracted may develop into a major ground water discharge problem in some areas. Reinjection of spent solutions into underground source strata is expensive but often is the only acceptable method of disposal.

Because sodium sulfate is water-soluble, most releases of sodium sulfate to the environment affect water quality rather than air or land quality. These releases are mainly from Kraft pulp mills, which typically discharge between 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 milligram 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.[7]

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 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 rail or truck. The method of transportation depends on the location of the customer, quantity purchased, and difference in freight rates. Due to 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 the competitiveness between the two types of sodium sulfate. Consumers in the Midwest and East tend to rely on synthetic sodium sulfate produced in various Midwest and Southern locations.

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[1] U.S. Department of Commerce. U.S. Industrial Outlook 1990. Paper and Allied Products, p. 10–3—10–4.

[2] Chemical Marketing Reporter. Avtex Fined Record Amount by a Judge in Richmond, VA. V. 236, No. 22, Nov. 27, 1989, p. 5.

[3] Hardin County Independent. No Big Changes at Ozark-Mahoning Anticipated Because of Reorganization. Dec. 7, 1989, p. 2.

[4] Chemical Week. Soap and Detergents. V. 144, No. 3, pp. 24–44.

[5] Chemical Marketing Reporter. Sodium Sulfate Hit By Detergent Switch. V. 236, No. 24, Dec. 11, 1989, p. 3.

[6] Saltcake Improving Today, But Future Looks Uncertain. V. 236, No. 7, Aug. 14, 1989, p. 26.

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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 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.

A total of 1.2 billion short tons of crushed stone was produced in the United States in 1989, a 2.8% decrease compared with the estimated 1988 total. This tonnage represents the third consecutive year of production over 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 7.1% to 3.9 million tons, while value decreased 23.2% to $23.3 million. Imports of crushed stone, including calcium carbonate, increased 20.9% to 4.4 million tons, while the value increased 119.6% to $36.9 million. Domestic apparent consumption of crushed stone was 1.2 billion tons.

The new regulatory requirements being proposed by the Occupational Safety and Health Administration (OSHA) constitute major areas of concern for the crushed stone 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 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, a preliminary survey that collects production information on a sample basis is used to generate only annual estimates for each State. In addition, a new quarterly sample survey for crushed stone and sand and gravel was implemented by the Bureau of Mines in 1989 that provides for the first-time production estimates by quarters for each State, and the nine geographic regions. The results of this survey are published each quarter in a separate publication, the Quarterly Mineral Industry Survey. Both sample surveys canvass most of the large companies in each State, accounting for up to 80% of the State's total tonnage.

Of the 4,862 crushed stone operations surveyed, 3,416 were active. Of these, 2,901 or 84.9% reported to the Bureau of Mines survey, and their total production represented 92.8% of the total U.S. crushed stone output. The nonrespondents' production was estimated using adjusted production reports and/or employment data of prior years. Of the 2,901 reporting operations, 839 did not report a breakdown by end use. Their production represented 27.5% of the U.S. total and is included in table 13 under "Unspecified uses, actual." The estimated production of 515 operations represented 7.2% of the U.S. total. A total of 1,446 quarries was either idle or presumed to have closed down because no information was available to estimate their production.

LEGISLATION AND GOVERNMENT PROGRAMS

On January 13, 1989, OSHA announced the final promulgation of exposure limits for 400 air contaminants, establishing a permissible exposure limit (PEL) of 0.1 milligram per cubic meter for crystalline silica, measured as respirable silica.[1] Despite this ruling, some statements in the preamble indicate that OSHA may reconsider in the future the need to lower the standard, based on "emerging developments in this area."

On August 29, 1989, the Mine Safety and Health Administration (MSHA), published a new proposed rule that revises MSHA's existing standards for air quality and chemical substances at coal and metal-nonmetal mines. The proposed rule contains permissible exposure limits for substances that may pose health hazards at these operations. In addition, the proposed rule contains revised requirements for exposure monitoring, carcinogens, and respiratory protection programs. The original deadline for receiving comments about the proposed ruling was November 27, 1989, and was extended later to March 2, 1990.[2]

TABLE 1

SALIENT U.S. CRUSHED STONE STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
Sold or used by producers:					
Quantity[1]	1,000,800	[e]1,023,200	1,200,100	[e]1,247,800	1,213,400
Value[1]	$4,053,000	[e]$4,255,000	$5,248,600	[e]$5,558,000	$5,325,800
Exports (value)	$29,347	$36,957	$26,063	$30,413	$23,345
Imports for consumption (value)[2]	$11,640	$12,451	$14,024	$16,789	$36,870

[e]Estimated.

[1]Does not include American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands.

[2]Excludes precipitated calcium carbonate.

On July 21, 1989, OSHA announced another extension through November 30, 1990, of the stay for the new provisions of its revised asbestos standards governing occupational exposure to nonasbestiform varieties of actinolite, tremolite, and anthophyllite (AT&A) minerals. The revised asbestos exposure standards were originally published by OSHA on June 20, 1986. The former asbestos standard remains in effect for the extent of the stay. Based on OSHA's Hazard Communication Standard, a product is considered carcinogenic if it contains 0.1% or more of an OSHA-designated carcinogen. The inclusion of nonasbestiform AT&A minerals in the asbestos exposure standards effectively designates large areas of the United States as containing carcinogenic minerals. 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.

In 1989, MSHA established a new program to combat illegal mining. The program will be enforced through an Illegal Mining Task Force, as well as MSHA officials at the local level. MSHA considers a mining site illegal when the operator fails to register the site with the agency.

ISSUES

On June 20, 1986, OSHA published a final rule titled "Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite; Final Rules." The regulation, which was amended in September 1988, established exposure limits for asbestos and nonasbestiform varieties of the amphibole minerals AT&A. Under OSHA regulation, all products containing a specified concentration of these minerals must be labeled as having a constituent that is a carcinogen. In an effort to assist OSHA in its decision regarding implementation of the final asbestos standard, the Bureau of Mines completed in August 1989 a study entitled "Analysis of the Cost Effectiveness of the OSHA Regulation of Nonasbestiform Amphiboles with Respect to Selected Sectors of the Domestic Minerals Industry."[3] The Bureau's analysis questions "whether OSHA has conclusively demonstrated a health risk associated with AT&A and, consequently, that these minerals should be regulated at all, given that no discernible net benefits will result." The study has also "identified a basic inconsistency between OSHA's definition of asbestos and its asbestos standard" and found that "the regulation will result in economic impacts on several mineral industry sectors."

"The economic impact of the OSHA regulation is expected to be greatest on the aggregates industry. Because of product liability considerations, it is expected that preliminary deposit evaluation and deposit sampling of some kind would have to be done at about 1,325 quarries, or one-fourth of the crushed stone quarries in the United States. It is estimated that about 780 quarries, or 15 percent of U.S. quarries, would need to conduct detailed testing. The annualized cost of preliminary deposit evaluation and deposit sampling of the 1,325 quarries is estimated at $22 million." Significantly, the Bureau analysis concludes that "the remaining 345 of the 780 quarries would be financially unable to afford the cost of the required detailed testing because of their small size. These quarries, which produced an estimated 16.6 million tons in 1987 valued at $72.5 million, f.o.b. plant, could be forced to close.

Sales losses in the aggregates industry are possible and would be contingent on the availability and cost of material that is essentially free of AT&A and the liability concerns associated with using products containing AT&A." In the concluding section of the study, "it is recommended that OSHA not regulate AT&A as asbestos unless medical data conclusively show that these minerals present a health risk which would be reduced through regulations"; that "OSHA should revise its asbestos and fiber definitions, to make the two terms consistent from a mineralogical standpoint"; and that "OSHA should specifically address the economic impact of its proposed regulation on the minerals industry and weigh these costs against possible benefits."

PRODUCTION

Of the total 1.2 billion tons of crushed stone produced in the United States, 856 million tons or 71% was limestone and dolomite, 168 million tons or 14% was granite, and 99 million tons or 8% was traprock. The remaining 7% was shared, in descending order of quantity, by sandstone and quartzite, miscellaneous stone, marble, shell, calcareous marl, volcanic cinder and scoria, and slate.

A comparison of the four major geographic regions indicates that, in 1989, the South continued to lead the Nation in the production of crushed stone with 577 million tons, or 47.5%, of the total, followed by the Midwest with 324 million tons or 26.7%, and the Northeast with 185 million tons or 15.2%.

Approximately 74% of the total U.S. crushed stone output was produced in two major geographic regions, the South and the Midwest. Of the nine geographic regions, the South Atlantic led the Nation in the production of crushed stone with 316 millions tons or 26% of the U.S. total. Next was the East North Central region with 212 or 17.4% of the total, followed by the Middle Atlantic with 154 million tons or 12.7%.

A comparison of the estimated 1988 and reported 1989 production data by regions indicates that the output of crushed stone decreased in all regions except the East North Central, East South Central, and the Pacific. The largest decreases were recorded in New England, -17.3%, the Mountain, -15.1%, and the Middle Atlantic, -6.2%, while the increases were significantly smaller and occurred in the Pacific, 3.2%, East South Central, 1.4%, and East North Central, 0.8%.

Crushed stone was produced in every State except Delaware and North Dakota. The 10 leading States in the production of crushed stone, in decreasing order of volume, were Pennsylvania, Florida, Texas, Virginia, Illinois, California, Tennessee, Missouri, North Carolina, and Georgia. Their combined production represented 52.8% of the national total.

Changes in ownership, acquisitions by foreign or domestic companies, and mergers continued in the crushed stone industry in 1989. In January 1989, Lone Star Industries Inc. of Greenwich, CT, completed the sale of its remaining 40% interest in Tarmac-Lone Star joint venture to Tarmac America of Herndon, VA, a division of Tarmac PLC of Wolverhampton, United Kingdom. The original joint venture was established in 1986. The latest transaction included remaining interest in aggregates, cement, concrete, and concrete products operations in North Carolina, South Carolina, and Virginia.

Pioneer Concrete of America of Bedford, TX, a subsidiary of Pioneer International Ltd. of St. Peters, Australia, acquired Fletcher Granite Co. Inc. of Chelmsford,

TABLE 2

CRUSHED STONE SOLD OR USED IN THE UNITED STATES, BY KIND

Kind	1987				1989			
	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value	Number of quarries	Quantity (thousand short tons)	Value (thousands)	Unit value
Limestone[1]	2,496	792,448	$3,249,713	$4.10	2,533	806,644	$3,234,317	$4.01
Dolomite	119	48,656	206,904	4.25	136	49,304	216,957	4.40
Marble	51	5,576	62,335	11.18	63	12,222	137,481	11.25
Calcareous marl	16	4,154	7,650	1.84	15	5,118	11,614	2.27
Shell	19	8,402	51,028	6.07	18	6,923	34,794	5.03
Granite	735	179,972	900,682	5.00	376	168,433	864,962	5.14
Traprock	813	103,413	505,187	4.89	446	99,161	524,271	5.29
Sandstone and quartzite	523	32,495	157,934	4.86	241	31,842	148,696	4.66
Slate	10	2,330	14,258	6.12	7	2,088	12,926	6.19
Volcanic cinder and scoria	359	3,657	14,952	4.09	118	3,630	20,206	5.57
Miscellaneous stone	304	19,027	77,954	4.10	110	28,065	119,538	4.26
Total[2]	XX	1,200,100	5,248,600	4.37	XX	1,213,400	5,325,800	4.39

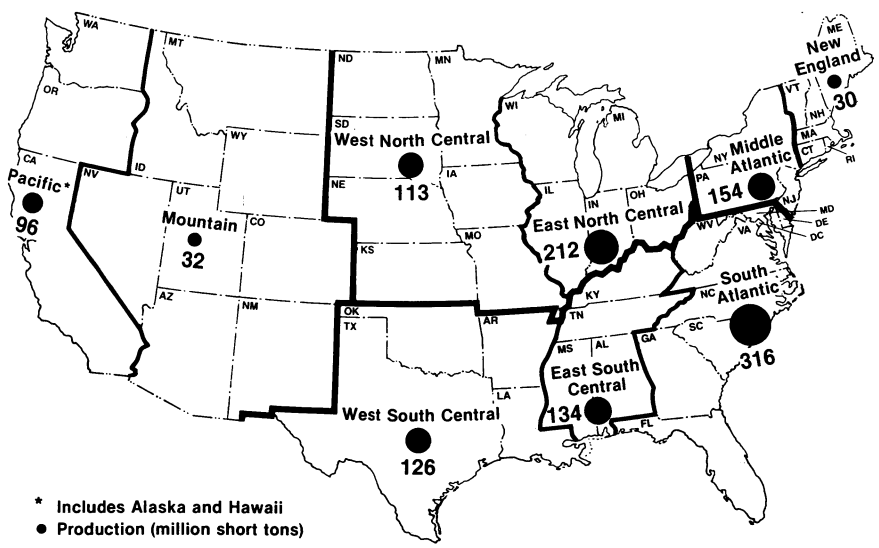
XX Not applicable.

[1]Includes "Limestone/dolomite," reported with no distinction between the two.

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

FIGURE 1

PRODUCTION OF CRUSHED STONE IN THE UNITED STATES IN 1989, BY GEOGRAPHIC REGION



MA. Fletcher operates six granite quarries in Maine, Massachusetts, and New Hampshire.

American Limestone Co. of Knoxville, TN, a wholly owned subsidiary of ASARCO Incorporated of New York, NY, acquired Porter Brown Limestone Co. and Robco Materials Co. of Springfield, TN, and Acme Stone Inc. of Abingdon, VA. Porter Brown operates two limestone quarries near Nashville, TN, while Acme Stone operates a limestone quarry near Knoxville, TN.

First Chicago Corp. of Chicago, IL, acquired Georgia Marble Co. of Atlanta, GA, a major producer of high-grade calcium carbonate with operations in Alabama, Georgia, and South Carolina. Georgia Marble Aggregates Corp. of Atlanta, GA, previously a division of Georgia Marble Co., was acquired by Blue Circle Holdings Inc. of Marietta, GA, the U.S. subsidiary of Blue Circle Industries PLC of London, United Kingdom. Georgia Marble Aggregates operates seven crushed stone quarries near Atlanta, GA.

Redland PLC of Gorby, United Kingdom, acquired through its subsidiary, Western-Mobile Inc. of Denver, CO, Flatiron Sand & Gravel Co. of Boulder, CO. The transaction included the assets of Flatiron Sand & Gravel, Flatiron Paving,

TABLE 3

CRUSHED STONE[1] SOLD OR USED IN THE UNITED STATES, BY REGION

(Thousand short tons and thousand dollars)

Region	1988[e]		1989	
	Quantity	Value	Quantity	Value
Northeast:				
New England	36,500	214,000	30,172	195,607
Middle Atlantic	164,700	794,400	154,421	801,476
Midwest:				
East North Central	210,000	852,500	211,579	787,107
West North Central	117,400	455,100	112,631	407,125
South:				
South Atlantic	[r]324,900	[r]1,588,700	316,306	1,497,971
East South Central	[r]134,100	[r]589,000	134,482	614,623
West South Central	129,600	465,200	125,995	448,560
West:				
Mountain	37,900	144,600	32,166	131,292
Pacific	92,700	451,200	95,679	442,001
Total[2]	1,247,800	5,558,000	1,213,400	5,325,800

[e]Estimated. [r]Revised.
[1]Includes volcanic cinder and scoria.
[2]Data may not add to totals shown because of independent rounding.

Flatiron Premix Concrete, and Plains Aggregate Co. Redland also owns in the United States Genstar Stone Products Co. of Hunt Valley, MD, and Redland Worth Corp. of San Antonio, TX.

ARC America Corp. of Newport Beach, CA, a subsidiary of ARC Ltd. of Bristol, United Kingdom, and one of the major crushed stone and sand and gravel producers in the United States, was acquired by Hanson Trust PLC of London, United Kingdom. The change in ownership followed the acquisition by Hanson PLC of the Consolidated Gold Fields PLC, of London, United Kingdom, the parent company of ARC Ltd. At the end of 1989, Hansen PLC was in the process of selling all ARC America operations to Colonial Sugar Refineries (CSR) Ltd. of Sydney, Australia, a major sugar and building-material producer. The transaction includes American Aggregates Co. of Greenville, OH, Associated Sand and Gravel Co. of Everett, WA, and WMK Co. of Las Vegas, NV. CSR already owns Rinker Materials Corp. of West Palm Beach, FL.

TABLE 4

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, 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	1,900	11,500	13,300	8,700	35,400	217,200	42	24
Middle Atlantic	21,800	44,700	52,200	38,700	157,400	843,700	59	37
Midwest:								
East North Central	22,200	64,500	74,900	57,000	218,600	1,111,300	64	44
West North Central	16,700	34,500	38,300	29,900	119,400	270,300	46	41
South:								
South Atlantic	67,100	83,100	86,400	73,700	310,300	1,571,600	78	42
East South Central	23,100	38,100	43,000	33,900	138,100	619,200	53	16
West South Central	24,900	32,500	32,000	29,600	119,000	425,600	62	35
West:								
Mountain	3,500	11,200	11,800	8,300	34,800	130,800	38	26
Pacific[2]	18,200	24,100	25,600	24,600	92,500	441,000	39	29
Total[3]	199,300	344,100	377,500	304,600	[4]1,235,100	[4]5,636,900	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.

TABLE 5

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons and thousand dollars)

State	1988[e]		1989	
	Quantity	Value	Quantity	Value
Alabama	29,700	140,100	[2]31,737	[2]167,332
Alaska	1,800	8,400	2,900	20,300
Arizona	7,400	33,000	6,649	28,552
Arkansas	17,100	70,100	[3]18,791	[3]76,419
California	49,100	275,000	54,887	238,034
Colorado	10,600	42,400	[4]7,261	[4]32,435
Connecticut	11,400	76,900	[3]11,480	[3]78,734
Florida	[5]83,200	[5]374,400	83,995	341,397
Georgia	57,400	317,200	50,417	262,805
Hawaii	5,700	41,000	6,205	46,746
Idaho	3,400	13,100	3,298	12,609
Illinois	57,900	251,200	[6]60,829	[6]256,832
Indiana	36,600	130,000	[7]36,188	[7]136,252
Iowa	29,200	128,500	28,049	111,182
Kansas	17,300	72,700	[6 8]15,850	[6 8]56,976
Kentucky	50,700	207,900	[3]48,178	[3]187,849
Louisiana	[7]3,700	[7]29,200	3,206	24,414
Maine	1,400	5,300	1,591	8,801
Maryland	32,700	167,000	30,841	153,375
Massachusetts	17,500	91,900	11,880	67,768
Michigan	38,800	120,300	40,905	123,678
Minnesota	8,300	28,200	8,760	30,218
Mississippi	1,500	9,000	1,069	3,994
Missouri	52,100	183,000	51,754	171,848
Montana	1,800	4,500	2,846	9,718
Nebraska	4,900	22,000	3,978	20,050
Nevada	[3]1,300	[3]5,700	1,560	4,638
New Hampshire	2,400	9,800	771	4,020
New Jersey	[9]19,300	[9]123,500	20,799	140,998
New Mexico	3,500	13,900	2,784	11,672
New York	39,900	193,500	39,851	201,749
North Carolina	50,500	250,000	51,519	257,976
North Dakota	W	W	—	—
Ohio	48,000	252,000	46,426	183,190
Oklahoma	[4]26,300	[4]92,000	[2]23,598	[2]81,969
Oregon	22,200	77,600	[3 8]18,407	[3 8]81,204
Pennsylvania	104,600	470,700	[2]93,123	[2]455,004
Rhode Island	1,500	9,400	[4]1,208	7,170
South Carolina[10]	23,500	105,800	24,429	111,656
South Dakota	5,500	20,600	3,833	14,303
Tennessee	52,200	235,000	52,917	252,785
Texas	82,000	271,300	76,823	252,982
Utah	7,300	20,600	4,683	19,176
Vermont	[2]2,000	[2]18,000	3,119	28,110
Virginia	66,000	326,700	64,061	328,050
Washington	13,900	48,700	13,259	55,624
West Virginia	11,600	47,600	[2]10,904	[2]42,538
Wisconsin	[4]28,500	[4]98,300	26,520	83,664

See footnotes at end of table.

Martin Marietta Corp. of Bethesda, MD, acquired eight limestone quarries in central Kansas and northern Iowa from Hallet Materials Corp. of Des Moines, IA.

George Wimpey PLC of London, United Kingdom, acquired Broyhill and Associates Inc. of Annville, PA, and its two rail-linked limestone quarries in Hanover and Annville, PA, that supply Baltimore-Washington and Delaware markets.

Vulcan Materials Co. of Birmingham, AL, acquired Dolcito Quarry Co. of Tarrant, AL, and Central Rock Minerals Inc. of Lexington, KY. Dolcito quarry is one of the oldest continuously operating crushed stone quarries in the southeast. Vulcan also announced the signing of a letter of intent to purchase Reed Crushed Stone Co. of Paducah, KY, and two subsidiary companies, Reed Terminal Co. and BRT Transfer Terminal Inc. Reed Crushed Stone presently operates the largest crushed stone quarry in the United States. Ideal Basic Industries of Denver, CO, started shipping limestone by barge from its newly completed Crystal River quarry in Florida to its Mobile, AL, cement plant.

Limestone

The 1989 output of crushed limestone, including some dolomite, increased slightly to 807 million tons valued at $3.2 billion, compared with the 1987 totals. In addition to the quarries reporting producing only limestone, 41 quarries reported producing both limestone and dolomite without making a distinction between the two kinds of stone. Their production was included with the limestone, and therefore, the limestone totals shown in this chapter include an undetermined amount of dolomite in addition to the dolomite reported separately. Limestone was produced by 1,102 companies at 2,444 quarries in 47 States. Leading States, in decreasing order of tonnage, were Florida, Texas, Pennsylvania, Illinois, and Tennessee; these five States accounted for 38.3% of the total U.S. output. Leading U.S. producers were, in order of volume, Vulcan Materials Co, Beazer USA, Martin Marietta Aggregates, General Dynamics, and the Rogers Group. These five companies accounted for about 20% of total U.S. output of limestone.

Dolomite

Production of dolomite remained relatively unchanged from the 1987 reported totals. Crushed dolomite was reportedly produced by 92 companies at

TABLE 5—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand short tons and thousand dollars)

State	1988[e]		1989	
	Quantity	Value	Quantity	Value
Wyoming	2,500	11,400	2,990	12,120
Other[1]	2,100	13,700	6,303	26,845
Total[11]	1,247,800	5,558,000	1,213,400	5,325,800

[e]Estimated. W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]To avoid disclosing company proprietary data, certain State totals do not include all kinds of stone produced within the State; the portion not shown has been included with "Other."
[2]Excludes granite.
[3]Excludes dolomite.
[4]Excludes traprock.
[5]Excludes marl.
[6]Excludes sandstone.
[7]Excludes other stone.
[8]Excludes quartzite.
[9]Excludes limestone.
[10]Excludes shell.
[11]Data may not add to totals shown because of independent rounding.

136 quarries in 27 States. An additional undetermined amount of dolomite is included in the total crushed limestone. Leading States in the production of dolomite, in decreasing order of tonnage, were Pennsylvania, Ohio, Michigan, Tennessee, and New York; these five States accounted for 67% of the total U.S. output. Leading U.S. producers were Stabler Co., Glasgow Inc., Asarco, Michigan Minerals Associates, and Dravo Lime; their combined production represented 38% of the total U.S. dolomite production.

Marble

Production of crushed marble increased 119% to 12 million tons valued at $137 million. Crushed marble was produced by 14 companies at 59 quarries in 12 States. Leading States, in decreasing order of tonnage, were Georgia, Virginia, Alabama, Vermont, and Texas; these five States accounted for 98% of the total U.S. output. Leading producers of crushed marble, in decreasing order of tonnage, were Georgia Marble Co., Beazer USA, and Jim Walter Corp; their combined production represented 82% of the total U.S. output.

Calcareous Marl

Output of marl increased 23% to 5.1 million tons valued at $11.6 million. Marl was produced by 15 companies at 15 quarries in 8 States. South Carolina accounted for 61% of total U.S. output. Leading producers, in decreasing order of tonnage, were Dundee Cement Co., Medusa Aggregates Co., and Giant Group LTD; their combined production represented 64% of the total U.S. output.

Shell

Shell is mainly derived from fossil reefs or oyster shell. The output of crushed shell decreased 18% to 6.9 million tons valued at $35 million. The decrease is mostly owing to the restrictions imposed on the industry in Louisiana as a result of concerns that shell dredging produces irreversible damage to the environment. Crushed shell was produced by 15 companies from 18 operations in 5 States. The major producing States were Florida and Louisiana, and the leading producers, in decreasing order of tonnage, were Dravo Lime Co., Ashland Oil Inc., Leisey Shell Corp., Pontchartrain Dredging Corp., and Quality Aggregates Inc.; their combined production represented 80% of the U.S. output.

Granite

Compared with that of 1987, the 1989 output of crushed granite decreased 6.4% to 168 million tons valued at $865 million. Crushed granite was produced by 134 companies at 375 quarries in 32 States. Leading States, in decreasing order of tonnage, were North Carolina, Georgia, Virginia, South Carolina, and California; these five States accounted for 76% of the U.S. output. Leading U.S. producers, in decreasing order of tonnage, were Vulcan Materials Co., Martin Marietta, Beazer USA, Tarmac America, and Luck Stone Corp; their combined production represented 56% of the U.S. total.

Traprock

Production of crushed traprock decreased 4% to 99 million tons valued at $524 million. Traprock was produced by 242 companies at 441 quarries in 27 States. Leading States, in decreasing order of tonnage, were Oregon, New Jersey, Washington, Connecticut, and Virginia; these five States accounted for 57% of U.S. output. Leading U.S. producers, in decreasing order of tonnage, were Traprock Industries Inc., Tilcon Inc., Beazer USA, and Luck Stone Corp; their combined production accounted for 25% of the total U.S. output.

Sandstone and Quartzite

The combined output of crushed sandstone and quartzite remained relatively unchanged at 32 million tons valued at $149 million. Crushed sandstone was produced by 113 companies at 216 quarries in 27 States, while crushed quartzite was produced by 23 companies at 24 quarries in 17 States. Leading States in decreasing order of production of sandstone were Arkansas, California, and Pennsylvania, and for quartzite California, Georgia, and South Dakota; the three States accounted for 55% of the U.S. output of sandstone and 76% of the U.S. output of quartzite. Leading producers, in decreasing order of tonnage, were Arkola Sand and Gravel Co., American Rock and Asphalt Inc., and Weaver Construction Co. for crushed sandstone, and Martin Marietta, Beazer USA, and Sweetman Construction Co. for crushed quartzite.

Slate

Compared with that of 1987, the 1989 output of crushed slate decreased 10% to 2.1 million tons valued at $12.9 million. Crushed slate was produced by six companies at seven quarries in six States. Leading States, in decreasing order of tonnage, were North Carolina and Georgia. Leading producers, in order of tonnage, were Martin Marietta, Big River Industries, and Lesuer-Richmond Slate Corp. The top three producers accounted for most of the U.S. output of crushed slate.

Volcanic Cinder and Scoria

Production of volcanic cinder and scoria showed a slight decrease to 3.6 million tons

TABLE 6

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY QUARTER AND STATE

(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			
Alabama	6,200	8,400	9,300	7,600	31,500	155,900	64	9
Alaska[2]	—	—	—	—	1,500	6,800	—	—
Arizona[2]	—	—	—	—	5,300	26,200	—	—
Arkansas	2,500	4,800	6,200	5,700	19,100	85,000	44	7
California	11,600	14,200	13,900	14,200	53,800	242,100	45	12
Colorado	800	2,200	2,900	1,800	7,700	32,700	356	7
Connecticut	900	4,200	4,500	3,200	12,700	87,000	39	6
Delaware	—	—	—	—	—	—	—	—
Florida[3]	21,000	22,600	21,600	19,200	84,300	392,000	62	12
Georgia	11,800	13,200	12,900	10,600	48,500	264,300	95	7
Hawaii[2]	—	—	—	—	6,100	47,900	—	—
Idaho	300	1,200	1,100	700	3,300	13,600	37	4
Illinois	5,900	17,700	20,200	17,300	61,100	259,700	64	11
Indiana	5,100	10,600	12,400	8,500	36,600	135,400	74	15
Iowa	3,300	9,300	9,500	8,300	30,400	127,700	40	6
Kansas	2,300	4,500	5,800	4,100	16,700	64,300	50	11
Kentucky	6,900	13,500	15,600	11,800	49,700	206,300	38	7
Louisiana	900	1,000	1,000	700	3,600	28,000	88	3
Maine	300	400	300	200	1,200	5,600	38	3
Maryland	6,100	8,400	9,400	8,000	31,900	167,500	90	9
Massachusetts	500	4,900	5,900	3,800	15,100	82,300	44	6
Michigan	3,400	11,900	13,000	9,400	37,700	120,600	70	9
Minnesota	300	3,200	4,000	2,000	9,500	36,100	64	7
Mississippi[2]	—	—	—	—	1,700	7,700	—	—
Missouri	9,700	13,900	15,600	13,600	52,800	200,600	40	16
Montana	200	200	700	500	1,600	4,400	59	3
Nebraska	900	1,400	1,400	1,100	4,800	24,500	96	6
Nevada[3]	300	300	800	600	1,900	8,600	68	4
New Hampshire	90	1,400	1,500	900	3,900	17,600	18	2
New Jersey[3]	3,200	4,900	5,900	5,000	18,900	122,700	100	9
New Mexico[2]	500	1,600	1,300	1,000	4,400	16,500	8	4
New York	3,300	12,000	15,700	9,400	40,400	210,100	60	9
North Carolina	8,500	13,300	14,300	11,900	48,100	259,700	95	9
North Dakota[2]	—	—	—	—	W	W	—	—
Ohio	4,900	15,600	18,500	12,600	51,600	283,800	69	11
Oklahoma[3]	4,900	6,600	7,100	6,200	24,700	81,500	77	12
Oregon	3,700	5,500	7,700	6,900	23,800	89,300	31	12
Pennsylvania	15,000	27,900	30,500	23,800	97,200	510,300	52	22
Rhode Island	80	500	500	300	1,400	9,000	73	5
South Carolina[3]	4,800	5,700	6,000	6,200	22,600	109,600	82	7
South Dakota	500	2,000	1,500	1,200	5,200	17,700	45	4
Tennessee	7,700	15,400	17,300	13,700	54,100	248,900	61	8
Texas	16,300	20,200	18,000	17,500	71,900	230,100	60	18
Utah[2]	—	—	—	—	6,000	19,500	—	—
Vermont[2 3]	—	—	—	—	2,000	15,000	—	—
Virginia	13,500	17,300	18,900	15,500	65,200	339,000	73	17
Washington	2,400	4,300	4,300	3,500	14,500	54,400	33	7
West Virginia[2]	—	—	—	—	11,000	38,500	—	—
Wisconsin[3]	2,700	8,800	11,400	11,300	34,100	110,800	35	8
Wyoming[3]	—	—	—	—	2,100	8,900	—	—
Other[2]	—	—	—	—	1,900	11,200	—	—
Total	XX	XX	XX	XX	[4]1,235,100	[4]5,636,900	XX	XX

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

[1]Number of companies reporting for the quarterly survey.

[2]Because of a low number of reporting companies, no production estimates by quarters were generated.

[3]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."

[4]These totals represent preliminary estimates, and therefore, do not equal the final totals resulting from the annual survey.

TABLE 7

CRUSHED STONE SOLD OR USED IN THE UNITED STATES IN 1989, BY REGION AND SIZE OF OPERATION

Size range (short tons)	Northeast				Midwest			
	Number of operations	Percent of total	Quantity (thousand) short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand) short tons)	Percent of total
Less than 25,000	32	8.1	319	0.2	316	23.9	3,435	1.1
25,000 to 49,999	20	5.1	835	.5	175	13.3	6,509	2.0
50,000 to 99,999	36	9.1	2,737	1.5	231	17.5	17,148	5.3
100,000 to 199,999	63	15.9	9,119	4.9	221	16.7	32,560	10.0
200,000 to 299,999	46	11.6	11,505	6.2	122	9.2	29,903	9.2
300,000 to 399,999	40	10.1	14,372	7.8	59	4.5	20,481	6.3
400,000 to 499,999	27	6.8	12,457	6.7	36	2.7	16,372	5.0
500,000 to 599,999	22	5.6	12,113	6.6	25	1.9	13,935	4.3
600,000 to 699,999	23	5.8	15,030	8.1	23	1.7	14,762	4.6
700,000 to 799,999	26	6.6	19,227	10.4	21	1.6	15,865	4.9
800,000 to 899,999	15	3.8	12,724	6.9	13	1.0	11,113	3.4
900,000 to 999,999	9	2.3	8,602	4.7	19	1.4	18,185	5.6
1,000,000 to 1,499,999	18	4.6	21,198	11.5	34	2.6	40,883	12.6
1,500,000 to 1,999,999	8	2.0	13,721	7.4	9	.7	14,897	4.6
2,000,000 to 2,499,999	2	.5	4,578	2.5	5	.4	11,146	3.4
2,500,000 to 4,999,999	8	2.0	26,055	14.1	7	.5	23,407	7.2
5,000,000 and over	—	—	—	—	4	.3	33,609	10.4
Total[1]	395	100.0	184,600	100.0	1,320	100.0	324,200	100.0

	South				West				U.S. total[1]			
	Number of operations	Percent of total	Quantity (thousand) short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand) short tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand) short tons)	Percent of total
Less than 25,000	89	8.3	981	0.2	227	35.4	1,778	1.4	664	19.4	6,512	0.5
25,000 to 49,999	66	5.9	2,464	.4	80	12.5	2,909	2.3	341	10.0	12,717	1.0
50,000 to 99,999	96	9.0	6,824	1.2	104	16.2	7,740	6.1	467	13.2	34,450	2.8
100,000 to 199,999	169	15.8	24,812	4.3	71	11.1	10,164	8.0	524	15.3	76,656	6.3
200,000 to 299,999	116	11.1	28,837	5.0	53	8.3	12,729	10.0	337	9.8	82,974	6.8
300,000 to 399,999	77	8.0	27,029	4.7	22	3.4	7,365	5.8	198	5.8	69,247	5.7
400,000 to 499,999	78	7.2	35,257	6.1	15	2.3	6,646	5.2	156	4.6	70,732	5.8
500,000 to 599,999	63	5.8	34,775	6.0	17	2.6	9,223	7.2	127	3.7	70,046	5.8
600,000 to 699,999	50	5.0	32,594	5.7	6	.9	3,887	3.0	102	3.0	66,272	5.5
700,000 to 799,999	49	5.1	36,272	6.3	9	1.4	6,718	5.3	105	3.1	78,081	6.4
800,000 to 899,999	27	2.9	22,970	4.0	8	1.2	6,866	5.4	63	1.8	53,674	4.4
900,000 to 999,999	34	2.9	32,164	5.6	5	.8	4,768	3.7	67	2.0	63,719	5.3
1,000,000 to 1,499,999	86	7.1	101,394	17.6	12	1.9	14,071	11.0	150	4.4	177,545	14.6
1,500,000 to 1,999,999	28	2.5	48,351	8.4	4	.6	7,254	5.7	49	1.4	84,223	6.9
2,000,000 to 2,499,999	12	1.0	26,334	4.6	5	.8	11,099	8.7	24	.7	53,157	4.4
2,500,000 to 4,999,999	23	2.1	72,854	12.6	4	.6	14,630	11.4	42	1.2	136,947	11.3
5,000,000 and over	6	.4	42,871	7.4	—	—	—	—	10	.3	76,479	6.3
Total[1]	1,069	100.0	576,800	100.0	642	100.0	127,800	100.0	[2]3,416	100.0	1,213,400	100.0

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

[2]Data do not add to total shown because of multiple kinds of stone reported by same operation.

TABLE 8

CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

(Thousand short tons and thousand dollars)

State	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Alabama	27,843	96,991	2,278	9,674
Alaska	1,890	16	1	W
Arizona	3,969	17,622	—	—
Arkansas	7,578	30,081	W	W
California	29,963	120,613	676	8,382
Colorado	4,157	14,686	—	—
Connecticut	1,760	13,260	—	—
Florida	73,058	305,920	1,561	8,099
Georgia	7,796	38,814	—	—
Hawaii	650	3,600	—	—
Idaho	960	4,575	—	—
Illinois	[1]57,293	[1]252,461	3,536	14,371
Indiana	34,091	126,742	2,095	9,510
Iowa	[1]27,850	[1]110,333	W	W
Kansas	15,850	56,976	—	—
Kentucky	48,178	187,849	W	W
Maine	1,143	5,104	—	—
Maryland	19,554	94,436	—	—
Massachusetts	W	W	W	W
Michigan	35,385	104,558	4,544	14,185
Minnesota	6,781	22,866	W	W
Mississippi	1,069	3,994	—	—
Missouri	[1]47,970	[1]159,490	1,159	3,979
Montana	2,680	9,135	—	—
Nebraska	3,978	20,050	—	—
Nevada	W	W	W	W
New Hampshire	W	W	—	—
New Jersey	1,968	15,416	—	—
New Mexico	1,545	4,546	—	—
New York	[1]29,514	[1]132,521	3,719	19,985
North Carolina	4,898	26,306	W	W
Ohio	41,197	166,161	5,121	16,747
Oklahoma	21,511	69,412	547	5,308
Oregon	1,480	5,490	W	W
Pennsylvania	57,984	289,594	13,543	60,483
Rhode Island	676	4,259	—	—
South Carolina	4,474	19,339	—	—
South Dakota	2,332	6,697	—	—
Tennessee	48,965	238,418	W	W
Texas	[1]72,011	[1]224,777	W	W
Utah	3,338	13,641	425	2,596
Vermont	1,716	7,895	—	—
Virginia	18,359	79,597	2,122	17,070
Washington	[1]456	5,645	232	866
West Virginia	9,854	37,480	—	—
Wisconsin	20,049	64,827	W	W
Wyoming	1,371	5,643	W	W
Other	1,493	26,479	7,747	25,700
Total[2]	806,600	3,234,300	49,300	217,000

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes "limestone/dolomite," reported with no distinction between the two.
[2]Data may not add to totals shown because of independent rounding.

TABLE 9

CRUSHED CALCAREOUS MARL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

(Thousand short tons and thousand dollars)

State	Quantity	Value
Florida	266	800
Michigan	12	28
South Carolina	3,133	6,178
Other[1]	1,705	4,608
Total[2]	5,100	11,600

[1]Includes data for Georgia, Indiana, Maine, North Carolina, and Texas.
[2]Data may not add to totals shown because of independent rounding.

valued at $20 million. Volcanic cinder and scoria were produced by 32 companies from 37 operations in 11 States. Leading States, in decreasing order of volume were, California, Arizona, Oregon, and Wyoming; their combined production accounted for 79% of the total U.S. output. Leading producers, in decreasing order of tonnage, were Martin Marietta, the U.S. Forest Service, and Superlite Block Co.; their combined production accounted for 44% of U.S. output.

Miscellaneous Stone

Output of other kinds of crushed stone increased 48% to 28 million tons valued at $120 million. Miscellaneous stone was produced by 91 companies from 104 quarries in 27 States. Leading States, in decreasing order of volume, were Pennsylvania, Florida, and Maryland; their combined production accounted for 55% of the total U.S. output. Leading producers, in decreasing order of tonnage, were Vecellio & Grogan Inc., Rockville Crushed Stone, and Lone Star Industries.

CONSUMPTION AND USES

Crushed stone production reported to the 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

TABLE 10

CRUSHED GRANITE, TRAPROCK, AND SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

(Thousand short tons and thousand dollars)

State	Granite		Traprock		Sandstone and quartzite	
	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	W	W	—	—	—	—
Alaska	W	W	844	3,475	—	—
Arizona	2,022	8,324	—	—	100	W
Arkansas	7,404	30,254	—	—	3,259	13,171
California	8,734	38,325	6,089	32,679	5,298	21,879
Colorado	1,809	8,936	W	W	266	1,283
Connecticut	W	W	9,720	65,473	—	—
Florida	—	—	—	—	—	—
Georgia	32,554	169,196	—	—	W	W
Hawaii	—	—	5,475	42,965	—	—
Idaho	167	425	2,083	7,428	88	182
Illinois	—	—	—	—	W	W
Indiana	—	—	—	—	—	—
Iowa	—	—	—	—	W	W
Kansas	—	—	—	—	407	2,548
Kentucky	—	—	—	—	—	—
Louisiana	—	—	—	—	W	W
Maine	W	W	W	W	W	W
Maryland	3,399	20,741	3,401	12,657	177	1,094
Massachusetts	2,812	19,171	7,567	37,317	W	W
Michigan	—	—	24	69	W	W
Minnesota	1,765	6,536	10	82	—	—
Mississippi	—	—	—	—	—	—
Missouri	W	W	W	W	610	2,019
Montana	—	—	W	W	97	375
Nebraska	—	—	—	—	—	—
Nevada	33	48	W	W	—	—
New Hampshire	W	1,383	W	W	—	—
New Jersey	6,487	47,093	12,345	78,490	—	—
New Mexico	745	4,467	W	W	W	W
New York	3,604	28,151	1,890	14,616	1,000	6,141
North Carolina	39,398	193,664	3,761	19,634	W	W
Ohio	—	—	—	—	108	281
Oklahoma	W	W	955	5,227	585	2,022
Oregon	219	977	15,242	65,222	W	W
Pennsylvania	W	W	8,037	39,311	7,515	34,017
Rhode Island	532	2,845	W	67	—	—
South Carolina	16,822	86,140	—	—	—	—
South Dakota	—	—	—	—	1,467	7,467
Tennessee	—	—	—	—	W	W
Texas	—	—	W	W	1,259	7,639
Utah	W	W	—	—	W	W
Vermont	W	W	—	—	—	—
Virginia	29,985	161,737	9,439	52,049	1,250	5,686
Washington	309	1,668	10,179	40,537	983	2,989
West Virginia	W	W	—	—	1,050	5,059
Wisconsin	2,185	6,395	W	W	2,337	7,732
Wyoming	W	W	—	—	—	—
Other	7,451	28,485	2,099	6,972	3,986	27,112
Total[1]	168,400	865,000	99,200	524,300	31,800	148,700

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

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

TABLE 11

CRUSHED VOLCANIC CINDER AND SCORIA AND MISCELLANEOUS CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

(Thousand short tons and thousand dollars)

State	Volcanic cinder and scoria		Miscellaneous stone	
	Quantity	Value	Quantity	Value
Alaska	—	—	150	1,002
Arizona	531	1,234	—	—
Arkansas	—	—	552	2,913
California	740	3,368	3,335	12,531
Colorado	258	3,980	771	3,551
Florida	—	—	5,580	16,636
Indiana	—	—	W	W
Louisiana	—	—	W	W
Maryland	—	—	W	W
Massachusetts	—	—	W	W
Michigan	—	—	W	W
Minnesota	—	—	W	W
Missouri	—	—	334	1,926
Nevada	96	640	407	1,136
New Hampshire	—	—	272	1,063
New Mexico	206	1,967	W	W
New York	—	—	W	W
Oregon	502	3,508	179	508
Pennsylvania	—	—	6,001	29,745
South Dakota	—	—	W	W
Tennessee	—	—	W	W
Texas	—	—	1,527	4,998
Utah	W	W	—	—
Vermont	—	—	W	W
Virginia	—	—	W	W
Washington	W	W	1,017	3,477
Wyoming	293	W	28	91
Other	[1]1,004	[1]5,510	[2]7,912	[2]39,961
Total[3]	3,600	20,200	28,100	119,500

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]Includes data for Hawaii and Washington.
[2]Includes data for Hawaii and North Carolina.
[3]Data may not add to totals shown because of independent rounding.

"Other unspecified uses, actual." The estimated production of nonrespondents is reported under "Other unspecified uses, estimated."

In 1989, U.S. consumption of crushed stone was 1.2 billion tons valued at $5.3 billion, a 2.8% decrease from the estimated consumption of 1988 and a slight increase over the reported consumption of 1987. About 52% of this tonnage was used as construction aggregates, mostly for highway and road construction and maintenance; 9% for cement and lime manufacturing; 2% for agricultural purposes; 1% for other chemical and metallurgical purposes; 1% for special uses and products; and 35% for other unspecified uses.

Limestone

Of the 807 million tons of crushed limestone consumed, 48% was used as construction aggregates, 13% for cement and lime manufacturing, 2% for agricultural purposes, 1% for chemical and metallurgical uses, 1% for special uses and products, and 34% as other unspecified uses. Any analysis of limestone uses should take into account the 278 million tons of limestone included under "Other unspecified uses, actual and estimated." It is recommended that in any such review, the quantities and values included in "Other unspecified uses" be distributed among the reported uses being analyzed, based on the following calculation: The percentage for each reported use should be calculated as a percentage of the U.S. total minus "Other unspecified uses"; the resulting percentages then should be applied to "Other unspecified uses" and the resulting quantities and values added to the reported uses published in the table.

Dolomite

Of the 49 million tons of crushed dolomite consumed, 51% was used as construction aggregates, 6% as agricultural lime, 3% for dead-burned dolomite, 1% as flux stone, 1% for lime manufacturing, and 33% for other unspecified uses. An additional undefined amount of dolomite consumed in a variety of uses is reported with the limestone.

Marble

Of the 12 million tons of crushed marble consumed, 8% was used as fillers and extenders, 7% for miscellaneous uses, and 85% was used for other unspecified uses.

Calcareous Marl

Of the 5 million tons of marl consumed, 93% was used for cement manufacturing, 2% as road base material, and 5% for other unspecified uses.

Shell

Of the 6.9 million tons of crushed shell consumed, 39% was used as construction aggregates and 61% for other unspecified uses.

Granite

Of the 168 million tons of crushed granite consumed, 71% was used as construction aggregates, of which 5% was for railroad ballast, and 28% was used for other unspecified uses.

Traprock

Of the 99 million tons of crushed traprock consumed, 57% was used as construction aggregates and 41% was used for other unspecified uses.

TABLE 12

KIND OF CRUSHED STONE PRODUCED IN THE UNITED STATES IN 1989, 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	X						
South Dakota	X							X	X			X
Tennessee	X	X						X				X
Texas	X	X	X	X			X	X				X
Utah	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 13

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1½ inch):		
Macadam	9,797	39,575
Riprap and jetty stone	21,817	111,406
Filter stone	9,111	38,744
Other coarse aggregate	1,964	7,525
Coarse aggregate, graded:		
Concrete aggregate, coarse	113,871	534,709
Bituminous aggregate, coarse	72,731	346,788
Bituminous surface-treatment aggregate	22,155	106,053
Railroad ballast	18,015	78,129
Other graded coarse aggregate	4,320	22,605
Fine aggregate (-3/8 inch):		
Stone sand, concrete	19,932	94,748
Stone sand, bituminous mix or seal	19,466	80,851
Screening, undesignated	32,027	133,535
Other fine aggregate	1,742	8,955
Coarse and fine aggregates:		
Graded road base or subbase	178,900	682,472
Unpaved road surfacing	28,517	109,901
Terrazzo and exposed aggregate	3,637	22,629
Crusher run or fill or waste	52,079	201,329
Other coarse and fine aggregates	747	2,537
Other construction materials[1]	21,033	97,561
Agricultural:		
Agricultural limestone	18,934	89,283
Poultry grit and mineral food	3,191	25,682
Other agricultural uses	910	4,834
Chemical and metallurgical:		
Cement manufacture	97,432	278,381
Lime manufacture	16,168	85,051
Dead-burned dolomite manufacture	1,366	7,441
Flux stone	5,604	23,743
Chemical stone	458	1,911
Glass manufacture	302	3,605
Sulfur oxide removal	1,159	4,536
Special:		
Mine dusting or acid water treatment	715	8,077
Asphalt fillers or extenders	1,870	13,396
Whiting or whiting substitute	1,642	69,752
Other fillers or extenders	4,525	81,869
Roofing granules	3,084	14,063
Other miscellaneous uses:		
Waste material	2,017	7,039
Other uses not listed[2]	2,030	15,929
Unspecified:		
Actual	333,085	1,482,690
Estimated	87,081	388,431
Total[3]	1,213,400	5,325,800

[1]Includes stone used in drain fields.

[2]Includes stone used in lightweight aggregate (slate), abrasives, building products, paper manufacture, and pipe bedding.

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

Sandstone and Quartzite

Of the 32 million tons of combined crushed sandstone and quartzite consumed, 64% was used as construction aggregates, of which 5% was for railroad ballast; 1% for cement manufacturing; and 31% for other unspecified uses.

Slate

Of the 2 million tons of crushed slate consumed, 74% was used for a variety of unspecified industrial applications and 26% was used as construction aggregates.

Volcanic Cinder and Scoria

Of the 3.6 million tons of volcanic cinder and scoria consumed, 50% was used as construction aggregates, mainly for road construction and maintenance, and 47% was used for other unspecified uses.

Miscellaneous Stone

Of the 42 million tons of miscellaneous crushed stone consumed, 46% was used as construction aggregates and 40% for other unspecified uses.

TRANSPORTATION

Of the total crushed stone produced, 54% was transported by truck from the processing plant or quarry to the first point of sale or use, 4% was transported by rail, and 3% by waterway. For about 39% of the total crushed stone produced in 1989, no means of transportation was reported by the producers, indicating that at least part of that production was used on-site.

PRICES

Compared with those of 1987, the 1989 average unit prices of crushed stone showed a slight increase of only 0.5% to $4.39. By kind of stone, the average unit prices showed increases of 36% for volcanic cinder, 23% for marl, 8% for traprock, 4% each for dolomite and miscellaneous stone, 3% for granite, 2% for limestone, and 1% each for marble and slate. At the same time, the average unit prices decreased by 17% for shell, 4% for sandstone and quartzite, and 2% for limestone.

As a result of rising costs of labor, energy, and mining and processing equipment, the average unit value of crushed stone increased from $1.58 per ton, f.o.b.

TABLE 14

CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS

(Thousand short tons

State	Concrete aggregate		Bituminous aggregate		Roadstone and coverings		Riprap and railroad ballast		Other construction uses	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	5,197	20,217	5,154	20,432	3,390	12,595	1,213	4,667	2,818	11,159
Alaska	—	—	378	3,160	511	4,268	—	—	340	2,844
Arizona	—	—	—	—	—	—	—	—	11	124
Arkansas	253	1,285	585	2,167	1,118	4,192	756	2,976	167	709
California	W	W	W	W	1,458	3,626	W	W	659	1,532
Colorado	W	W	W	W	161	442	—	—	362	767
Connecticut	—	—	—	—	—	—	—	—	—	—
Florida	23,155	127,901	6,068	29,035	19,734	58,619	606	1,990	14,661	48,407
Georgia	3,017	15,309	376	1,984	1,276	5,599	255	1,226	1,979	9,877
Hawaii	W	W	—	—	218	1,891	—	—	W	W
Idaho	—	—	29	106	369	1,227	—	—	W	W
Illinois	7,440	29,652	5,331	24,920	15,200	56,003	876	4,449	2,133	8,306
Indiana	4,406	14,023	4,477	15,237	5,427	21,035	1,073	3,882	3,607	17,425
Iowa	1,256	6,434	2,352	11,717	7,079	26,587	125	671	538	1,933
Kansas	1,427	6,094	1,431	6,592	2,765	8,310	82	298	1,066	3,895
Kentucky	4,209	16,074	6,095	23,220	10,396	38,869	2,153	7,841	2,377	7,983
Maine	—	—	W	W	—	—	W	W	—	—
Maryland	1,109	5,121	428	1,956	697	3,109	86	420	576	5,300
Massachusetts	—	—	—	—	—	—	—	—	—	—
Michigan	4,072	12,294	1,063	2,671	4,967	17,196	380	1,714	2,455	8,778
Minnesota	284	1,027	186	514	2,566	8,320	60	293	610	2,250
Mississippi	W	W	W	W	W	W	W	W	W	W
Missouri	5,900	22,425	5,406	19,789	11,290	38,118	3,896	12,138	2,315	7,105
Montana	52	157	64	196	320	956	—	—	—	—
Nebraska	W	W	320	1,854	292	1,642	44	295	1,370	7,340
Nevada	—	—	—	—	—	—	—	—	—	—
New Hampshire	—	—	—	—	W	W	—	—	—	—
New Jersey	W	W	W	W	W	W	W	W	W	W
New Mexico	243	801	114	372	322	755	6	40	66	236
New York	1,960	13,612	5,421	26,129	3,618	21,077	350	1,651	4,224	18,871
North Carolina	W	W	W	W	159	445	W	W	203	1,022
Ohio	3,293	12,279	2,947	12,430	10,815	51,395	1,895	6,744	2,265	7,506
Oklahoma	1,712	6,999	718	2,754	1,506	4,426	102	303	1,945	4,786
Oregon	—	—	W	W	W	W	—	—	W	W
Pennsylvania	4,923	22,676	10,141	44,874	10,133	40,474	714	3,573	3,481	15,386
Rhode Island	—	—	—	—	—	—	—	—	—	—
South Carolina	W	W	W	W	1,429	5,795	W	W	W	W
South Dakota	W	W	W	W	W	W	W	W	105	390
Tennessee	8,789	38,365	8,859	40,410	5,690	23,702	1,309	5,044	12,824	53,830
Texas	8,484	28,686	6,728	28,957	15,306	35,003	468	2,396	2,599	6,791
Utah	—	—	—	—	—	—	—	—	144	520
Vermont	—	—	—	—	W	W	—	—	—	—
Virginia	2,671	13,278	1,990	9,856	2,748	12,183	586	2,704	3,351	13,373
Washington	W	W	40	168	89	325	W	W	19	182
West Virginia	520	1,958	475	2,056	298	1,212	40	194	1,202	5,039
Wisconsin	1,278	4,576	727	2,588	5,670	17,759	123	734	1,063	2,793
Wyoming	40	189	W	W	232	742	W	W	7	223
Total: (excludes withheld)[2]	95,689	421,435	77,905	336,144	147,251	527,897	17,201	66,243	71,542	276,686
Total withheld	1,682	9,272	2,043	6,902	499	3,434	291	1,426	1,152	7,693
Grand total[2]	97,727	432,172	80,811	345,654	151,579	542,686	17,946	69,461	722	288,023
Guam	740	8,211	40	519	100	815	10	176	173	1,413
Puerto Rico	485	3,474	321	1,922	51	315	W	W	49	318

W Withheld to avoid disclosing company proprietary data; included with "Total withheld" and "Other uses." XX Not applicable.
[1]Less than 1/2.
[2]Data may not add to totals shown because of independent rounding.

IN THE UNITED STATES IN 1989, BY STATE AND USE

and thousand dollars)

Cement manufacture		Agricultural uses		Lime manufacture		Other uses		Total	
Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
4,854	11,706	651	4,406	2,422	8,644	4,421	12,839	30,121	106,665
—	—	473	3,950	—	—	189	1,580	1,891	15,801
W	W	—	—	W	W	3,958	17,498	3,969	17,622
W	W	280	1,456	—	—	5,765	21,944	8,925	34,729
17,385	57,501	180	2,151	W	W	10,957	64,184	30,639	128,995
W	W	W	W	W	W	3,634	13,476	4,157	14,686
—	—	W	264	—	—	1,760	13,260	1,760	13,260
W	W	1,408	6,791	—	—	8,986	41,275	74,618	314,019
—	—	W	W	—	—	892	4,818	7,796	38,814
W	W	W	W	—	—	431	1,709	650	3,600
W	W	W	W	—	—	562	3,241	960	4,575
2,979	9,690	4,146	14,645	W	W	22,723	109,164	60,829	256,832
3,738	10,411	1,900	9,159	—	—	11,559	45,080	36,185	136,252
2,930	5,857	2,377	13,965	W	W	11,320	43,659	27,978	110,824
2,424	5,793	327	759	W	W	6,328	25,234	15,850	56,976
W	W	1,435	5,369	W	W	21,717	89,301	48,382	188,658
W	W	W	W	W	W	1,143	5,104	1,143	5,104
2,710	5,209	—	—	—	—	13,948	73,321	19,554	94,436
W	W	W	W	W	W	W	W	W	W
6,118	10,717	287	1,372	W	W	20,588	64,003	39,929	118,744
—	—	221	780	—	—	2,978	10,057	6,905	23,240
—	—	92	454	—	—	977	3,540	1,069	3,994
6,199	13,189	1,644	5,157	W	W	12,487	45,549	49,137	163,470
1,768	6,024	W	862	—	—	476	W	2,680	9,135
W	W	313	2,343	—	—	1,640	6,576	3,978	20,050
W	W	W	W	W	W	833	2,622	833	2,622
—	—	—	—	—	—	W	W	W	W
—	—	W	W	—	—	1,968	15,416	1,968	15,416
W	W	—	—	—	—	793	2,342	1,545	4,546
4,457	12,433	174	1,736	—	—	13,028	56,998	33,233	152,507
W	W	W	W	—	—	4,699	25,776	5,061	27,242
W	W	894	3,936	W	W	24,209	88,619	46,318	182,909
W	W	42	153	—	—	16,032	55,298	22,058	74,720
W	W	—	—	—	—	1,488	5,515	1,488	5,515
8,550	39,998	1,191	10,998	1,949	12,023	30,446	160,075	71,527	350,077
—	—	15	71	—	—	661	4,187	676	4,259
—	—	W	W	—	—	3,044	13,544	4,474	19,339
W	W	—	—	W	W	2,227	6,308	2,332	6,697
W	W	1,084	5,147	969	15,469	13,255	70,125	52,780	252,093
7,770	19,051	385	1,832	1,046	4,499	29,723	99,020	72,510	226,236
W	W	W	W	W	W	3,618	15,717	3,763	16,237
—	—	W	W	—	—	1,716	7,895	1,716	7,895
W	W	946	7,248	743	3,819	7,447	34,205	20,481	96,667
93	265	17	128	—	—	430	5,445	688	6,511
W	W	15	90	—	—	7,304	26,931	9,854	37,480
—	—	507	3,295	W	W	11,622	34,805	20,991	66,550
W	W	—	—	(1)	5	1,216	4,961	1,496	6,120
71,976	207,845	21,004	108,517	7,130	44,459	345,198	1,452,216	854,896	3,442,116
20,164	57,541	952	5,436	10,404	48,016	1,053	9,831	1,053	9,157
92,140	265,386	22,777	116,975	17,535	92,580	XX	XX	855,900	3,451,300
—	—	—	—	—	—	—	—	1,063	11,133
1,798	7,258	14	126	—	—	2,361	14	5,084	27,187

TABLE 15

CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1½ inch):				
Macadam	7,118	26,970	892	3,437
Riprap and jetty stone	12,300	48,612	603	2,213
Filter stone	5,852	22,760	63	284
Other coarse aggregate	1,465	4,134	W	W
Coarse aggregate, graded:				
Concrete aggregate, coarse	76,799	340,740	6,351	23,230
Bituminous aggregate, coarse	43,839	190,816	3,940	14,832
Bituminous surface-treatment aggregate	14,470	63,848	1,371	5,937
Railroad ballast	3,878	14,246	711	2,596
Other graded coarse agggregate	1,324	3,399	—	—
Fine aggregate (-3/8 inch):				
Stone sand, concrete	12,852	59,622	381	1,666
Stone sand, bituminous mix or seal	12,142	48,175	1,222	4,311
Screening, undesignated	19,319	77,773	426	1,762
Other fine aggregate	623	2,481	W	W
Coarse and fine aggregates:				
Graded road base or subbase	110,025	392,120	7,136	24,852
Unpaved road surfacing	20,264	76,917	793	2,661
Terrazzo and exposed aggregate	2,874	16,284	(1)	(1)
Crusher run or fill or waste	31,371	116,119	1,158	4,617
Other coarse and fine aggregates	530	1,589	41	129
Other construction materials[2]	10,684	38,502	256	1,065
Agricultural:				
Agricultural limestone	16,286	73,036	2,648	16,247
Poultry grit and mineral food	2,362	21,115	(3)	(3)
Other agricultural uses	812	3,911	101	853
Chemical and metallurgical:				
Cement manufacture	91,537	264,028	603	1,359
Lime manufacture	15,827	83,641	341	1,393
Dead-burned dolomite manufacture	72	278	1,294	7,162
Flux stone	4,713	19,636	707	2,556
Chemical stone	458	1,911	—	—
Glass manufacture	266	3,063	W	W
Sulfur oxide removal	1,159	4,536	—	—
Special:				
Mine dusting or acid water treatment	674	7,433	W	W
Asphalt fillers or extenders	1,639	11,727	—	—
Whiting or whiting substitute	665	11,344	—	—
Other fillers or extenders	2,085	50,304	1,025	10,136
Roofing granules	117	3,483	—	—
Other miscellaneous uses:				
Waste material	2,015	7,024		
Other uses not listed	[4]381	5,750	[5]757	6,208
Unspecified:[6]				
Actual	224,352	900,919	12,883	63,676
Estimated	53,495	216,070	3,603	13,774
Total[7]	806,600	3,234,300	49,300	217,000

W Withheld to avoid disclosing company proprietary data: included with "Other uses not listed."
[1]Included with "Other construction materials."
[2]Includes stone used in drain fields.
[3]Included with "Other agricultural uses."
[4]Includes stone used in abrasives, paper manufacture, and pipe bedding.
[5]Includes stone used in other course and fine aggregates, glass manufacture, and mine dusting or acid water treatment.
[6]Includes production reported without a breakdown by use and estimates for nonrespondents.
[7]Data may not add to totals shown because of independent rounding.

plant, in 1970 to $4.39 in 1989. However, the unit value 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 these trends. 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. Increased operating costs have been mostly offset by automation and other means of increasing operating efficiency. Constant dollar prices are expected to rise in the future because of increased energy costs and more stringent environmental and land use regulations.

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 7.1% to 3.9 million tons compared with 1988, while value decreased 23.2% to $23.3 million. About 96% of the exported crushed stone was limestone, Canada being the major destination with 98% of the total.

Imports

Imports of crushed stone increased 34.2% to 4.4 million tons compared with 1988, while the value increased 241% to $35.6 million. About 78% of this tonnage was limestone, 58% of which came from Canada, 23% from the Dominican Republic, and 16% from the Bahamas.

Imports of natural calcium carbonate fines showed a drastic decrease, most probably owing to some reporting errors to the U.S. Bureau of the Census that could not be identified by the time this chapter was published. About 88% of processed calcium carbonate was imported from France.

Shipments of crushed stone from the Bahamas, Canada, Nova Scotia, and Mexico, into the United States continued in 1989. The imported crushed stone, used

TABLE 16

CRUSHED MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1½ inch):		
Riprap and jetty stone	6	312
Filter stone	6	13
Coarse aggregate, graded:		
Terrazzo and exposed aggregate	62	1,658
Crusher run or fill or waste	61	261
Special: Whiting or whiting substitutes	977	58,408
Other miscellaneous uses not listed[1]	856	17,847
Unspecified:[2]		
Actual	10,136	56,090
Estimated	117	2,892
Total[3]	12,200	137,500

[1]Includes agricultural stone, other fine aggregates, other fillers or extenders, and roofing granules.
[2]Includes production reported without a breakdown by end use and estimates for nonrespondents.
[3]Data may not add to totals shown because of independent rounding.

mostly as construction aggregates, was distributed in Florida, Louisiana, New York, North Carolina, South Carolina, and Texas. This trend is expected to continue and the volume of imports to increase.

WORLD REVIEW

Canada

The 1988 production of stone in Canada was 122 million metric tons, a decrease of 2.3% over the 1987 total, valued at $642 million. About 98% of this output was crushed stone. The Province of Ontario continued to be the largest producer of stone, with 58.5 million tons valued at $313 million, followed by Quebec with 46.5 million tons valued at $235 million. The two Provinces accounted for 86% of the total stone production. Preliminary estimates for 1989 stone production indicate a decrease of 2.3% to 122 million tons, but an increase in value to $633 million. The Provinces of Ontario and Quebec continued to be the largest producers of stone with about 86% of the total output.

TABLE 17

CRUSHED GRANITE AND TRAPROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Granite		Traprock	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1½ inch):				
Macadam	538	3,389	1,111	5,391
Riprap and jetty stone	5,351	31,409	2,285	19,284
Filter stone	1,500	7,798	813	4,642
Other coarse aggregate	—	—	370	2,868
Coarse aggregate, graded:				
Concrete aggregate, coarse	20,520	115,569	6,530	37,811
Bituminous aggregate, coarse	14,386	84,385	5,652	31,972
Bituminous surface-treatment aggregate	3,238	20,605	2,158	10,891
Railroad ballast	8,461	37,766	2,411	12,418
Fine aggregate (-3/8 inch):				
Stone sand, concrete	3,307	17,089	795	6,196
Stone sand, bituminous mix or seal	3,531	16,706	1,366	6,781
Screening, undesignated	10,013	46,198	1,368	4,750
Coarse and fine aggregates:				
Graded road base or subbase	28,249	134,566	18,330	77,639
Unpaved road surfacing	2,558	9,265	3,430	14,332
Crusher run or fill or waste	12,438	58,454	3,128	11,691
Other construction materials[1]	4,650	26,457	6,630	44,484
Agricultural: Poultry grit and mineral food	697	3,674	—	—
Special:				
Asphalt fillers or extenders	W	W	121	884
Roofing granules	W	W	756	4,106
Other miscellaneous uses not listed[2]	2,678	8,096	914	3,917
Unspecified:[3]				
Actual	38,469	208,359	26,349	138,530
Estimated	7,850	35,162	14,644	85,681
Total[4]	168,400	865,000	99,200	524,300

W Withheld to avoid disclosing proprietary data; included with "Other uses, not listed."
[1]Includes terrazzo and exposed aggregates and other coarse and fine aggregates.
[2]Includes other fine aggregates, lime manufacture, and other fillers and extenders.
[3]Includes production reported without a breakdown by end use and estimates for nonrespondents.
[4]Data may not add to totals shown because of independent rounding.

United Kingdom

The 1988 production of crushed stone in the United Kingdom (Northern Ireland not included) was 184 million metric tons, of which 161 million tons was for construction purposes, as reported by the British Aggregate Construction Materials Industries Association (BACMI). About 67% of this output was limestone and dolomite. South West was the largest producing region with 40.5 million tons, followed by East Midlands with 40.4 million tons and Wales with 25 million tons. Preliminary estimates made by BACMI indicate that a total of 195 million metric tons of crushed stone was produced in 1989, a 6% increase compared with that of 1988, of which 170 million tons was used for construction purposes.

CURRENT RESEARCH

The 5-year $150 million Strategic Highway Research Program (SHRP) reached its midpoint in 1989. Management of ongoing research, rather than the initiation of contracts, became the focus of SHRP's activities. SHRP's mission is to produce usable research results targeted toward technical areas where there is potential for

TABLE 18

CRUSHED SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Sandstone		Quartzite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1½ inch):				
Macadam	13	60	—	—
Riprap and jetty stone	872	7,321	52	124
Filter stone	722	2,821	3	16
Other coarse aggregate	50	250	—	—
Coarse aggregate, graded:				
Concrete aggregate, coarse	1,383	7,474	760	3,914
Bituminous aggregate, coarse	2,688	13,578	174	915
Bituminous surface-treatment aggregate	516	2,750	146	814
Railroad ballast	1,463	5,403	W	W
Fine aggregate (-3/8 inch):				
Stone sand, concrete	963	4,877	14	35
Stone sand, bituminous mix or seal	912	3,692	91	299
Screening, undesignated	792	2,671	9	18
Coarse and fine aggregates:				
Graded road base or subbase	5,608	22,287	751	3,658
Unpaved road surfaces	324	1,576	W	W
Crusher run or fill or waste	1,781	5,092	6	18
Other construction materials	238	1,223	W	W
Chemical and metallurgical:				
Cement manufacture	270	990	W	W
Flux stone	53	279	W	W
Special: Other fillers or extenders	—	—	2	13
Other miscellaneous uses not listed	105	615	1,292	7,881
Unspecified:[1]				
Actual	5,495	28,200	2,047	6,778
Estimated	1,907	10,329	340	2,726
Total	[2]26,200	121,500	5,700	27,200

W Withheld to avoid disclosing company proprietary data: included with "Other miscellaneous uses."
[1]Includes production reported without a breakdown by end use and estimates for nonrespondents.
[2]Data do not add to total shown because of independent rounding.

rapid progress that could yield significant cost savings. The four areas of research are asphalt, concrete and structures, highway operations, and long-term pavement performance.

SHRP's main objective in asphalt research is to produce new performance-based specifications for asphalt binders.[4] A wide range of advanced materials characterization techniques such as nuclear magnetic resonance and spectroscopy and computer-aided tomography (CAT) scans are being tested. The CAT scan research conducted at the University of Southern California at Los Angeles could provide a powerful new nondestructive test technique for diagnosing problems in asphalt pavements.

The concrete and structure program includes research in the area of improved concrete materials and corrosion of concrete structures. Under this program, a rapid laboratory test that will determine aggregate reactivity in less than 2 weeks has been developed. Current tests require 9 months to 3 years.

About $20 billion is spent on highway maintenance in the United States each year, representing about one-third of total highway spending. This expenditure is growing at a rate of about 9% annually. More cost-effective maintenance methods, equipment, and materials are badly needed. SHRP is addressing this problem through its highway operations program by conducting a series of nationwide field performance tests. The Texas A&M Research Foundation has designed an experiment to compare the cost-effectiveness of six preventive maintenance methods to be tested under various climate and traffic conditions. The performance of the maintenance methods will be monitored over 5 years at specially constructed side-by-side test sections on inservice roads throughout the country.

Snow and ice control is another area of interest for the highway operations program. The Department of Mechanical Engineering of the University of Wyoming is using computer simulation, model studies, and full-scale prototyping to design and test more efficient and flexible snow and ice control equipment and methods.

The University of Washington is developing a rapid laboratory test method for identifying aggregates that are susceptible to freeze-thaw damage. Concrete bridge corrosion is a major problem affecting a large number of structures around the country. The evaluation of the effectiveness of electrochemical chloride removal technology, an experimental but promising technique for extracting chloride from concrete using electrical current, is advancing under SHRP's concrete and structures program.

SHRP's long-term pavement performance (LTPP) program is a first-ever major effort to measure pavement performance in different climate and soil conditions at about 1,000 inservice test sections in all 50 States and in Canada. The LTPP program has been planned to run for 20 years, with SHRP being funded to conduct the first 5 years of data-gathering and analysis. The data collected as part of the SHRP program are expected to provide sufficient information to refine pavement design that will significantly improve the performance of new pavements.

The Third International Symposium on Unbound Aggregates in Roads was held on April 11–13, 1989, at the University of Nottingham, United Kingdom.[5] This symposium was dedicated entirely to the utilization and characterization of unbound aggregate bases.

Some of the topics discussed at this year's symposium were: the in situ testing of compacted pavement layers; innovative methods for placing unbound aggregates to obtain a more uniform end product with a leveled surface; and the use of vibrating hammers or computerized vibratory rollers for compacting both unbound base material and asphalt concrete.

TABLE 19

CRUSHED VOLCANIC CINDER AND SCORIA SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

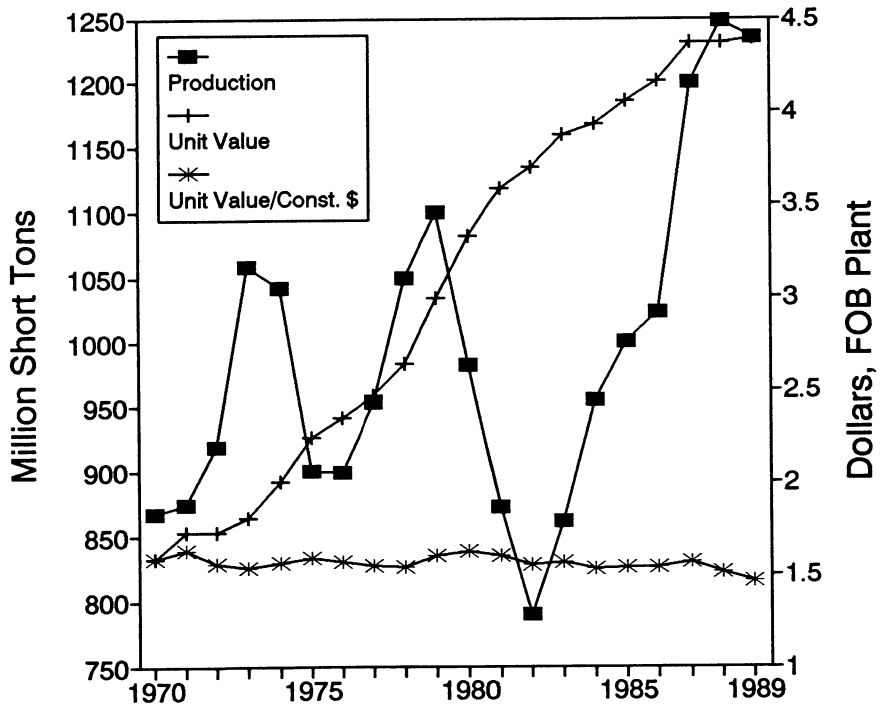
(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1½ inch): Other coarse aggregate[1]	102	214
Coarse aggregate, graded:		
Concrete aggregate, coarse	48	241
Railroad ballast	5	10
Fine aggregate (-3/8 inch): Stone sand, concrete	429	2,224
Coarse and fine aggregates:		
Graded road base or subbase	422	992
Unpaved road surfacing	343	591
Terrazzo and exposed aggregate	87	1,790
Other construction materials[2]	374	1,631
Special: Roofing granules	20	141
Other miscellaneous uses not listed[3]	117	663
Unspecified:[4]		
Actual	1,179	8,201
Estimated	501	3,508
Total[5]	3,600	20,200

[1]Includes riprap and jetty stone and filter stone.
[2]Includes crusher run or fill or waste.
[3]Includes screening, undesignated.
[4]Includes production reported without a breakdown by end use and estimates for nonrespondents.
[5]Data may not add to totals shown because of independent rounding.

FIGURE 2

TOTAL PRODUCTION AND UNIT VALUE IN ACTUAL AND 1970 CONSTANT DOLLARS OF CRUSHED STONE IN THE UNITED STATES FOR 1970-89



In response to growing concern over rutting of asphalt concrete pavements, in July 1987, the American Association of State Highway and Transportation Officials (AASHTO) organized a joint task force of Federal, State, and industry representatives to study the problem. Participating agencies included AASHTO, the National Asphalt Pavement Association (NAPA), the Asphalt Institute, the National Stone Association (NSA), the National Aggregates Association (NAA), the Construction Industry Manufacturers Association (CIMA), the National Cooperative Highway Research Program (NCHR), SHRP, and the Federal Highway Administration (FHWA).[6] About 70% of all paved public roads and streets and 57% of the interstate highways are surfaced with flexible pavements (asphalt). Asphalt concrete rutting is a longitudinal deformation that develops under the action of channelized loads. It occurs because of consolidation or shear failure in the subgrade or pavement structure. Aggregates make up about 95% of the weight of asphalt concrete and provide most of the pavement's load carrying capacity. The quality and physical properties of aggregates, especially gradation, are critical in preventing rutting and in improving pavement performance in general. One way to make a mix more resistant to rutting is to increase friction between the particles by using more crushed aggregates. FHWA Technical Advisory T5040.27 recommends that natural sands be limited to 15% to 20% of the total weight of aggregates for high-volume roads. Another gradation problem that causes rutting is an excessive amount of minus No. 200 material in the mix. FHWA's technical advisory recommends that mixes be designed with dust to asphalt ratio between 0.6 and 1.2. The task force final report was published in February 1989. It concludes that most of the causes of rutting are known, and the solutions to the rutting problem are now available. The report also indicates that FHWA Technical Advisory T5040.27, "Asphalt Concrete Mix Design and Field Control," is a state-of-the-art technical document.

About 240,000 highway bridges in the United States are currently classified as "structurally deficient," mainly because of bridge-deck deterioration. Reinforced concrete bridge decks and piers are particularly vulnerable to salt penetration. The salt affecting the reinforced concrete structures comes from deicing salts as well as from seawater. The combination of chloride ions

TABLE 20

CRUSHED MISCELLANEOUS STONE[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

(Thousand short tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate (+1½ inch):		
Macadam	125	329
Riprap and jetty stone	332	2,089
Filter stone	85	277
Course aggregate, graded:		
Concrete aggregate, coarse	1,481	5,729
Bituminous aggregate, coarse	2,053	10,289
Bituminous surface-treatment aggregate	256	1,209
Railroad ballast	653	3,397
Fine aggregate (-3/8 inch):		
Stone sand, concrete	1,221	3,176
Stone sand, bituminous mix or seal	202	886
Screening, undesignated	71	277
Coarse and fine aggregates:		
Graded road base or subbase	8,380	26,360
Unpaved road surfacing	734	4,259
Terrazzo and exposed aggregate	437	2,106
Crusher run or fill or waste	2,014	4,758
Other construction materials[2]	1,454	4,237
Agricultural: Other agricultural uses	3	6
Chemical and metallurgical: Cement manufacture	4,857	10,843
Special:		
Other fillers or extenders	566	3,159
Roofing granules	103	877
Other miscellaneous uses not listed[3]	405	4,537
Unspecified:[4]		
Actual	12,614	73,825
Estimated	4,150	16,246
Total	[5]42,200	178,900

[1]Includes marl, shell, slate, and other stone.
[2]Includes other coarse and fine aggregates.
[3]Includes poultry grit and mineral food and lightweight aggregate (slate).
[4]Includes production reported without a breakdown by end use and estimates for nonrespondents.
[5]Data do not add to total shown because of independent rounding.

from the salt, reinforcing bars, and moisture leads to an electrochemical process that causes the rebars to corrode and expand in size. As the bars expand, they exert internal pressure on the concrete, which splits along the rebars and leads to rapid deterioration of the concrete. The deterioration process of reinforced concrete can be significantly reduced through cathodic protection that reverses the flow of electrical current developed when corrosion occurs. Several anode systems for cathodic protection of bridges now available were evaluated in two reports published by FHWA.[7]

OUTLOOK

The demand for crushed stone in 1990 is expected to be about 1.2 billion tons, at about the same level as in 1989. The weakness in the nonresidential and multifamily residential building construction markets is expected to be compensated by a stronger demand in road construction and repair work. Gradual increases in demand for construction aggregates are anticipated after 1990, based on increased volume of work on the infrastructure. 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[8] 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.

Crushed stone f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates will rise over the forecasts. However, the delivered prices of crushed stone are expected to increase, especially in and near metropolitan areas, mainly because more aggregates are transported from distant sources.

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.[9] The modern crushed stone industry began in England in about 1815 and expanded rapidly after the invention of the mechanical rock crusher in 1858.[10]

In the United States, railroad ballast was the principal market for the crushed stone

TABLE 21

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY REGION AND METHOD OF TRANSPORTATION

(Thousand short tons)

Region	Truck	Rail	Water	Other	Unspecified	Total[1]
Northeast:						
New England	8,078	223	—	2,028	19,843	30,172
Middle Atlantic	104,350	1,718	—	4,867	43,486	154,421
Midwest:						
East North Central	97,851	4,971	19,202	12,004	77,550	211,579
West North Central	60,297	2,244	7,836	13,156	29,097	112,631
South:						
South Atlantic	178,486	20,895	3,903	36,899	76,124	316,306
East South Central	79,759	4,053	6,244	14,023	30,403	134,482
West South Central	47,573	12,098	41	26,203	40,079	125,995
West:						
Mountain	18,958	1,684	—	3,111	8,413	32,166
Pacific	55,023	2,874	2,508	8,362	26,912	95,679
Total[1]	650,400	50,800	39,700	120,600	351,900	1,213,400

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

TABLE 22

TIME-PRICE RELATIONSHIP FOR CRUSHED STONE

Year	Actual unit price	Unit price in 1982 constant dollars
1970	$1.58	$3.76
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

[e]Estimated.

industry during the last half of the 19th century. Passage of the Federal Aid Highway Act in 1916 acknowledged the national importance of highways, and subsequent highway construction created a new and significantly larger market. The crushed stone industry grew tremendously, especially in the second half of this century. Production increased from 130 million tons in 1928 to a high of 1.25 billion tons in 1988, mainly owing to rapidly increasing demand for highway, railroad, and other construction work. Today the volume of crushed and broken stone produced is greater than that of any other mineral mined in the United States. The United States is, in general, self-sufficient in crushed stone, producing enough to meet most of the domestic needs. Small quantities of crushed stone, used mostly as construction aggregates, are being imported by water from the Bahamas, Canada, Mexico, and to a smaller extent Scotland, United Kingdom.

Crushed stone is used mostly 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 constructions 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 Bureau of Mines generally accepts the rock type classification and the

TABLE 23

NUMBER OF CRUSHED AND BROKEN STONE OPERATIONS[1] AND PROCESSING PLANTS IN THE UNITED STATES IN 1989, BY STATE

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No plants or unspecified		
Alabama	44	3	—	—	1	48
Alaska	5	5	1	4	—	15
Arizona	15	5	1	7	—	28
Arkansas	29	12	3	2	—	46
California	115	29	6	23	1	174
Colorado	19	8	2	5	—	34
Connecticut	16	—	—	1	—	17
Florida	36	39	12	12	14	113
Georgia	72	5	—	—	—	77
Hawaii	9	7	2	5	—	23
Idaho	8	27	2	—	—	37
Illinois	90	68	12	5	—	175
Indiana	71	6	2	1	1	81
Iowa	50	223	2	18	—	293
Kansas	35	88	1	6	—	130
Kentucky	73	12	1	4	—	90
Louisiana	1	1	—	—	5	7
Maine	4	5	1	—	—	10
Maryland	18	10	—	2	1	31
Massachusetts	12	9	2	3	—	26
Michigan	18	12	2	4	1	37
Minnesota	10	28	—	—	—	38
Mississippi	5	2	—	—	—	7
Missouri	132	77	9	3	—	221
Montana	7	5	—	1	—	13
Nebraska	11	3	—	1	—	15
Nevada	7	5	1	1	—	14
New Hampshire	5	3	—	—	—	8
New Jersey	13	3	8	1	—	25
New Mexico	18	19	2	—	—	39
New York	73	8	5	3	—	89
North Carolina	80	2	4	2	—	88
Ohio	99	7	1	9	2	118
Oklahoma	52	4	4	2	—	62
Oregon	44	47	5	18	—	114
Pennsylvania	144	23	17	16	—	200
Rhode Island	4	—	1	—	—	5
South Carolina	24	1	2	7	—	34
South Dakota	4	4	—	5	—	13
Tennessee	104	7	3	10	—	124
Texas	74	68	11	32	—	185
Utah	10	6	—	—	—	16
Vermont	7	4	—	3	—	14
Virginia	86	4	5	13	—	108
Washington	24	62	4	32	—	122
West Virginia	27	7	3	8	—	45
Wisconsin	31	115	3	46	—	195
Wyoming	6	5	1	—	—	12
Total	1,841	1,093	141	315	26	3,416

[1]An undetermined number of operations leased from the Bureau of Land Management in Alaska are counted as one operation.

TABLE 24

U.S. EXPORTS OF CRUSHED STONE IN 1989, BY DESTINATION

(Short tons)

Destination	Limestone[1]	Limestone for cement manufacturing	Other	Total
North America:				
Bahamas	2,230	—	332	2,562
Bermuda	—	15,412	1,002	16,414
Canada	3,436,706	233,037	109,249	3,778,992
Mexico	47,602	466	6,915	54,983
Other	1,091	24	292	1,407
Total	3,487,629	248,939	117,790	3,854,358
South America:				
Chile	596	—	—	596
Venezuela	133	—	—	133
Other	319	—	38	357
Total	1,048	—	38	1,086
Europe:				
France	—	—	76	76
Germany, Federal Republic of	4,975	136	21,058	26,169
Netherlands	—	—	1	1
United Kingdom	861	388	303	1,552
Other	492	13	206	711
Total	6,328	537	21,644	28,509
Asia:				
Japan	13	7,988	13	8,014
Korea, Republic of	—	44	740	784
Taiwan	—	—	244	244
Other	49	330	4,616	4,995
Total	62	8,362	5,613	14,037
Oceania	387	460	91	938
Middle East and Africa	—	97	1,045	1,142
Grand total	3,495,454	258,395	146,221	3,900,000
Total value thousands	$13,190	$2,628	$7,527	$23,345

[1]Includes ground limestone.

Source: U.S. Bureau of the Census.

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)[11] and AASTO. For construction aggregates, these are regarded by industry as guide or reference specifications. State specifications are often much more stringent and vary from State to State. The most common specifications and tests relate primarily to gradation, but soundness, shape, abrasion resistance, porosity, chemical compatibility, and content of soft particles are also important.[12] Specifications for construction aggregates are written by commercial users, government agencies including Federal, State, county, and city construction and highway departments, and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Specifications for limestone used in portland cement manufacture require a content of more than 75% calcium carbonate ($CaCO_3$) and less than 3% magnesium carbonate ($MgCO_3$). For white portland cement, the iron content of the raw materials should be very low, less than 0.01%. Because raw materials are finely ground for processing, chert nodules or coarse quartz grains are undesirable. Limestone for lime manufacture should contain more than 90% calcium carbonate, often more than 97% or 98%, less than 5% magnesium carbonate, and less than 3% of other impurities. For lime produced in vertical kilns, 5- to 8-inch stone is recommended, while in rotary kilns 3/8- to 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 glass making 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 Number 10 sieve (2 millimeters) and 96% to 100% should be retained on a Number 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.[13]

TABLE 25

U.S. IMPORTS OF CRUSHED STONE AND CALCIUM CARBONATE FINES, BY TYPE

(Thousands short tons and thousand dollars)

Type	1988		1989	
	Quantity	Customs value	Quantity	Customs value
Crushed stone and chips:				
Limestone[1]	358	1,404	1,076	6,955
Limestone for cement manufacturing	—	—	2,311	19,464
Marble, breccia	2	166	—	—
Quartzite	100	1,686	14	854
Slate	7	167	—	—
Other	2,778	11,393	950	8,359
Total[2]	3,244	14,815	4,352	35,631
Calcium carbonate fines:[3]				
Natural aragonite[4]	352	1,074	(5)	284
Chalk, whiting	6	899	4	950
Total[2]	358	1,973	4	1,234
Grand total[2]	3,602	16,789	4,356	36,870

[1]Excludes limestone for cement manufacturing.
[2]Data may not add to totals shown because of independent rounding.
[3]Excludes precipitated calcium carbonate.
[4]Includes some chalk and other calcareous materials.
[5]Less than ½ unit.

Source: U.S. Bureau of the Census.

Products for Trade and Industry

The ultimate use of crushed stone determines the specification for particle size and gradation, shape, rock type, and chemical composition. Crushed stone can be used without any binder, for a variety of construction or industrial applications, or it may be mixed with a matrix binding material such as bituminous or portland cement. The most common use of crushed stone for construction purposes is as aggregate without a binder, including road base or road surfacing material, macadam, riprap, railroad ballast, filter stone, etc. The second largest use of crushed stone is as aggregate for cement and bituminous concrete in a variety of forms and applications in residential and nonresidential construction, highway and road construction and repair, airports, dams, sewers, and foundations. Sized crushed stone is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than rounded surfaces do and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than rounded particles do and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses. Other uses include limestone for cement and lime manufacturing and as agricultural limestone used as direct application to soil, as filler and conditioner for fertilizers, in animal mineral feeds, or as poultry grit. Smaller amounts of crushed stone are used for a wide variety of applications ranging from metallurgical fluxing of antimony, copper, iron, lead, and zinc to the manufacture of glass, ceramic pottery, paper, and as fillers and extenders in asphalt, paint, rubber, and plastics.

A growing amount of limestone is being used in the removal of sulfur oxides from stack gases, primarily from coal-burning electric generating stations, and for mine dusting to enhance mine safety by reducing the explosion risk of highly combustible coal dust.

Industry Structure

Because of the low unit value, crushed stone is usually produced near the point of use; therefore, the industry is concentrated mostly in or nearby large, rapidly expanding urban areas. Crushed stone is produced in every State except Delaware, with more than 73% 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 population and largest production of crushed stone.[14]

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 traprock is produced mainly in the northeast and the Pacific Coast States, with California, Connecticut, Massachusetts, New Jersey, Oregon, and Washington the largest producing States. Crushed sandstone and quartzite are produced in 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, 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, some of them associated with the influx of foreign capital. Two of the top five crushed stone producing companies in 1989 are subsidiaries of foreign companies.

The United States is the largest producer of crushed and broken stone among the market economy countries. Other major producing countries are Australia, Canada, the Federal Republic of Germany, France, Japan, and the United Kingdom. Some information about the production of crushed stone in foreign countries may be found in the 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.[14] 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.[15] 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.[16]

On the basis of geologic evidence, stone resources of the United States and the world are sufficient to meet demands, although not always precisely at the locations where needed. Reserves, which are measurable amounts of crushed stone that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of stone available is so vast as to preclude the necessity of measurement on a large scale. The local shortages that occasionally exist are caused less by a lack of stone than by urban encroachment or zoning regulations that force closure of operating quarries or prevent the development of new ones.

Technology

Major technological developments have been instrumental in maintaining adequate production at relatively stable real costs in the crushed stone industry. Equipment manufacturers usually conduct most of the research related to improvements in the mining and processing of crushed stone operations. Larger, more efficient equipment is being developed and improved constantly. The use of computerized control systems in plant operation and quality control has increased significantly in recent years. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations. Automated plants have significantly improved operating efficiency and produce the optimal product mixture to fit market requirements at lower cost.

As part of the national drive to reduce air pollution, significant progress is being made toward the desulfurization of stack gases resulting from coal-burning electric generating stations and some industrial installations.[17] Limestone and lime are used as chemically reactive agents in most of the dry or wet scrubbing processes as well as in the treatment of acidified waters, specifically lakes and streams.

Exploration.—A large number of geologic formations that have economic potential as a source of crushed stone have been mapped and described in the literature over the years. Consequently, detailed exploration and development work for any new crushed stone operation will most probably be done on one of these formations. However, in the event that a new stone deposit is discovered, more exploration and evaluation work would be required before development. Preliminary examination can

establish the extent and nature of the deposit. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information about the quality of the available material, including the kind of stone, its chemical composition and degree of cementation, and the degree of uniformity throughout the deposit. Also, the nature and the amount of waste material and the economic feasibility of its removal, processing, and marketing must be studied. In most cases, an environmental impact study is required by local or State agencies.

If the raw material cost and quality are proven to be adequate and sufficient reserves are demonstrated, the development stage of the operation can be started. Economic feasibility and marketing studies include analysis of the availability of power and water supply; mining and processing costs and requirements; the condition of nearby roads and highways and the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population, as well as its attitude toward such a project.

Mining.—Most crushed and broken stone is mined from open quarries; however, in many areas, factors favoring large-scale production by underground mining are becoming more frequent and more prominent.

Surface mining equipment varies with the kind of stone mined, the production capacity needed, the size and shape of the deposit, estimated life of the operation, location of the deposit with respect to urban centers, and other important factors. Ordinarily, drilling is done with tricone rotary drills, long-hole percussion drills, and churn drills. Blasting in smaller operations may still be done with dynamite, but in most medium- to large-size operations ammonium nitrate-fuel oil mixtures (ANFO), 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 mined. 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. 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. 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 use of in-pit movable primary crushers is also increasing. 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.

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.[18]

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. But despite the rising cost of labor, energy, and land values, competition among stone producers and the nearness of supply areas to markets have kept the relative cost of crushed stone low. Constant dollar unit values have been quite steady during the past 20 years. Increased operating costs have been somewhat offset by automation and other means of increasing efficiency. 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 is becoming very important. For this reason, large companies are better able to compete in the crushed stone business, especially when there is a need for a wide variety of products. Smaller, less efficient operations become less economical as operating costs, as well as costs associated with meeting various Federal, State and local regulations, continue to increase. The only alternatives these producers have are to supply local markets with a limited number of products. The gradual trend toward larger operations has continued, mostly because the stone industry is capital intensive, and it is becoming less economical to operate small quarries. The viability of small operations is dependent on the demand in the local markets, mining costs, and the degree of processing required to supply the final product.

A 5% depletion allowance based on gross income is allowed for crushed stone used in construction, including aggregates. The depletion allowance for chemical and metallurgical crushed stone is 14%.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a crushed stone company owns or leases land within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines or regulations of the appropriate governmental agency must also be approved. Environmental concerns such as noise, dust, beautification, and storage of wastes must be accounted for in a manner satisfactory to the governmental entity involved. Wastewater discharge requirements must be planned for and met. If the deposit to be worked is on land controlled by a State or Federal agency, that agency's requirements must also be satisfied.

In most States, permits for crushed stone operations require an Environmental Impact Report (EIR) or Environment Impact Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Many of the environmental problems facing crushed stone producers arise because a great number of stone quarries and processing plants are 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 producers is becoming a necessity that may require sophisticated and expensive processing methods. Significant progress has been made in reducing noise pollution both inside and outside of the quarries, including noise and vibration produced by blasting and movement of heavy trucks. Therefore, the industry must be concerned first about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Because crushed stone is a local industry, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of crushed stone into the marketplace. Also, stringent controls by the local governments that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of crushed stone into the marketplace.

Although much progress is being made through premining planning, the crushed stone industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas.

Transportation.—Transportation is a major factor in the delivered price of construction 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, crushed stone continues to be marketed locally. However, increasing land values combined with local environmental concerns are moving crushed stone quarries farther from the end-use locations, increasing prices 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. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of crushed stone, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable or down. Rail and water transportation combined account for about 7% to 10% of total crushed stone shipments.

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DIMENSION STONE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with the Branch of Industrial Minerals, has covered dimension stone for 9 years. Domestic survey data and trade data were prepared by Ms. Maria Arguelles, minerals data assistant, Branch of Data Collection and Coordination.

Production of dimension stone increased slightly to 1.21 million short tons valued at $208 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 7% in value to $35 million. The value of dimension stone imports for consumption increased slightly to $525 million, equivalent to 252% of the value of domestic production.

TABLE 1

SALIENT U.S. DIMENSION STONE STATISTICS

(Thousand short tons and thousand dollars)

	1985	1986	1987	1988	1989
Sold or used by producers	1,104	r e1,060	r1,179	e1,189	1,207
Value	$172,435	r e$167,429	r$191,117	e$196,289	$208,311
Exports (value)	$13,835	$14,623	$20,470	$32,219	$34,610
Imports for consumption (value)	$291,246	$379,724	$439,278	$517,835	$525,052

eEstimated. rRevised.

DOMESTIC DATA COVERAGE

Domestic production data for dimension stone are developed by the Bureau of Mines from voluntary surveys of U.S. producers of rough and finished dimension stone. Of the 368 dimension stone operations surveyed, including those that were idle, 317, or 72%, responded, representing 96% of the total value sold or used by producers shown in table 1. Production data for nonrespondents were estimated using preliminary production reports, adjusted prior years production levels, and employment data.

PRODUCTION

Dimension stone was produced by 176 companies at 282 quarries in 34 States. Leading States, in order of tonnage, were Indiana, Georgia, and Vermont, together producing 38% 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.

Granite

Dimension granite includes all coarse-grained igneous rocks. Production decreased slightly to 640,000 tons and increased 23% in value to $130.2 million. Granite was produced by 62 companies at 111 quarries in 20 States. Georgia continued to be the leading State, producing 23% of the U.S. total, followed by Vermont and Massachusetts. These three States together produced more than 46% of the U.S. total. Cold Spring Granite, Rock of Ages, and Fletcher Granite were the leading producers and accounted for 42% of U.S. production by tonnage.

Fletcher Granite was acquired by Pioneer International Ltd. of Australia, an industrial and resource firm, in early 1989. Pioneer has been present in the domestic aggregate industry for some time and recently bought two more aggregate operations.

Georgia-Carolina Quarries Inc. recently opened a granite curbing plant near Elberton, GA. This is the second such plant in Georgia, the other one belonging to Fratto Construction Inc.

Limestone

Dimension limestone includes bituminous, dolomitic, and siliceous limestones. It was produced by 35 companies at 54 quarries in 13 states. Indiana, the leading State, was followed by Wisconsin and Texas. Leading producers were Indiana Limestone Co. Inc., Independent Limestone Co., and Victor Oolitic Stone Co. The top three companies accounted for 32% of U.S. output.

Marble

Dimension marble includes certain hard limestones, travertines, and any other calcareous stone that can be polished. Dimension marble was produced by 7 companies at 10 quarries in 7 States. Georgia, Vermont, and New Mexico tied with Alabama, in order of tonnage, were the four leading States, accounting for approximately 86% of U.S. output. Leading producers were Georgia Marble Co., Vermont Marble Co., and Rocky Mountain Stone Co. The top three companies accounted for 75% of U.S. output.

Sandstone

Dimension sandstone includes calcareous- and siliceous-cemented sandstones or conglomerates. Quartzite, which is also included, may be described as any siliceous-cemented sandstone. It was produced by 34 companies at 47 quarries in 15 States. The leading three States were, in order of volume, Ohio, New York, and Pennsylvania. Briar Hill Stone Co., Waller Bros.

Stone Co., and Standard Slag Co. were the leading producers and accounted for 41% of U.S. production. In addition to the quantities shown in table 5, dimension quartzite totaled 19,451 tons worth $1,465,315.

Slate

Dimension slate was produced by 17 companies at 27 quarries in 5 States. The two leading States, Pennsylvania and Vermont in order of volume, accounted for 70% of U.S. output. The top three producers, A. Dally and Sons Inc., Le Sueur-Richmond Slate Co. Inc., and Williams and Sons Slate and Tile Inc., accounted for an estimated 50% of U.S. output by volume.

Miscellaneous Stone

Miscellaneous dimension stone, including traprock, was produced by eight companies from seven quarries in four States, and totaled 24,637 tons value at $1,619,256.

CONSUMPTION AND USES

Dimension stone was marketed over wide areas. Industry stockpiles were not monitored, and production during 1989 was assumed to equal consumption.

Consumption of domestic dimension stone increased slightly to 1.21 million tons valued at $208.3 million. Ashlars and partially squared, dressed pieces were 21% of the total value of consumption, followed by rough monumental stone with 15%; slabs and blocks for building and construction with 13%; dressed monumental stone with 12%; curbing with 12%; and other uses, 27%.

Of the total consumption of domestic granite, 24% by value was rough monumental stone, 18% was ashlars and partially squared pieces, and 18% was curbing.

Consumption of domestic limestone totaled 327,050 tons valued at $42.2 million, of which 38% by value was slabs and blocks for building and construction, 27% was ashlars and partially squared pieces, and 25% was rough blocks for building and construction.

In a long-enduring trend before 1980, building dimension stone was replaced to a large extent by concrete, glass, brick, stainless steel, aluminum, porcelain-enameled steel, and plastics. These materials are used in the manufacture of modern mass-produced building modules and precast building panels. The installed cost of many of these alternate materials has been lower than that of stone. Since 1980, stone has been increasingly preferred for more dignified buildings where its architectural adaptability, permanence, and prestige are of prime importance. A movement back to stone has occurred because of the greater impact of rising energy costs on these substitutes. Resin-bonded stone panels made from stone chips are becoming an important substitute for dimension stone.

Slate has to meet competition from many sources. As a roofing material, alternates such as sheet metal, wood shingles, asbestos-cement shingles, and tile are available. For blackboards, it competes

TABLE 2

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1987		1988[e]		1989	
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Value (thousands)
Arizona	W	W	W	$1	W	W
Arkansas	10,541	$629	10,541	629	W	W
California	33,335	4,554	42,048	5,991	28,829	$5,564
Colorado	3,000	133	3,450	143	5,310	398
Connecticut	18,140	1,646	19,718	1,914	W	W
Georgia	179,207	21,683	190,472	27,768	[1]145,545	[1]12,087
Illinois	W	W	1,175	129	W	W
Indiana	183,609	23,115	195,444	24,956	[1]198,531	[1]27,212
Iowa	W	W	W	588	15,151	613
Kansas	11,423	445	6,889	219	W	W
Maine	7,512	5,924	7,512	5,924	W	W
Maryland	22,843	1,516	20,729	1,515	27,529	2,072
Massachusetts	[r]69,936	[r]12,801	W	W	67,533	10,302
Minnesota	[r]43,322	[r]13,877	45,000	13,000	44,605	16,031
Missouri	3,212	454	3,644	547	W	W
New Hampshire	67,479	10,684	73,393	10,546	55,305	8,769
New Mexico	21,893	626	21,893	626	W	W
New York	38,553	5,822	30,751	4,333	23,756	3,575
North Carolina	32,669	5,128	31,977	5,026	62,665	10,477
Ohio	47,816	2,427	38,300	3,137	59,923	3,455
Oklahoma	8,311	861	7,746	785	8,290	762
Pennsylvania	60,118	10,177	59,022	9,584	44,267	10,032
South Carolina	2,319	312	353	37	W	W
South Dakota	50,718	18,209	43,297	16,472	54,623	17,738
Tennessee	3,360	573	3,942	567	4,888	437
Texas	75,426	10,030	66,354	8,310	81,268	12,449
Utah	2,004	[r]93	2,004	93	—	—
Vermont	103,923	30,074	105,000	30,500	100,698	31,413
Virginia	9,077	2,720	10,000	2,900	W	W
Washington	297	42	697	60	W	W
Wisconsin	36,903	3,697	49,900	6,200	35,587	4,376
Other[2]	32,228	2,865	98,082	13,789	142,692	30,552
Total	[3] [r]1,179,174	[r]191,117	1,189,333	196,289	1,206,995	208,311

[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, Idaho, Michigan, Montana, and data which is withheld.
[3]Data may not add to totals shown because of independent rounding.

TABLE 3

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1988[e]		1989		
	Quantity (short tons)	Value (thousands)	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
California	20,856	$4,304	W	W	W
Connecticut	19,718	1,914	W	W	W
Georgia	176,568	11,750	145,545	1,496	$12,087
Maine	7,512	5,924	W	W	W
Massachusetts	65,197	10,989	67,333	729	W
New Hampshire	73,393	10,546	55,305	654	8,769
North Carolina	27,948	4,689	W	W	W
Oklahoma	5,546	742	W	W	W
Pennsylvania	12,335	2,529	11,652	145	3,107
South Carolina	353	37	W	W	W
South Dakota	43,297	16,472	54,623	654	17,738
Texas	41,139	6,107	W	W	W
Vermont	84,525	15,559	83,073	1,026	15,522
Wisconsin	3,692	3,031	W	W	W
Other[1]	47,857	11,062	222,018	2,640	57,479
Total	629,936	105,655	639,549	7,344	114,702

[e]Estimated. W Withheld to avoid disclosing company proprietary data, included with "Other."
[1]Includes Colorado, Maryland, Minnesota, Missouri, New York, Washington, and data indicated by symbol W.

TABLE 4

DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Indiana	198,531	2,700	$27,212
Wisconsin	29,697	371	1,225
Other[1]	98,821	1,276	13,727
Total	327,049	4,347	42,164

[1]Includes Alabama, California, Illinois, Iowa, Kansas, Minnesota, Montana, New Mexico, New York, Ohio, and Texas.

TABLE 5

DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Massachusetts	200	2	W
Other[1]	22,297	262	$21,321
Total	22,497	264	21,321

W Withheld to avoid disclosing company properietary data, included with "Other."
[1]Includes data for Alabama, Georgia, Idaho, New Mexico, Tennessee, and Vermont.

with colored glass, porcelain-enameled steel, and special painted surfaces.

PRICES

The average price for dimension stone increased to $173 per ton, up 5% from $165 in 1988.

FOREIGN TRADE

Exports.—Exports of dimension stone, about one-half of which was granite, probably increased 7% in value.

Imports.—Imports of dimension stone increased slightly in value to $525 million. The United States changed its tariff classification to the Harmonized Tariff Schedule on January 1, 1989. Because import and export data are classified by tariff category, the 1988 and 1989 import and export statistics are often noncomparable. A number of import categories have had to be estimated because of this and other problems.

WORLD REVIEW

Dimension stone is quarried in most countries of the world. As usual, Italy produced about half of world production. The major importing countries were the United States, Japan, and for rough stone, Italy. Other significant producers were Brazil, China, Finland, India, Norway, Portugal, Spain, Sweden, Turkey, and the United States.

Brazil

The United Nations published a comprehensive study of the Brazilian dimension stone industry, covering it quarry by quarry in each State. For each quarry it describes the geology, commercial name of its stone, and location. In addition, it gives the physical properties of many of the stones, the color, and costs and technology of extraction.[1]

Italy

The north end of the island of Sardinia usually accounts for the majority of Italian granite production, or about 650,000 tons. The industry is centered around the towns of Budduso and Tempio Pausania, west of

TABLE 6

DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY STATE

State	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
California	12	19	$2
New York	14,847	190	1,345
Pennsylvania	12,437	156	545
Other[1]	104,711	1,369	6,822
Total	132,007	1,734	8,714

[1]Includes data for Alabama, Arizona, Arkansas, Colorado, Indiana, Maryland, Michigan, Missouri, North Carolina, Ohio, Oklahoma, and Tennessee.

TABLE 7

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	271,803	3,294	$22,316
Irregular-shaped stone[1]	103,382	1,294	5,783
Monumental	219,752	2,465	30,866
Other[2]	32,101	426	3,453
Dressed stone:			
Ashlars and partially squared pieces	216,690	2,688	43,515
Slabs and blocks for building and construction	89,842	1,158	26,725
Monumental	36,864	410	25,020
Curbing	141,083	1,717	23,972
Flagging	36,441	454	4,508
Flagging (slate)	7,578	—	1,299
Roofing slate	11,408	—	9,132
Structural and sanitary	4,470	—	3,709
Flooring slate	3,197	—	2,198
Other[3]	32,384	312	5,815
Total	1,206,995	[4]14,219	208,311

[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 do not add to total shown because of independent rounding.

Olbia. Around 145 granite quarries produce seven major types, mostly light pink or grey. The production is mostly rough blocks that are finished on the Italian mainland. The Sardinian granite producers are expanding production moderately and shifting to doing more of their own finishing work. Industry sources stated that two additional granite tile plants are being built.

The granite in the quarry is usually extracted by drilling and blasting with primacord; only a few diamond wire saws are in use in granite on the island of Sardinia.

United Kingdom

A new publication, the United Kingdom Minerals Yearbook 1988, gave production statistics for dimension stone. Net production of limestone for building purposes totaled 270,000 tons in 1987, mostly quarried in England. Granite production was not separated out, but was believed to be about 25,000 tons. Architectural slate production was about 75,000 tons, excluding granules and powder.

Burlington Slate Ltd. has been on a campaign to upgrade and modernize its facilities. As part of this, it has begun to use diamond wire saws for horizontal cuts in its quarries, eliminating the need for blasting. The change has also significantly reduced the amount of waste rock created.

CURRENT RESEARCH

A United Nations related primer on the dimension stone industry has just been published. It covers terminology, physical properties, types of deposits, locating resources, structural geology, and methods and technology of stone extraction, including tools. It discusses different types of uses, hints for trouble-free installation, and the latest automated technology for stone cutting, polishing, and finishing.[2]

OUTLOOK

Projected demand for dimension granite totaled 1.7 million tons for 1995 and 2.5 million tons for the year 2000. Projected demand for dimension marble totaled 750,000 tons for 1995 and 1.1 million tons for 2000. Demand for dimension limestone totaled 350,000 tons for 1995 and 380,000 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 the expected maturing of the market for building stone. 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.

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

TABLE 8

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	91,603	999	$9,727
Irregular-shaped stone[1]	19,719	225	1,621
Monumental	217,986	2,443	30,789
Other[2]	7,809	117	733
Dressed stone:			
Ashlars and partially squared pieces	113,387	1,315	24,015
Slabs and blocks for building and construction	22,613	273	3,787
Flagging	3,908	47	1,741
Monumental	28,232	307	17,860
Curbing	129,064	1,567	23,707
Other[3]	5,228	52	723
Total[4]	639,549	7,344	114,702

[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 9

DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	137,479	1,851	$10,367
Irregular-shaped stone[1]	39,821	513	933
Other[2]	18,897	249	2,341
Dressed stone:			
Ashlars and partially squared pieces	68,174	898	11,376
Slabs and blocks for building and construction	48,164	647	16,059
Flagging	9,569	125	350
Other[3]	4,945	65	739
Total	327,049	4,347	[4]42,164

[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.

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 Bureau of Mines generally accepts the classification reported by producers, or commercial classification. Granite includes all feldspathic crystalline rocks of predominantly interlocking texture and with mineral grains visible to the naked eye; these include igneous and metamorphic rocks, including quartz diorites, syenites, quartz porphyries, gabbros, anorthosites, and gneisses. White, gray, black, pink, and red are the common colors for granite, but greens, browns, and other shades are produced in some localities.

Limestone includes dolomitic types as well as calcitic. The latter 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 feldspathic sandstone that splits easily along a plane into thin, smooth slabs. It is commonly dark or slate gray in color, and its name no longer has color significance. Brownstone is a feldspathic sandstone of brown to reddish-brown color caused by abundant interstitial iron oxide. Flagstone may be either a sandstone or a slate that splits into large, thin slabs.

Quartzite is a metamorphic equivalent of sandstone that has been firmly cemented by secondary silica or by recrystallization so that it is essentially homogeneous and fractures through rather than around the original sand grains. Slate is a fine-grained metamorphic rock derived from shale, siltstone, or claystone. It has prominent cleavage that is oriented independently from the original sedimentary bedding. Mineral constituents are quartz, mica, sericite, or chlorite with assorted minor accessories. Shale is composed mostly of original clay minerals, and cleavage is parallel to the bedding.

Traprock is a commercial term for all dark, igneous rocks too fine in grain size to be called black granite. In addition to extrusive flow rocks such as basalt, andesite, or dacite, traprock includes intrusive igneous rocks such as diabase, diorites, gabbros, pyroxenites, amphibolites, and peridotites.

TABLE 10

DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Other[1]	4,552	53	$1,196
Dressed stone:			
Ashlars and partially squared pieces	W	W	W
Slabs and blocks for building and construction	5,104	60	6,103
Monumental	W	W	W
Flagging	189	2	29
Other[2]	12,652	149	13,994
Total	22,497	264	[3]21,321

W Withheld to avoid disclosing company proprietary data, included with "Other."
[1]Includes rubble, rough blocks for building and construction, irregular shaped stone, and monumental.
[2]Includes uses not specified.
[3]Data do not add to total shown because of independent rounding.

TABLE 11

DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	29,524	405	$956
Irregular-shaped stone[1]	28,914	376	1,812
Other[2]	204	3	17
Dressed stone:			
Ashlars and partially squared pieces	25,204	334	1,248
Slabs and blocks for building and construction	11,579	149	577
Flagging	9,768	125	1,396
Other[3]	26,814	342	2,709
Total	132,007	1,734	[4]8,714

[1]Includes rubble.
[2]Includes uses not specified.
[3]Includes monumental, curbing and unspecified uses.
[4]Data do not add to total shown because of independent rounding.

TABLE 12

DIMENSION SLATE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1989, BY USE

Use	Quantity (short tons)	Value (thousands)
Flagging (slate)	7,578	$1,299
Roofing (slate)	11,408	9,132
Structural and sanitary	4,470	3,709
Flooring slate	3,197	2,198
Other[1]	6,955	1,378
Total	33,608	17,716

[1]Includes a minor amount of slate used for billiard tabletops, blackborads, and unspecified uses.

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 are practically unlimited. There is considerable interstate transportation of certain types of stone such as Indiana limestone, Georgia marble and granite, and Vermont granite, marble, and slate. A lack of deposits of certain specific varieties of dimension stone especially noted for their esthetic qualities in architecture and artifact manufacture is an important cause of importation of these varieties; for example, brightly colored marbles from Italy.

Technology

Mining.—Present mining methods range from antiquated and very inefficient to modern and technically superior. Quarrying methods include use of various combinations of diamond saws, wire saws, diamond wire saws, chain saws, channeling machines, drilling machines, wedges, and broaching tools. The choice of equipment depends on the type of dimension stone, size and shape of deposit, production capacity, labor costs, economics, and management investment attitudes.

Little blasting is done in the mining of dimension stone. Blocks cut from the face are sawed or split into smaller or thinner blocks for ease in transportation and handling and taken to processing plants, often located at the quarry site, for final cutting and finishing operations.

Processing.—Stone-finishing equipment includes large circular saws 10 feet or more in diameter, some with diamond inserts and some using steel shot or other abrasives; diamond circular saws of smaller size; reciprocating diamond-bladed or loose-abrasive gang saws for multiple cuts; and various types of diamond and other equipment for smoothing, polishing, edging, and decorating the finished stone products.

Economic Factors

Tariffs.—Current import duties (tariffs) are shown in table 17. The depletion allowance for dimension stone is 14%. Dimension stone quarries are generally located in mountainous or hilly areas remote from area of dense population.

TABLE 13

U.S. EXPORTS OF DIMENSION STONE

(Thousand short tons and thousand dollars)

	Quantity	Value	Major destination in 1989, (percent[1])
Marble, Travertine, Alabaster worked	9	$1,733	NA
Marble, Travertine - crude or roughly trimmed	NA	343	Mexico 25%.
Marble, Travertine - merely cut, by sawing or otherwise	23	1,156	Canada 22%.
Granite, crude or roughly trimmed	NA	12,159	Japan 48%.
Granite, merely cut by sawing or otherwise	NA	9,107	Japan 31%.
Sandstone, crude or roughly trimmed	NA	390	NA
Sandstone, merely cut, by sawing or otherwise	6	771	Canada 98%.
Slate, worked and articles of slate	NA	6,228	NA
Slate, whether or not roughly trimmed or merely cut	NA	1,038	France 70%.
Other calcareous monumental or building stone; Alabaster	24	618	Canada 71%.
Other monumental or building stone	7	1,067	Japan 24%.
Total	NA	34,610	

NA Not available.
[1]By value.

Source: Bureau of the Census.

TABLE 14

U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY, 1989

(Thousand cubic feet and thousand dollars)

Country	Rough[1]		Dressed			
			Stone and articles		Worked	
	Quantity	Value	Quantity	Value	Quantity	Value
Brazil	1,840	882	9	494	282	3,350
Canada	2,561	8,093	18	4,432	197	14,841
China	106	365	7	345	18	654
India	1,879	3,169	33	980	78	5,633
Italy	2,598	14,607	359	18,237	3,067	84,221
Japan	29	206	(2)	3	4	122
Portugal	424	990	3	64	13	326
Saudi Arabia	3	27	4	336	19	346
South Africa, Republic of	1,402	2,477	—	—	—	—
Spain	474	1,281	27	3,995	182	11,091
Other	3,883	2,810	54	2,461	1,152	7,435
Total	15,199	34,907	514	31,347	5,012	128,019

[1]Includes crude or roughly trimmed, and merely cut by sawing or otherwise.
[2]Less than 1/2 unit.

Source: U.S. Bureau of the Census as modified by the Bureau of Mines.

Because land use for other purposes is limited, the cost of land is reasonable.

Operating Factors

Enviromental Requirements.—Environmental requirements vary from State to State and are often a cause of conflict between State or local governments and the quarry operators.

Toxicity.—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.

Employment.—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.

Energy Requirement.—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.

Transportation.—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.

[1]UNITAR. Stone in Brazil. United Nations Inst. of Train. and Res. New York, NY 1988, 66 pp.
[2]Shadmon, A. Stone: An Introduction. Intermed. Tech. Publ., New York, NY, 1989, 140 pp.

OTHER SOURCES OF INFORMATION

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Leading Country Activity.
Market Activity.

Other Sources

Dimensional Stone.
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Rock Products.
Stone Industries (United Kingdom).
Stone World.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF MAJOR CATEGORIES OF DIMENSION MARBLE AND OTHER CALCAREOUS STONES, BY COUNTRY, 1989

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)
China	6,033	$2,951	606	$430	417	$245
France	2,170	2,509	236	304	306	423
Germany, Federal Republic of	1,250	1,329	484	657	227	288
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
Mexico	3,923	3,029	5,896	3,779	1,652	691
Pakistan	35	56	553	860	11	10
Phillipines	1,247	1,263	473	443	44	42
Portugal	7,728	6,701	1,786	1,634	664	496
Spain	31,774	23,735	5,275	5,143	1,893	874
Taiwan	8,003	6,951	6,473	6,678	1,454	1,315
Other	12,580	10,774	6,851	3,671	1,966	772
Total	217,382	187,000	65,418	58,189	29,994	15,000

[1]Marble - merely cut by sawing or otherwise.

Source: U.S. Bureau of the Census as modified by the Bureau of Mines.

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF OTHER DIMENSION STONE, BY TYPE

Type		1989 Quantity	1989 Value (thousands)	Major source for 1989 (percent[1])
Alabaster, worked monumental or building stone	short tons	10,433	$1,467	Italy 83%.
Alabaster, other calcareous monumental or building stone	do.	14,830	1,029	Italy 81%.
Calcareous stone-other	do.	22,660	10,465	France 48%.
Marble, Travertine and Alabaster and Other	do.	10,860	8,932	Italy 61%.
Sandstone, crude or roughly trimmed	do.	23,029	78	India 87%.
Sandstone, merely cut, by sawing or otherwise	do.	4,926	569	India 52%.
Sett, Curbstone and Flagstone, of Natural Stone	do.	24,194	25	United Kingdom 70%.
Slate, Roofing	million square feet	10.3	4,474	China 34%.
Slate, whether or not roughly trimmed or merely cut		NA	3,008	NA
Slate, worked Slate, articles of Slate, and other		NA	12,319	NA
Stone, worked monumental or building stone-other	short tons	19,642	8,625	Italy 46%.
Travertine, monumental/building stone and articles thereof	do.	3,416	3,000	Italy 90%.
Travertine, worked monumental or building stone	do.	25,173	11,114	Italy 96%.
Other monumental or building stone	short tons	34,767	3,764	France 52%.
Other, stone-monumental or building stone-articles thereof	do.	8,008	1,721	Mexico 82%.

NA Not available

[1]By value.

Source: U.S. Bureau of the Census as modified by the Bureau of Mines.

TABLE 17

U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	Harmonized tariff No.	Most favored nation (MFN) Jan. 1, 1990	Non-MFN Jan. 1, 1990
Slate:			
Rough blocks or slabs	2514.00	3.7%	25%
Rough blocks or slabs of marble, travertine, and other calcareous monumental or building stone:	2515		
Marble and travertine:			
Crude or roughly trimmed	2515.11	$3.46 per cubic meter	$22.95 per cubic meter
Marble, merely cut	2515.12.10	2.1%	13%
Travertine, merely cut	2515.12.20	6%	50%
Other calcareous stone; alabaster	2515.20.00	6%	50%
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%	60%
Sandstone:			
Crude or roughly trimmed	2516.21.00	Free	$5.30 per cubic meter
Merely cut	2516.22.00	6%	50%
Other monumental or building stone	2516.90.00	6%	50%
Setts, curbstones, and flagstones	6801.00.00	4.2%	60%
Worked monumental or building stone	6802		
Tiles and cubes under 7 cm square; granules	6802.10.00	6.9%	40%
Other stone and articles with a flat or even surface:			
Marble, travertine and alabaster:	6802.21		
Travertine	6802.21.10	6%	50%
Other:	6802.21.50	2.1%	13%
Other calcareous stone	6802.22.00	6%	50%
Granite	6802.23.00	4.2%	60%
Other stone	6802.29.00	7.5%	30%
Other:			
Marble, travertine, and alabaster	6802.91		
Marble:			
Slabs	6802.91.05	2.8%	15%
Other	6802.91.15	6%	50%
Travertine:			
Articles of subheading 6802.21.10 that have been dressed or polished, but not further worked	6802.91.20	6%	50%
Other	6802.91.25	5.3%	40%
Alabaster	6802.91.30	5.3%	50%
Other calcareous stone	6802.92.00	6%	50%
Granite	6802.93.00	4.2%	60%
Other stone	6802.99.00	6.5%	40%
Worked slate and articles:			
Roofing slate	6803.00.10	6.6%	25%
Other	6803.00.50	3.7%	25%

STRONTIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 12 years of industry and Bureau of Mines experience, has been the commodity specialist for strontium since 1986. Domestic survey data were prepared by Maureen Nash, mineral data assistant, and the international production table was prepared by Gio Jacarepaqua, international data assistant.

The production of color television picture tube faceplate glass was once again the largest consumer of strontium compounds domestically and internationally. Strontium carbonate, recovered from 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.

DOMESTIC DATA COVERAGE

The sole U.S. strontium carbonate producer voluntarily provided domestic production data to the Bureau of Mines. However, production and stock data 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 nearly 100% of the end-use data shown in table 2. Consumption for the nonrespondents was estimated using reported prior-year consumption levels.

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 Texas and California. 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 by one major company in the United States. CPC was the only company that produced strontium chemicals from celestite. The majority of the celestite CPC used was from Mexican deposits. CPC utilized the black ash method of strontium carbonate production at its facility. The black ash method and the soda ash method were the two most common recovery techniques. The black ash method, known alternatively as the calcining method, produced chemical-grade strontium carbonate, which contained at least 98% strontium carbonate. The soda ash or direct conversion method produced 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 reduced at 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 reacted to form

TABLE 1

SALIENT STRONTIUM STATISTICS

(Metric tons of contained strontium unless otherwise noted[1])

	1985	1986	1987	1988	1989
United States:					
Production, strontium minerals	—	—	—	—	—
Imports for consumption:					
Strontium minerals	15,000	13,200	16,900	18,100	12,000
Strontium compounds	3,600	4,300	5,000	7,800	11,300
Exports[2] (compounds)	17	680	1,600	3,000	3,200
Shipments from Government stockpile excesses	—	—	—	—	—
Price, average value of mineral imports of exportation, dollars per ton at port	$97	$107	$95	$85	$76
World production[3] (celestite)	163,000	150,000	182,000	[p]231,000	[e]244,000

[e]Estimated. [p]Preliminary.

[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.

strontium carbonate and sodium sulfate. Sodium sulfate dissolves in water, 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 were under construction using black ash technology.

CPC purchased the strontium nitrate production facilities from FMC Corp. in Modesto, CA, when that company discontinued production 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 nitrate. 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 the military effort. Immediately following the war, this demand disappeared, causing domestic production to decrease quickly and eventually taper off to nothing.

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]

The metric system is the official system of measurement of most countries. The Bureau of Mines, in an effort to provide statistical data on strontium that are consistent with international usage, will henceforth report data in kilograms and metric tons unless otherwise noted.

CONSUMPTION AND USES

Approximately 80% of all strontium was consumed in ceramics and glass manufacture, primarily in television faceplate glass and ceramic ferrite magnets, but 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.[3] 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 nitrate, and during processing, it is converted to strontium oxide.[4] 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.[5] 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. However, development of flat-screen technology that could replace cathode-ray tubes continued. Commercialization of flat screens consisting of liquid-crystal displays or some other advanced technology could eventually render cathode-ray tubes obsolete.

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.[6] 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 were used in pyrotechnic applications, but strontium nitrate was used in significantly larger quantities than any of these.[7]

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 die-casting 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.[8] The use of cast aluminum parts is currently gaining popularity in the automotive industry. Aluminum parts have not been practical before modification techniques were developed. The reduction in the car weight by using cast aluminum parts instead of steel helps to improve energy efficiency of the automobiles 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 eliminating the toxicity that may be present in glazes containing lead or barium.[9] 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 of some of them in the parts per million range.[10]

Strontium phosphate was used in the manufacture of fluorescent lights, and the entire range of strontium chemicals was used in analytical chemistry laboratories.[11]

PRICES

The average customs value for celestite imported from Mexico, the only source in 1989, was about $76 per ton ($70 per short ton). This value was approximately the same as the average customs value reported for 1988. 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 5,300 tons, a 10% decrease from the exports reported from the same source in 1988. Of these exports, 98.5% was strontium carbonate that went to Japan, Taiwan, and the Republic of Korea. 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. Because of these changes, foreign trade information for strontium was available for most materials, but the actual reported figures for celestite from the Bureau of the Census differed from what was expected based on recent trends in foreign trade. A decrease in imports of celestite was expected, but a decrease of nearly 40% did not correspond with reports from other sources.

According to Census, Mexico became the most important source for imported strontium compounds, and the Federal Republic of Germany was second. Imports of strontium carbonate increased about 50%; imports from Mexico were more than twice the level

TABLE 2

U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	1987	1988	1989
Electrolytic production of zinc	5	4	4
Ferrite ceramic magnets	11	11	10
Pigments and fillers	5	4	3
Pyrotechnics and signals	13	10	10
Television picture tubes	63	68	70
Other	3	3	3
Total	100	100	100

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM MINERALS,[1] BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
France	30	$9	—	—
Germany, Federal Republic of	34	29	—	—
Mexico	38,681	2,988	25,640	$1,956
Spain	2,497	476	—	—
Total	41,242	3,502	25,640	1,956

[1] Celestite (strontium sulfate).
[2] Customs value.
Source: Bureau of the Census.

reported in 1988. Strontium carbonate from Germany decreased nearly 30% as Mexico took over that market. Imports of strontium nitrate nearly tripled after 2 years of decreases.

WORLD REVIEW

Capacity

The data in table 5 are annual rated capacity for chemical processing plants 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.

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

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS AND METAL, BY COUNTRY

Country	1988		1989	
	Kilograms	Value[1]	Kilograms	Value[1]
Strontium carbonate:				
Canada	18,000	$11,176	18,000	$11,256
France	—	—	216,000	131,602
Germany, Federal Republic of	6,243,741	3,831,489	4,427,276	2,992,291
Italy	3,010	5,280	3,648	3,520
Japan	8,240	29,769	934,883	635,860
Mexico	6,047,481	3,122,012	12,872,502	6,669,611
United Kingdom	12,988	22,541	6,137	11,012
Total	12,333,460	7,022,267	18,478,446	10,455,152
Strontium chromate:				
Australia	2,310	13,365	NA	NA
Belgium	24,619	83,080	NA	NA
Canada	6,350	17,923	NA	NA
France	62,999	181,945	NA	NA
Germany, Federal Republic of	17,962	44,748	NA	NA
Korea, Republic of	7,346	19,804	NA	NA
Total	121,586	360,865	NA	NA
Strontium nitrate:				
Germany, Federal Republic of	—	—	600	8,536
Italy	123,412	175,028	43,003	40,725
Mexico	24,658	22,755	571,849	546,291
Spain	72,700	73,050	18,000	17,100
Total	220,770	270,833	633,452	612,652
Strontium compounds, other:				
Canada	42	1,284	—	—
China	—	—	17,000	4,482
France	44,166	158,334	—	—
Germany, Federal Republic of	24,098	132,519	—	—
Italy	1,194	1,169	—	—
Japan	224,554	457,535	—	—
Netherlands	18	4,680	—	—
United Kingdom	47,883	176,746	—	—
Total	341,955	932,267	17,000	4,482
Strontium salts (potassium oxalate and others):				
Belgium	1,257	7,000	NA	NA
Canada	20,200	7,960	NA	NA
Japan	600	4,570	NA	NA
Switzerland	1,000	5,513	NA	NA
Total	23,057	25,043	NA	NA
Strontium sulfate (other than celestite):				
Canada	19,051	2,843	NA	NA
Strontium metal, unwrought:				
Canada	34,342	694,973	NA	NA
Mexico	107	4,009	NA	NA
Total	34,449	698,982	NA	NA

NA Not available.
[1] Customs value.

Source: Bureau of the Census.

growth in international sales of color television sets.

Capacity data for the United States were estimated based on celestite imports, assuming an 85% recovery of strontium from celestite containing a minimum ore grade of 90% strontium sulfate. Capacity information for other countries was compiled from published reports.

Algeria

Celestite was mined in Algeria from a surface deposit near Beni Mansour. Estimated reserves were more than 1 million short tons. The deposit was mined by Enterprise des Produits Non-Ferreux et des Substances Utiles (ENOF) and was controlled by L'Enterprise Nationale de Developpement Minière (Edemines), a division of Société Nationale de Recherches et d'Exploitations Minières (SONAREM). No strontium has been exported in recent years, but in the past, up to 3,600 tons per year has been exported to Soviet Bloc nations 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.[12]

TABLE 5

WORLD STRONTIUM CARBONATE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Metric tons)

Country	Rated capacity[1]
North America:	
Mexico	34,000
United States[e 2 3]	10,000
Total	44,000
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	139,800

[e]Estimated.
[1]Included capacity at operating plants as well as plants on a standby basis.
[2]Production was entirely from imported celestite.
[3]Includes strontium notrate production capacity.
[4]Strontium carbonate production capacity existed in these countries, but specific data were not available.

TABLE 6

STRONTIUM MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Algeria[e]	5,400	5,400	5,400	5,400	5,400
Argentina	983	1,133	1,349	2,120	1,400
Cyprus (celestite)	1,400	7,365	6,300	(3)	—
Iran (celestite)[e 4]	20,000	22,000	22,000	22,000	22,000
Italy	4,611	4,667	177	(3)	—
Mexico (celestite)	32,320	24,042	47,739	81,452	91,000
Pakistan	718	997	1,083	488	500
Spain	39,101	34,500	[e]40,000	[e]40,000	40,000
Turkey[e]	35,000	35,000	35,000	[5]54,000	59,000
United Kingdom	23,039	14,739	22,655	25,553	25,000
Total	162,572	149,843	181,703	231,013	244,300

[e]Estimated. [p]Preliminary.
[1]Table includes data available through May 23, 1990.
[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]Revised to zero.
[4]Data are for year beginning Mar. 21 of that stated.
[5]Reported figure.

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.[13]

Canada

Canada has produced celestite ore in the past from the McRae deposit, also known as the old Kaiser Celestite Mining Ltd. mine. It is located at 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,[14] 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 recently completed a new processing facility in Westmeath, Ontario, which increased the potential strontium output by more than 40%.[15] The strontium production facilities in Westmeath and the old 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.[16] Past import data indicated that strontium chemical plants must exist, but no specific details were available. Reports indicated that Japan im-

ports 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.[17] No mining has occurred for the past 2 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 recently expanded 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.[18]

Iran

One of the world's largest celestite deposits is in the northwestern part of the Dasht-e-Kavir salt desert. The deposit was mined by Iran Strontium Co., a subsidiary of Cherkate Sahami Sanati Va Maadani Irani (Simiran). Average strontium sulfate values for the deposit were reported at more than 91%, but there were unfavorably high levels of barium sulfate and calcium sulfate. Proven reserves total 1.8 million tons of celestite, 430,000 tons of which have no overburden.[19] 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.[20] 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.[21] 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 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 goes to the United States.[22]

Japan

No celestite was mined in Japan, but that country was the largest consumer of strontium carbonate in the world, mostly due to its large television and electronics industry. Four companies produce strontium carbonate from imported celestite. Honjo Chemical Corp. operated a production facility for 18,000 tons per year of carbonate at Neyagawa in Osaka using celestite from Spain and China. Sakai Chemical Industries Co. also produced strontium carbonate, by the black ash method, in Osaka at a 12,000-ton-per-year plant using Chinese, Mexican, and Spanish celestite. Japan Special Chemicals (Nihon Tokushu Kasei) and 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.[23]

Korea, Republic of

Although celestite deposits have not been identified in Korea, its growing electronics and television industry has prompted a European company to form a joint venture with a Korean firm. The companies planned to build production facilities for strontium carbonate and barium carbonate. Kali-Chemie, in a joint venture with Samsung Corning Ltd., Korea, formed Daehan Specialty Chemicals Co. Ltd. and built a strontium carbonate and barium carbonate plant. The plant was expected to begin operation in May 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.[24]

Mexico

Mexico was the world's largest producer of celestite in 1989. The most recent Directory of Mexican Non-Metallic Minerals Trust lists 11 companies currently mining celestite. Compañía Minera La Valenciana SA (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. Sales y Oxidos (SYOSA), formerly 49% owned by a U.S. company, Church and Dwight, mines west of Monterrey. Kali-Chemie bought Church and Dwight's share of SYOSA. 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. These deposits have not been extensively explored, but reserves are believed to be vast.[25]

Strontium carbonate production has been a recent development in Mexico. Because of the huge celestite resources in the country, this is a very attractive location for additional production facilities. After a major U.S. strontium carbonate and strontium nitrate producer (FMC Corp.) closed its plant in 1984, Cia. Minera La Valenciana SA 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 a mine. The plant capacity was expanded to 22,000 tons per year in 1989. Shipments from the plant, targeted for the television and electronics industry in the Far East, commenced in May 1987. SYOSA expanded strontium carbonate capacity at its plant near Monterrey to 15,000 tons per year. SY-

OSA, which produced carbonate by the black ash method from celestite it mines nearby, is marketing its production in the United States.[26]

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.[27] 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.[28] Other deposits with 500,000 tons of reported reserves have been identified in the Punjab Province.[29]

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, although some remains in Spain, and the rest is exported to the Federal Republic of Germany.[30] 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.[31]

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.[32]

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.[33] 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.[34] 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.[35]

OUTLOOK

The future looks bright for the strontium industry for the near term. Continued growth is expected in the color television industry, and larger screens are expected to increase in popularity. Demand for strontium carbonate for television application should expand 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. But flat screen display systems may eventually replace cathode-ray tubes, and, at that point, strontium producers may experience a serious setback.

BACKGROUND

Resources

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.[36] 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.[37] In almost all instances, celestite deposits occur in remote, undeveloped locations far from population centers in areas where inexpensive labor is available for mining. Huge deposits of high-grade celestite have been discovered throughout the world. Strontium commonly occurs along with barium and calcium, two elements 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 facili-

ties 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 located in countries from which specific mineral information is not easily obtained.

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SULFUR

By David E. Morse

Mr. Morse, a physical scientist with 14 years Bureau of Mines experience, has been the commodity specialist for sulfur since 1981. Domestic survey data were prepared by Mrs. Jessie G. Austin, mineral data assistant; and the international data table was prepared by Mr. Harold D. Willis, international data assistant.

The United States retained its position as the world's foremost producer and consumer of sulfur and sulfuric acid in 1989. Production from U.S. Frasch mines increased significantly to nearly 3.9 million metric tons. One Frasch mine was deactivated and plans were announced for the development of 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.

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 and 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 located near western copper mines and far from major sulfuric acid markets.

Total world production of sulfur in all forms increased slightly compared to 1988; Frasch sulfur output increased because of activities in the United States and Iraq. Recovered elemental production increased in Asia, decreased slightly in Western Europe and North America because of declining production from gas plants, and fell significantly 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, especially in the fertilizer-producing countries of North Africa. Consumption for a myriad of industrial uses continued to be pressured by environmental con-

TABLE 1

SALIENT SULFUR STATISTICS

(Thousand metric tons, sulfur content, and thousand dollars unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Frasch	5,011	4,043	3,202	3,174	3,888
Recovered[1]	5,313	5,816	6,161	6,444	6,510
Other forms	1,285	1,228	1,176	1,128	1,194
Total	11,609	11,087	10,539	10,746	11,592
Shipments:					
Frasch	4,678	4,108	3,610	4,341	3,780
Recovered[1]	5,266	5,798	6,180	6,470	6,475
Other forms	1,285	1,228	1,176	1,128	1,194
Total	11,229	11,134	10,966	11,939	11,449
Exports, elemental[2]	1,365	1,895	1,242	1,223	1,024
Imports, elemental	2,104	1,347	1,599	1,996	2,260
Consumption, all forms	11,968	10,586	11,323	12,712	12,685
Stocks, Dec. 31: Producer, Frasch and recovered	2,799	2,748	2,316	1,112	1,301
Value:					
Shipments, f.o.b. mine or plant:					
Frasch	$573,570	$508,512	$386,834	$430,814	$378,712
Recovered[1]	485,084	533,752	492,136	498,368	509,582
Other forms	123,937	105,639	90,707	88,181	104,304
Total	1,182,591	1,147,903	969,677	1,017,363	992,598
Exports, elemental[3]	$189,248	$251,664	$139,431	$131,863	$107,126
Imports, elemental[4]	$199,240	$142,220	$152,096	$185,864	$209,465
Price, elemental, dollars per metric ton, f.o.b. mine or plant	$106.46	$105.22	$89.78	$85.95	$86.62
World: Production, all forms (including pyrites)	r53,771	r53,601	56,068	p58,096	e58,348

e Estimated. p Preliminary. r Revised.

[1] Includes Puerto Rico and the Virgin Islands.

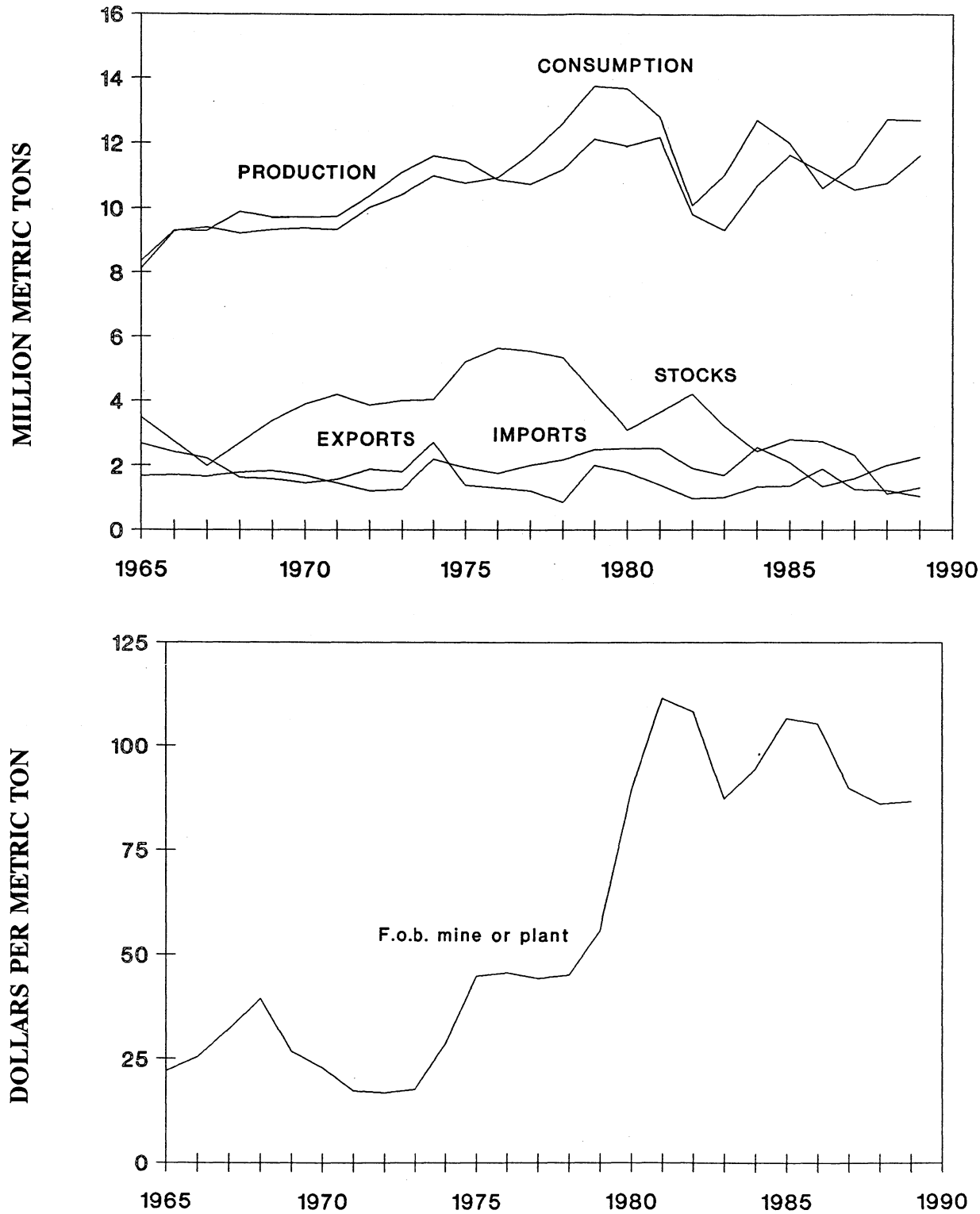
[2] Includes exports from the Virgin Islands to foreign countries.

[3] Includes value of exports from the Virgin Islands to foreign countries.

[4] Declared customs valuation.

FIGURE 1

TRENDS IN THE SULFUR INDUSTRY IN THE UNITED STATES



straints placed on the products produced or effluents from the chemical processes utilizing sulfur or its major derivative, sulfuric acid. World trade of elemental sulfur decreased, by more than 2.8 million metric tons. Although individual country sulfur inventories showed important variations from yearend 1988, total world producers stocks of elemental sulfur were essentially unchanged, which was a departure from the annual decreases that had been characteristic of the 1980's.

DOMESTIC DATA COVERAGE

Domestic production data for sulfur are developed by the Bureau of Mines from four separate, voluntary surveys of U.S. operations. Typical of these surveys is the "Elemental Sulfur" survey. Of the 177 operations to which a survey request was sent, 175 responded, representing 99.99% of the total production shown in tables 1 and 2. The production of the nonrespondents was estimated using prior production histories adjusted to reflect trends in output of their primary products.

PRODUCTION

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.

Frasch

Native sulfur associated with the caprock of salt domes and in sedimentary deposits is mined by the Frasch hot water method, in which the native sulfur is melted underground and brought to the surface by compressed air. In January 1989, the United States had six 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 and at its Comanche Creek facility near Fort Stocton in western Texas. TG deactivated the Comanche Creek mine at the end of October, citing low prices and high operating costs as the underlying reasons for the closure. At yearend the Frasch mining industry was operating at about 80% 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 which 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 planned to bring Main Pass 299 into production in late 1991 or early 1992, which would require an investment of over $550 million. Pennzoil performed exploratory drilling operations on two of the three offshore Federal leases that it had acquired in 1988. Placer Dome U.S., Inc. as operator in a joint-venture agreement with Gold and Mineral Exploration NL and Laverton Gold NL, (both of Australia) drilled six explor-

TABLE 2

PRODUCTION OF SULFUR AND SULFUR-CONTAINING RAW MATERIALS IN THE UNITED STATES

(Thousand metric tons)

	1988		1989	
	Gross weight	Sulfur content	Gross weight	Sulfur content
Frasch sulfur	3,174	3,174	3,888	3,888
Recovered sulfur[1]	6,444	6,444	6,510	6,510
Byproduct sulfuric acid (100% basis) produced at copper, lead, molybdenum, and zinc plants	3,443	1,125	3,641	1,190
Other forms[2]	7	3	8	4
Total	XX	10,746	XX	11,592

XX Not applicable.
[1] Includes Puerto Rico and the Virgin Islands.
[2] Includes hydrogen sulfide, liquid sulfur dioxide, and pyrites.

TABLE 3

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]
1985	2,940	2,071	5,011	4,678	573,570
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

[1] Data may not add to totals shown because of independent rounding.
[2] F.o.b. mine.

atory holes on the Mustang Draw property in Glasscock County, TX. Preliminary estimates of the inplace sulfur resource were 4.5 to 7.9 million tons of sulfur with the depth to the top of the sulfur bearing interval ranging from 2,500 feet to 2,800 feet. In addition to the Mustang Draw prospect, Placer began an exploration program that covers an additional 13 west Texas counties.

TG celebrated the 60th year of commercial operations at New Gulf sulfur mine on Boling Dome. It has been the most prolific sulfur operation in the United States, having produced over 80 million long tons of sulfur. The mine was projected to continue operations until 1995.

Frasch sulfur output increased 700,000 tons from the quantity produced in 1988. Total shipments to domestic and overseas consumers decreased, however, by more than 550,000 tons. Frasch sulfur accounted for 34% of domestic production in 1989. Approximately 91% of Frasch sulfur shipments was for domestic consumption, and 9% for export. The total value of Frasch sulfur shipments decreased by over $52 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 56% of the total domestic output of sulfur in all forms, compared with 60% in 1988. Production and shipments reached alltime high levels owing to record production from the Nation's petroleum refineries and natural gas processing plants. Recovered elemental sulfur was produced by 57 companies at 154 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, 61% was produced at 84 refineries or satellite plants treating refinery gases and 3 coking plants. The remainder was produced by 27 companies at 67 natural gas treatment plants. The five largest recovered-sulfur producers in 1988 were Chevron U.S.A. Inc., Exxon Co. U.S.A., Shell Oil Co., Standard Oil Co. (Indiana), and Star Enterprise. The 54 plants owned by these companies accounted for 62% of recovered elemental sulfur output during the year.

Refinery sulfur output was restricted by abnormally cold weather during December that adversely effected petroleum refinery operations in the south and midwest. The Hess refinery in the U.S. Virgin Islands was shut down for several weeks by a major Atlantic hurricane that devastated St. Thomas.

Byproduct Sulfuric Acid

Byproduct sulfuric acid at copper,

TABLE 4

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]
1985	2,373	2,940	5,313	5,266	485,084
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

[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 5

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

Year	1988			1989		
	Production	Shipments		Production	Shipments	
		Quantity	Value		Quantity	Value
Alabama	375	372	33,634	410	411	40,443
California	697	696	42,852	680	677	39,881
Florida	68	68	W	67	67	W
Illinois	258	258	22,367	252	252	21,852
Louisiana	569	571	53,198	613	616	59,217
Michigan and Minnesota	170	170	13,544	172	172	14,463
Mississippi	764	773	67,266	703	710	64,839
New Mexico	44	44	2,797	45	45	3,001
North Dakota	115	115	7,178	98	99	6,460
Ohio	48	48	4,296	48	48	3,968
Pennsylvania	61	62	5,457	67	68	6,001
Texas	1,654	1,653	137,635	1,603	1,602	141,818
Wyoming	991	982	44,461	1,104	1,110	51,709
Other[1]	627	660	63,684	647	599	55,932
Total[2]	6,444	6,470	498,368	6,510	6,475	509,582

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.

TABLE 6

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT

(Thousand metric tons)

District and source	1988		1989	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	279	283	305	302
Natural gas	68	68	66	66
Total[1]	347	351	371	369
PAD 2:				
Petroleum and coke	640	641	630	629
Natural gas	114	115	98	99
Total[1]	755	756	729	728
PAD 3:[2]				
Petroleum	2,151	2,181	2,182	2,153
Natural gas	1,339	1,338	1,281	1,284
Total[1]	3,491	3,520	3,464	3,437
PAD 4 and 5:				
Petroleum	871	872	854	842
Natural gas	978	969	1,090	1,096
Total	1,849	1,841	1,944	1,938
Grand total[1]	6,444	6,470	6,510	6,475

[1] Data may not add to totals shown because of independent rounding.
[2] Includes Puerto Rico and the Virgin Islands.

TABLE 7

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
1985	729	141	87	957	56,299
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

[1] Includes acid from foreign materials.
[2] Excludes acid made from pyrites concentrates.
[3] Excludes acid made from native sulfur.

TABLE 8

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
1985	W	W	43	328	67,638
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

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

lead, molybdenum, and zinc roasters and smelters amounted to 10% 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 72% of the output, and production in five States was 88% 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 86% of the 1989 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.

CONSUMPTION AND USES

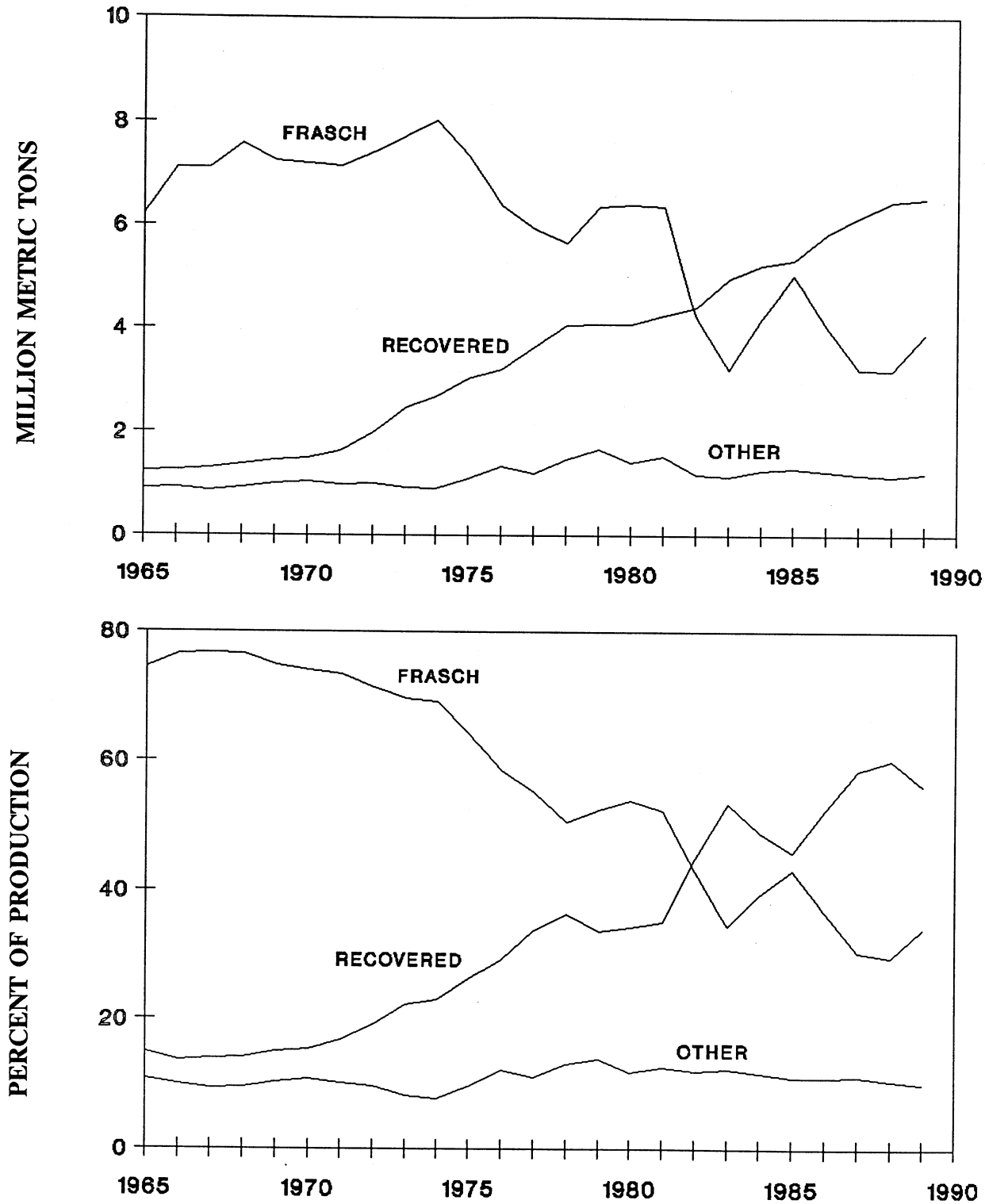
Domestic consumption of sulfur in all forms continued the strong performance of 1988. In 1989, 82% of the sulfur consumed was obtained from domestic sources, compared with 84% in 1988. The sources of supply were domestic recovered elemental sulfur, 46%; domestic Frasch sulfur, 27%; and combined domestic byproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 9%. The remaining 18% was supplied by imports of Frasch and recovered elemental sulfur.

The Bureau of Mines collected end-use data on sulfur and sulfuric acid according to the Standard Industrial Classification of industrial activities. Shipments by end use of elemental sulfur were reported by 60 companies, and shipments of sulfuric acid were reported by 56 companies. Shipments of both elemental sulfur and sulfuric acid were reported by eight 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

FIGURE 2

TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES



industry. The largest sulfur end use, sulfuric acid, represented 90% 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 1 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 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 0.7 million tons in 1989 because of continued high demand for the production of phosphoric acid, the largest single end use. Shipments of sulfuric acid for petroleum refining and other petroleum and coal products, the second largest end use, decreased significantly from those of 1988. Sulfuric acid demand for copper ore leaching increased 300,000 tons to nearly 1.8 million tons because solvent extraction-electrowinning (SX-EW) operations could produce high-purity copper at a significantly lower cost than by conventional smelting methods.

According to the 1989 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 52% of the total returned. The petroleum refining industry was a net user of 689,000 tons of sulfuric acid. 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,

TABLE 9

CONSUMPTION OF SULFUR[1] IN THE UNITED STATES

(Thousand metric tons)

	1985	1986	1987	1988	1989
Frasch:					
Shipments	4,678	4,108	3,610	4,341	3,780
Imports	724	726	793	1,079	1,086
Exports	986	1,250	465	464	330
Total	4,416	3,584	3,938	4,956	4,536
Recovered:					
Shipments[2]	5,266	5,798	6,180	6,470	6,475
Imports	1,380	621	806	917	1,174
Exports	379	645	777	759	694
Total	6,267	5,774	6,209	6,628	6,955
Total elemental	10,683	9,358	10,147	11,584	11,491
Pyrites, shipments	W	W	W	W	W
Byproduct sulfuric acid, shipments	957	919	1,003	1,125	1,190
Other forms, shipments[3]	328	309	173	3	4
Total, all forms	11,968	10,586	11,323	12,712	12,685

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 10

ELEMENTAL SULFUR SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons)

SIC	End use	1988	1989
20	Food and kindred products	W	W
26, 261	Pulp and paper products	8	8
282, 2822	Synthetic rubber and other plastic products	W	W
287	Agricultural chemicals	460	277
28, 286	Other chemical products and industrial organic chemicals	144	122
284	Soaps and detergents	8	W
29, 291	Petroleum refining and petroleum and coal products	172	142
281	Other industrial inorganic chemicals	80	188
	Sulfuric acid:		
	Domestic sulfur	8,589	8,241
	Imported sulfur	1,756	2,245
	Total	10,345	10,486
	Unidentified	289	372
	Total domestic uses	11,506	11,595
	Exports	1,055	923
	Grand total	12,561	12,518

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

TABLE 11

SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	End use	1988	1989
102	Copper ores	1,491	1,797
1094	Uranium and vanadium ores	103	134
10	Other ores	67	123
261	Pulpmills	826	859
26	Other paper products	31	119
285, 2816	Inorganic pigments and paints and allied products	373	423
281	Other inorganic chemicals	959	872
282, 2822	Synthetic rubber and other plastic materials and synthetics	1,035	1,172
2823	Cellulosic fibers, including rayon	136	159
283	Drugs	73	78
284	Soaps and detergents	299	260
286	Industrial organic chemicals	1,092	876
2873	Nitrogenous fertilizers	243	285
2874	Phosphatic fertilizers	25,711	26,436
2879	Pesticides	18	99
287	Other agricultural chemicals	161	89
2892	Explosives	134	52
2899	Water-treating compounds	353	353
28	Other chemical products	155	240
29, 291	Petroleum refining and other petroleum and coal products	2,403	2,088
30	Rubber and miscellaneous plastic products	W	5
331	Steel pickling	226	181
333	Nonferrous metals	49	151
33	Other primary metals	25	6
3691	Storage batteries (acid)	155	140
	Unidentified	1,528	1,403
	Total domestic	37,646	38,400
	Exports	86	33
	Grand total	37,732	38,433

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

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 9.0 million tons in 1988 to nearly 9.1 million tons. The quantity of sulfur needed to manufacture exported agricultural products increased, however, by over 300,000 tons to 4.65 million tons indicating that consumption for domestic purposes declined despite an increase in acreage planted by U.S. farmers.

STOCKS

Yearend inventories held by Frasch and recovered elemental sulfur producers increased 17% from those of 1988, but remained well below historical levels. Combined yearend stocks amounted to approximately a 45-day supply compared to 38-day supply in 1988 and an 82-day supply in 1987, based on domestic and export demands for Frasch and recovered sulfur.

PRICES

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.

On the basis of total shipments and value reported to the Bureau of Mines, the average value of shipments of Frasch sulfur, f.o.b. mine, for domestic consumption and exports combined increased from $85.75 to $86.62 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 16% in quantity and 19% in value. According to the Bureau of the Census, exports from the west coast were 473,000 tons or 56% of total U.S. exports.

The United States was a net importer of sulfur, and imports exceeded exports by more than 1.2 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 13% in quantity; imports by rail from Canada increased 26%, while waterborne shipments from Mexico were slightly higher than in 1988. An estimated 380,000

FIGURE 3

TRENDS IN THE CONSUMPTION OF SULFUR IN THE UNITED STATES

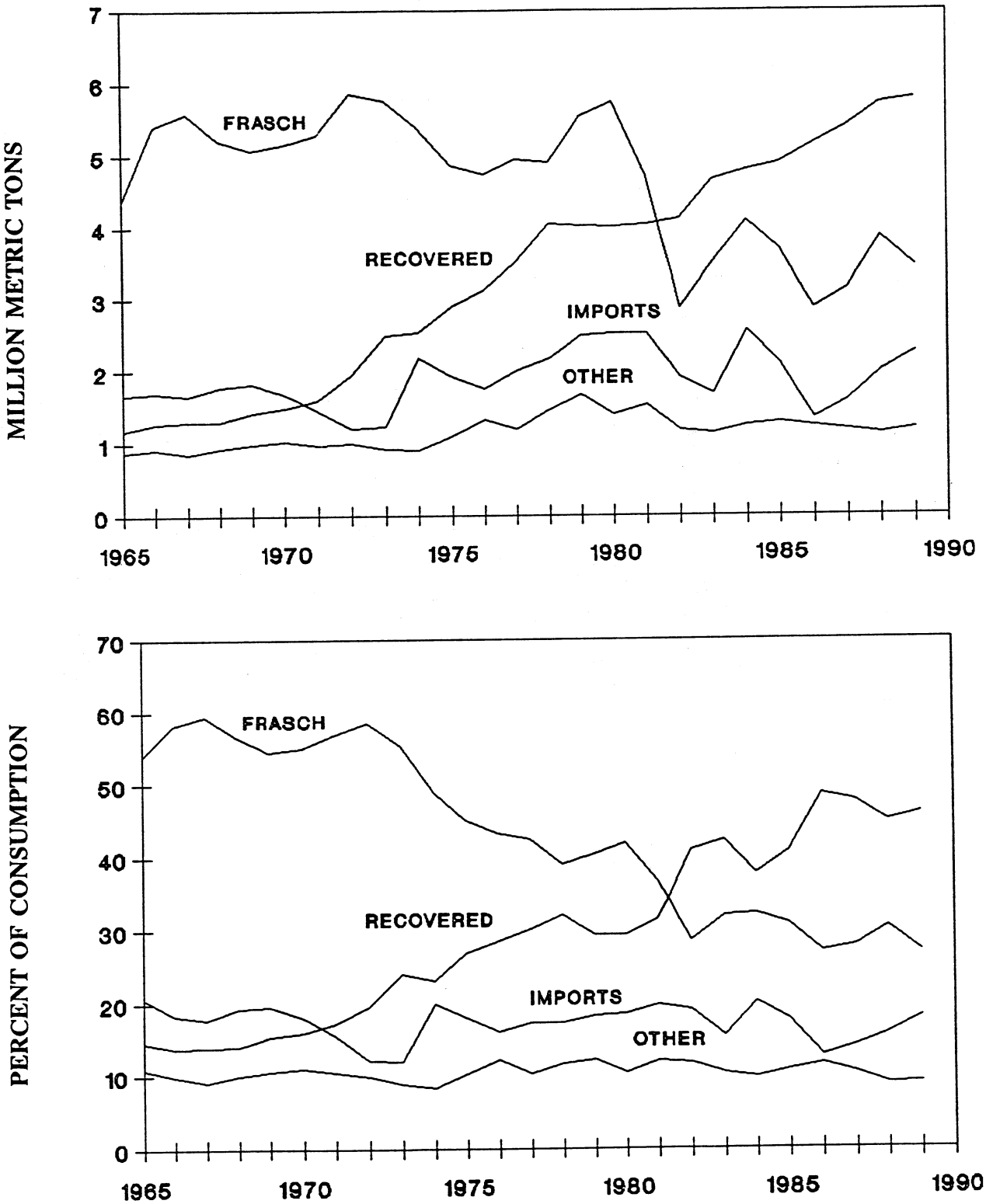
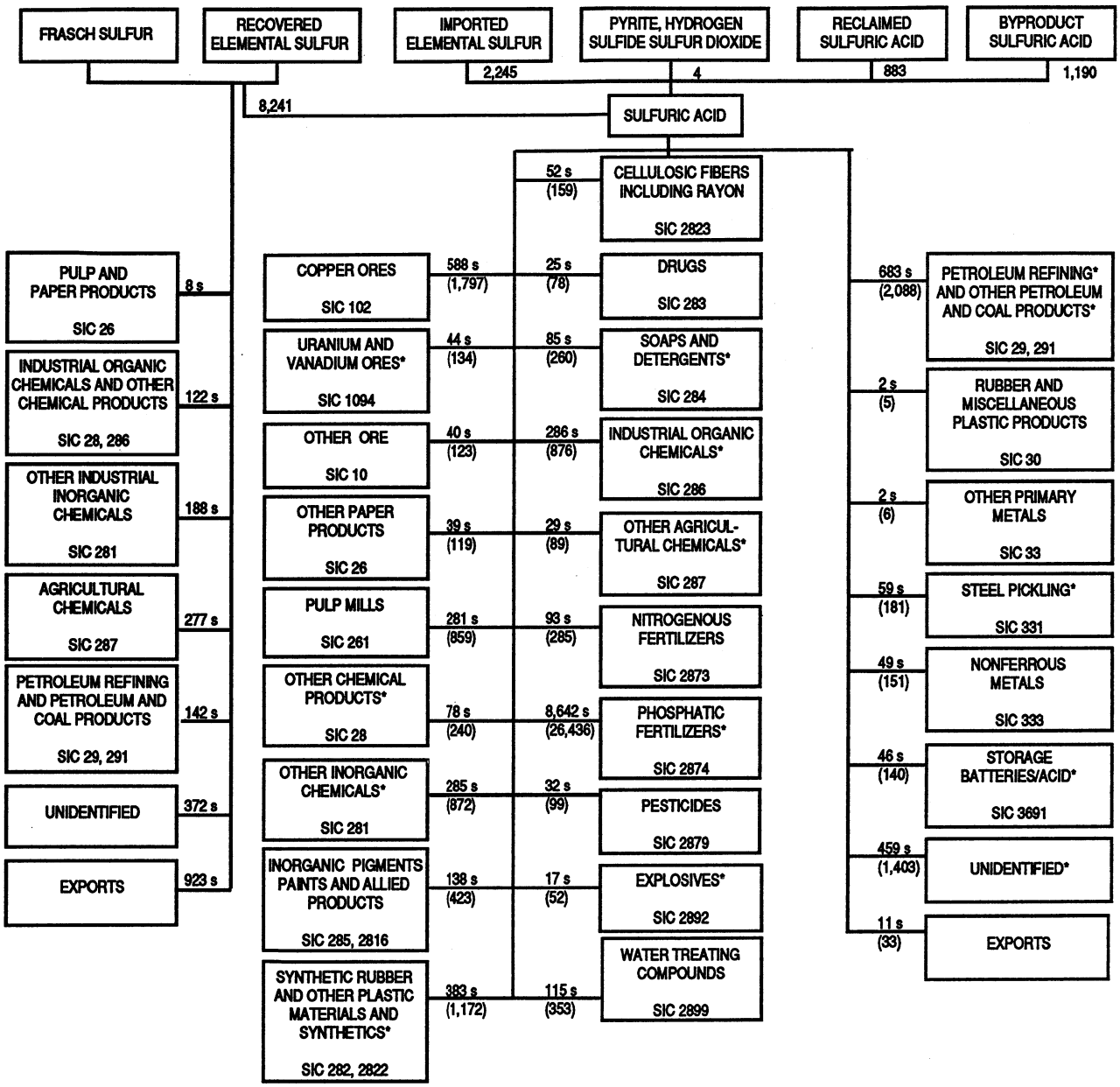


FIGURE 4

SULFUR-SULFURIC ACID SUPPLY AND END-USE RELATIONSHIP IN 1989



#s - SULFUR CONTENT THOUSAND METRIC TONS
(#) - 100% SULFURIC ACID THOUSAND METRIC TONS
* - SOURCES OF SPENT ACID FOR RECLAIMING

tons of sulfur shipped to the west coast of Mexico from Canada and the United States was exchanged for Mexican sulfur delivered to Florida and U.S. east coast ports.

The United States also had significant trade in sulfuric acid. Sulfuric acid exports decreased slightly from those of 1988. Imports, which were significantly greater than exports, were mostly by rail from Canada. The tonnage increased 31% from the quantity reported in 1988; the value of imported sulfuric acid, however, increased by only 26%. Approximately 220,000 tons of acid was imported into the Tampa, FL, area. Two new sulfuric acid terminals were established there. One of these was established by the Sulfuric Acid Trading Co. at what was previously the Texasgulf sulfur terminal. The other was established by Boliden Chemicals, Inc. at Port Sutton on the eastern shore of Hillsborough Bay, which was in close proximity to the Pan American and Pennzoil sulfur terminals. Total sulfuric acid storage capacity at the two terminals was nearly 78,000 tons.

WORLD REVIEW

International and domestic sulfur prices experienced a severe downturn in the third quarter of 1989, retreating to levels not seen since 1983. Canadian international sulfur sales, in the first half, dropped by $150 million compared to the year earlier. As a result of precipitously lower exports, Canadian sulfur was offered at $20 to $30 per metric ton below first half 1989 levels during the second half. By early Septem-

TABLE 12

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	
		1988	1989	1988	1989	1988	1989
102	Copper ores	—	—	487	588	487	588
1094	Uranium and vanadium ores	—	—	34	44	34	44
10	Other ores	—	—	22	40	22	40
20	Food and kindred products	W	W	—	—	W	W
26, 261	Pulpmills and paper products	8	8	280	320	288	328
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products	[2]144	[2]122	122	138	266	260
281	Other inorganic chemicals	80	188	313	285	393	473
282, 2822	Synthetic rubber and other plastic materials and synthetics	W	W	339	383	339	383
2823	Cellulosic fibers, including rayon	—	—	44	52	44	52
283	Drugs	—	—	24	25	24	25
284	Soaps and detergents	8	W	98	85	106	85
286	Industrial organic chemicals	—	—	357	286	357	286
2873	Nitrogenous fertilizers	—	—	79	93	79	93
2874	Phosphatic fertilizers	—	—	8,404	8,642	8,404	8,642
2879	Pesticides	—	—	6	32	6	32
287	Other agricultural chemicals	460	277	53	29	513	306
2892	Explosives	—	—	44	17	44	17
2899	Water-treating compounds	—	—	115	115	115	115
28	Other chemical products	—	—	51	78	51	78
29, 291	Petroleum refining and other petroleum and coal products	172	142	786	683	958	825
30	Rubber and miscellaneous plastic products	—	—	W	2	W	2
331	Steel pickling	—	—	74	59	74	59
333	Nonferrous metals	—	—	16	49	16	49
33	Other primary metals	—	—	8	2	8	2
3691	Storage batteries (acid)	—	—	51	46	51	46
	Exported sulfuric acid	—	—	28	11	28	11
	Total identified	872	737	11,835	12,104	12,707	12,841
	Unidentified	289	372	499	459	788	831
	Grand total	1,161	1,109	12,334	12,563	13,495	13,672

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 13

SULFURIC ACID FROM SMELTERS SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	Use	1988	1989
102	Copper ores	1,200	1,403
1094	Uranium and vanadium ores	82	114
10	Other ores	W	25
26, 261	Pulp mills and other paper products	81	167
2816	Inorganic pigments	W	W
281	Other inorganic chemicals	130	197
2823	Cellulosic fibers	—	W
283	Drugs	W	W
2873	Nitrogenous fertilizers	W	72
2874	Phosphatic fertilizers	689	658
287	Other agricultural chemicals	34	49
2899	Water-treating compounds	191	134
28	Other chemical products	58	22
29, 291	Petroleum refining and other petroleum and coal products	W	18
331	Steel pickling	W	W
33, 333	Nonferrous metals and other primary metals	35	W
3691	Storage batteries (acid)	47	25
	Unidentified	993	869
	Total domestic	3,540	3,753
	Exports	W	W
	Total	3,540	3,753

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

TABLE 14

YEAREND SULFUR STOCKS OF U.S. PRODUCERS

(Thousand metric tons)

Year	Frasch	Recovered	Total
1985	2,598	201	2,799
1986	2,532	216	2,748
1987	2,122	194	2,316
1988	954	158	1,112
1989	1,109	193	[1]1,301

[1] Data do not add to total shown because of independent rounding.

TABLE 15

REPORTED SALES VALUES OF SHIPMENTS OF SULFUR, F.O.B. MINE OR PLANT

(Dollars per metric ton)

Year	Frasch	Recovered	Average
1985	122.62	92.11	106.46
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

ber the price of sulfur stood at $78 to $85 per ton f.o.b. Vancouver, British Columbia. Because Canada continued to be the world's largest sulfur exporting nation, the severe drop in Vancouver prices had a ripple effect on prices worldwide. The per-long-ton posted price for liquid Frasch sulfur exterminal Tampa, FL, was reduced $4 in July, $8 in August and $12.50 in September, ending at $117.50. Middle East prices declined $15 to $25 to $90 per metric ton, and liquid prices from terminals in northwest Europe were reduced $11 per metric ton to $122 per metric ton.

A combination of events and sulfur consumers' decisions were responsible for the severe drop in sulfur prices in the third quarter of 1989. Throughout 1988, international fertilizer sales were good; U.S. fertilizer producers anticipated a 1989 increase in domestic sales of from 9% to 12% because of the 1988 drought in North America. Strong international sulfur movements resulting in a tight supply condition during the latter half of 1988 and coupled with a projected increase in demand in 1989, encouraged consumers to buy forward to offset costs associated with an anticipated increase in 1989 sulfur prices. Additionally, some major world fertilizer consumers also bought forward. An artificially strong apparent world sulfur demand characterized the last quarter of 1988. By yearend, an estimated 1.5 to 1.8 million tons of sulfur or sulfur equivalent in finished products was accumulated by fertilizer producers and consumers.

International sulfur prices were raised by $9 to $15 per metric ton in January 1989; prices for finished fertilizers and phosphoric acid were also raised substantially. The price increases were resisted by consumers of fertilizers and sulfur. India declined to purchase Moroccan phosphoric acid at the new price levels and Morocco curtailed sulfur imports in the first half by 1.15 million tons compared to 1988. Worldwide, first half (1989) sulfur movements were nearly 26% below the first half of 1988; Canadian exports were off nearly 1.6 million tons or almost 40% and represented more than 60% of the dropoff in world sulfur trade. Total world sulfur movements were off nearly 18% in 1989 compared with 1988 trade volumes.

While international sulfur movements and prices were in considerable disorder, U.S. demand remained strong because India replaced phosphoric acid imports with finished fertilizer imports, primarily diammonium phosphate (DAP), from the United States. Sulfur movements from Vancouver increased to more normal volumes from August onward through the end of the year. Canadian exports to the U.S.S.R. resumed in August after a 30-month hiatus.

Industry Structure

In 1989, 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

TABLE 16

U.S. EXPORTS[1] OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Australia	12	1,949	6	1,344
Belgium-Luxembourg	300	36,067	172	20,270
Brazil	262	29,137	204	23,066
Canada	33	2,499	49	3,551
China	—	—	62	6,500
Colombia	36	3,343	8	893
Denmark	—	—	13	2,039
India	39	3,738	79	5,293
Indonesia	59	5,572	(2)	43
Korea, Republic of	21	4,958	8	2,413
Mexico	211	18,820	155	14,883
Morocco	40	3,640	26	1,423
Netherlands	29	1,352	1	40
Philippines	11	1,066	1	195
Senegal	66	6,603	89	7,753
South Africa, Republic of	(2)	6	38	3,981
Taiwan	22	2,213	37	3,634
Tunisia	21	1,990	30	3,261
Other	r62	r8,916	49	6,544
Total[3]	1,223	131,863	1,024	107,126

rRevised.
[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.

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 1989, involuntary sources represented nearly 64% of the elemental sulfur produced worldwide, and the combination of recovered elemental sulfur and byproduct sulfuric acid equaled over 57% 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, Iraq, Mexico, the United States, Saudi Arabia, the Federal Republic of Germany, and France accounted for 90% of sulfur trade in 1989. Major sulfur importers in 1989 were India, the United States, the U.S.S.R., Brazil, Morocco, Tunisia, the United Kingdom, Australia, the Republic of South Africa, and Jordan in decending order of importance.

World Capacity

The data in table 20 are rated capacity for Frasch mines, elemental sulfur mining facilities and attendant beneficiation plants, pyrites mines and plants, and sulfur-sulfuric acid recovery units associated with petroleum refineries, natural gas processing plants, metal smelting operations, electric powerplants, and coke ovens 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 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 recov-

TABLE 17

U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	5,464	$295	9,101	$331
Canada	22,336	857	29,802	1,223
Chile	28,215	1,586	38,447	1,836
Costa Rica	1,853	68	282	25
Dominican Republic	607	50	1,944	125
Ecuador	3,375	203	—	—
Israel	2,258	144	5,316	250
Japan	1,957	67	255	31
Korea, Republic of	6,402	1,235	9,379	1,976
Mexico	27,204	1,663	14,551	762
Netherlands	1,996	100	27	58
Netherlands Antilles	4,291	271	7,255	497
Pakistan	1,926	64	—	—
Panama	4,683	245	1,747	101
Saudi Arabia	5,657	223	1,416	49
Spain	—	—	3,995	132
Taiwan	4,525	269	5,924	309
Trinidad and Tobago	1,511	50	611	20
United Kingdom	6,516	215	1,321	49
Venezuela	10,513	431	—	—
Other	r5,945	r444	14,256	946
Total[1]	147,234	8,479	145,629	8,721

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

Source: Bureau of the Census.

TABLE 18

U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1988		1989	
	Quantity	Value[1]	Quantity	Value[1]
Canada	913	58,835	1,149	80,577
Mexico	1,079	124,878	1,086	125,166
Other[2]	4	2,151	25	3,723
Total	1,996	185,864	2,260	[3]209,465

[1] Declared customs valuation.
[2] Includes France, Gabon, the Federal Republic of Germany, Japan, and the Netherlands in 1988; and Chile, the Dominican Republic, France, Gabon, the Federal Republic of Germany, India, Japan, and the Netherlands in 1989.
[3] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

ered by domestic petroleum refineries in the United States during 1989 was equal to slightly more than 50% of the installed engineering capacity. Rated capacity for petroleum refineries is assumed to be 50% of installed engineering capacity.

Natural gas processing plants may be installed to service gasfields and/or oilfields that contain significant quantities of associated gas. Gas plants are designed to accommodate the natural gas from a specific field that may contain in addition to methane, which is sold as pipeline gas, varying amounts of nitrogen, carbon dioxide, helium, condensable hydrocarbon liquids, and poisonous hydrogen sulfide. The poisonous nature of hydrogen sulfide makes its removal from pipeline gas imperative. Sulfur removal and recovery plants in natural gas facilities vary in size from small units rated at 5 to 10 tons per day to multiple-train plants capable of recovering thousands of tons per day. In general, sulfur recovery rates from gasfields approximate installed engineering capacity, based on a 340- to 345-day-per-year operation of all units, in the first 7 years of operation. In succeeding years, sulfur recovery declines steadily because the gas apparently becomes "sweeter" over time and because gas flow rates drop as the field is depleted. Rated capacity for gas processing plants is based on the age of the plant and its recent production history.

Rated capacity for plants operating in conjunction with metal smelters, powerplants, and coking operations is assumed to approximate engineering capacity. Where information on design capacity is unknown, rated capacity was estimated to be equal to the greatest output recorded by a plant or country in the past 5 years. World rated sulfur annual production capacity is significantly lower than the installed world engineering capacity of approximately 92 million tons.

Canada

Shipments of sulfur in all forms were about 7.4 million tons, or 0.7 million tons greater than production. Elemental sulfur exports decreased significantly from 7.4 million tons in 1988 to 5.8 million tons in 1989; offshore exports from Vancouver, British Columbia, fell 1.8 million tons from 1988 to 4.65 mil-

TABLE 19

U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1988		1989	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Argentina	2,112	$22	2,970	$30
Canada	807,232	27,429	931,001	29,586
France	21	40	—	—
Ireland	—	—	454	188
Italy	21,110	947	—	—
Japan	50,107	1,634	111,887	4,590
Korea, Republic of	41	32	3	6
Mexico	47,261	1,906	163,125	6,143
Netherlands	—	—	10,117	481
Spain	14,393	1,237	14,618	888
Sweden	(2)	6	32	8
Switzerland	16,452	747	19,575	1,108
Taiwan	6	13	57	25
Other	r4	r39	10	6
Total	958,739	34,052	1,253,849	[3]43,060

rRevised.
[1] Declared c.i.f. valuation.
[2] Less than 1/2 unit.
[3] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

lion tons; despite the dropoff in exports, 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 decreased about 350,000 tons from 1988 despite a slight increase in natural gas production. Severe cold weather in February adversely affected sulfur production from Husky Oil Ltd.'s Ram River plant, which reduced output for over a month. Sulfur production from gas plants in British Columbia increased to a record high of over 410,000 tons.

Mobil Oil Canada Ltd., Norcen Energy Resources Ltd., PanCanada Petroleum Ltd., and Shell Canada Ltd. began field construction on the Bearberry, Alberta, demonstration project to develop facilities to extract sulfur from the field's ultra sour gas (90% H_2S). A 200-ton-per-day pilot plant was due for completion 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.

Esso Resources Canada Ltd. was developing the Obed sour gas field (25% H_2S) near Edson, Alberta. Gas from the field was to be pipelined to the Chevron Standard Ltd.'s Kaybob III plant for processing. Production of sulfur from Obed sour gas was expected by the end of 1990 and would increase Kaybob III output by 300,000 to 350,000 tons per year.

Expansion of Petro-Canada Inc.'s Brazu River, Alberta, natural gas processing plant was essentially completed during 1989. The expansion tripled capacity at the facility to 100,000 tons per year.

Husky Oil Ltd. and Shell Canada Ltd. were seeking approval for their respective plans to develop the Caroline gas-condensate field near Sundre, Alberta. The Caroline was discovered by Shell, which heads a consortium that holds 80% of the rights to the natural gas reservoir; the field has been estimated to contain nearly 2 trillion cubic feet of sour natural gas (30% to 35% H_2S). The Alberta Province Energy Resources Conservation Board was to determine which of the two plans to accept in early 1990, and development of the field was expected to be completed during 1993.

Noranda Inc. completed construction of a 350,000-ton-per-year sulfuric acid plant at its Horne copper smelter in Rouyn-Noranda, Quebec. The acid

TABLE 20

WORLD SULFUR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989, RATED CAPACITY, SULFUR IN ALL FORMS[1]

(Thousand metric tons, sulfur content)

	Capacity
North America:	
Canada	8,400
United States	12,670
Total	21,070
Latin America:	
Brazil	500
Chile	440
Mexico	2,975
Other	675
Total	4,590
Europe:	
Belgium	400
Finland	620
France	1,850
Germany, Federal Republic of	2,451
Italy	760
Netherlands	350
Poland	5,350
Spain	1,550
Sweden	544
Turkey	613
United Kingdom	500
U.S.S.R.	11,500
Yugoslavia	750
Other	1,724
Total	28,962
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	680
Saudi Arabia	1,780
Other	1,400
Total	15,510
Oceania	330
World total	71,732

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

plant was to reduce SO_2 emissions from the smelter by more than 50%.

Inco Ltd. proceeded with engineering work at its Sudbury, Ontario, nickel smelter to reduce sulfur dioxide (SO_2) emissions. The company plans to construct two flash furnaces and an additional sulfuric acid plant by late 1991. Ore dressing circuits were to be revamped to maximize pyrrhotite rejection and reduce sulfur input to the furnaces. The overall projected, scheduled for completion by 1994, was designed to reduce SO_2 emissions by 60% and increase annual sulfuric acid output by 100,000 tons.

Chile

Corporación Nacional del Cobra de Chile was in the midst of expanding sulfuric acid production from its Chuquicamata copper smelter. Most of the acid was for processing Chuquicamata's oxide zone copper ore in a heap-leach, SX-EW system that was scheduled to recover 80,000 tons per year of copper by 1990.

Iraq

Sulfur exports increased to an estimated 600,000 tons; domestic consumption was about 400,000 tons. Production was increased at the Misraq Mine and from the Kurkuk gas plant. Expansion of water heating capacity, which was designed to double the Misraq mine's capacity to 2 million tons per year, began in 1989.

Mexico

Frasch sulfur production decreased slightly from 1988. 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 nearly 380,000 tons, which did not appear in official Mexican trade statistics. Most of these imports occurred by means of exchange agreements for deliveries of Mexican Frasch sulfur to the United States.

Morocco

Morocco was a major world importer of elemental sulfur because of consumption at its phosphate fertilizer facilities at Safi and Jorf Lasfar. Imports decreased from 2.9 million tons in 1988 to approximately 1 million tons in 1989. A major dispute concerning phosphoric acid prices and exports to India curtailed phosphoric acid production and the need for sulfur imports. In addition, several hundred thousand tons of sulfur that had been inventoried in 1988 were apparently consumed in 1989, which further reduced import requirements.

Poland

Sulfur exports decreased from 3.85 million tons in 1988 to 3.65 million tons. More than 1.9 million tons was shipped to Eastern Europe and 0.8 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 1989, 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 decreased substantially to 930,000 tons from 1.46 million tons in 1988. India received more than 50% of Saudi sulfur exports.

U.S.S.R.

Production of elemental sulfur decreased substantially because of reduced output from the Astrakhan natural gas processing plant. Technical problems and environmental concerns restricted the output from Astrakhan to 25% of capacity. Construction of the second phase to double the size of the Astrakhan facility was completed during the year. The second phase was not commissioned because of the problems plaguing the first phase. The engineering works for the first of three gas processing plants at the Tengiz oil-gas-condensate field near the northeast shore of the Caspian Sea were completed; each plant had a design annual sulfur capacity of 450,000 tons.

A Russian language journal[1], published in Moscow, described the U.S.S.R. sulfuric acid industry. U.S.S.R. sulfuric acid production grew from 12.1 million tons in 1970 to 29.4 million tons in 1988. The quantity produced from elemental sulfur represented 23.6% of output in 1970 and 63.5% in 1988. The quantity produced from pyrites decreased from 45.8% to 19.2% during the same time period. Metallurgical exhaust gases provided 23.2% of production in 1970 and 14.3% in 1988. Hydrogen sulfide, primarily at petroleum refineries, accounted for 7.2% and 3% in 1970 and 1988, respectively.

OUTLOOK

World sulfur demand, from 1990 to the year 2000, is forecast to increase at an annual rate of about 2% per year. World demand is projected to attain 65.5 million tons in 1995 and increase to over 72.5 million tons in the year 2000. In the short term, U.S. sulfur demand is forecast to decline from 12.7 million tons consumed in 1989; demand will probably decrease to 12.1 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 over 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, which is used to manufacture a spectrum of high-grade fertilizers; the acid itself may also be used for direct application to soil in order 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 sulfuric acid to soils, pesticide manufacture, and for animal feed supplements. Over 95% of U.S. agricultural sulfur demand and nearly 80% of world agricultural sulfur consumption was for the manufacture of phosphoric acid in 1989.

World demand for phosphate fertilizers is forecast to increase at a rate of 2.2% annually through 1995 and 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; (2) demand for exported phosphate fertilizers. In 1989, 4.66 million tons of sulfur were required to manufacture the phosphatic fertilizers exported from the United States compared to 3.98 million tons of sulfur for domestic phosphoric acid uses. Sulfur demand for domestically consumed phosphates is forecast to increase to nearly 4.6 million tons by 1995 and remain relatively stable thereafter. The export component is not expected to repeat the strong performance of 1989 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 nearly 30% of U.S. sulfur consumption and over 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 29 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 nearly 55 million tons. In 1989 these same sources supplied only 43% of world production of 58.3 million tons. Not only did the voluntary producers share of production decrease, the volume of output fell by 2.78 million tons or over 10%; U.S. Frasch production accounted for most of the drop, plunging from 6.39 million tons to 3.89 million tons. Additionally, world sulfur stocks fell from nearly 27 million tons to about 10 million tons during the period 1980 through 1989; over 16 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, 1990 through mid-1992, world sulfur demand will surpass output and that stocks will continue to decline. A temporary severe shortage could develop by late 1991. 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 gas field should increase Canadian capacity by 1.2 million tons in 1993. Expansion of the Misraq mine in Iraq should increase its output 500,000 tons by late 1992. The development of the Osiek mine in Poland should result in a net increase in Polish sulfur output of 100,000 tons by 1993. In the U.S.S.R., an 800,000-ton-per-year expansion at the Orenburg gas plant should be completed by late 1992. 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 to the estimated 700,000 tons produced at Astrakhan in 1989. Freeport plans to have its new Main Pass 299 mine on-stream by early 1992 and be producing at a rate of over 2 million tons per year by early 1993, increasing U.S. Frasch capability 1 million tons compared to 1989. Net additions to world production from expansions and new facilities at oil refineries and gas processing plants should amount to between 800,000 and 1 million tons by 1993. A worldwide sulfur surplus will probably develop in 1993, a surplus that could persist for much of the remainder of the century. World sulfur production will likely increase to 67 million tons in 1993, attain a level of 68 million tons in 1995, and exceed 72.5 million tons in the year 2000.

While the outlook for a substantial worldwide sulfur surplus in the mid-1990's can be amply justified, one may question the ability of some producers to get the product to the marketplace and also the ability to maintain production at the forecast levels. Because of the enormous size of the Astrakhan facility in the U.S.S.R., it has been, since the mid-1980's, the focus of considerable discourse among industry planners and consultants outside of the Soviet Union. All were trying to answer these questions: How much sulfur, if any, will there be? When and where will it be marketed, internally or exported? Can the needed transportation infrastructure be built and properly managed? The underlying reason for so much concern was that this single facility could put the world sulfur supply-demand balance into one of surplus or into deficit in the 1990's.

BACKGROUND

Sulfur, known as brimstone, "the stone that burns," was used in small quantities for thousands of years. Man was probably first drawn to native sulfur by its bright yellow color and pungent odor. Early man used sulfur as a colorant for cave drawings, as a fumigant, for medicinal purposes, and as

TABLE 21

U.S. SULFUR SUPPLY-DEMAND RELATION

(Thousand metric tons)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION[1]											
United States	12,101	11,866	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592
Rest of world	41,126	43,117	41,405	40,772	40,480	41,847	42,162	42,514	45,529	47,350	46,756
Total	53,227	54,983	53,550	50,559	49,770	52,499	53,771	53,601	56,068	58,096	58,348
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Production:											
Frasch mines	6,357	6,390	6,348	4,210	3,202	4,193	5,011	4,043	3,202	3,174	3,888
Recovered elemental:											
Natural gas processing	1,760	1,757	1,971	1,960	2,371	2,407	2,373	2,246	2,536	2,501	2,537
Petroleum refining	2,310	2,316	2,288	2,444	2,584	2,807	2,940	3,570	3,624	3,943	3,973
Other forms	1,674	1,403	1,538	1,173	1,133	1,245	1,285	1,228	1,176	1,128	1,194
Total all forms	12,101	11,866	12,145	9,787	9,290	10,652	11,609	11,087	10,539	10,746	11,592
Industry stocks, Jan. 1	5,345	4,239	3,056	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112
Imports	2,494	2,523	2,522	1,905	1,695	2,557	2,104	1,347	1,599	1,996	2,260
Total U.S. supply	19,940	18,628	17,723	15,238	15,203	16,432	16,132	15,233	14,886	15,058	14,964
Distribution of U.S. supply:											
Industry stocks, Dec. 31	4,239	3,094	3,546	4,218	3,223	2,419	2,799	2,748	2,316	1,112	1,301
Exports	2,044	1,782	1,392	961	992	1,334	1,365	1,895	1,242	1,223	1,024
Demand	13,739	13,659	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685
Apparent surplus (+), deficit (−) of supply[2]	−82	+93	—	—	—	—	—	+4	+5	+11	−46
U.S. DEMAND PATTERN											
Agriculture:											
Phosphoric acid	7,581	8,499	7,748	6,415	7,113	8,621	7,872	6,973	7,556	8,404	8,642
Other	561	634	659	566	703	603	686	683	642	598	431
Total	8,142	9,133	8,407	6,981	7,816	9,224	8,558	7,656	8,198	9,002	9,073
Drugs and food products	101	36	19	15	35	27	56	65	32	27	28
Soaps, detergents, and water treatment	323	228	284	287	257	167	215	249	204	221	200
Plastics and synthetic products	454	371	301	347	479	457	314	338	352	458	501
Paper products	372	348	302	267	262	295	286	266	294	288	328
Paints	343	257	149	178	128	113	111	119	118	122	138
Metal mining and processing	869	687	626	448	319	510	442	376	426	567	723
Explosives	19	13	14	15	20	39	31	30	49	44	17
Petroleum refining	875	1,023	1,230	935	819	954	913	947	973	958	825
Iron and steel production	288	103	88	86	94	88	69	69	67	74	59
Storage batteries (acid)	51	34	57	53	58	58	67	50	41	51	46
Other	1,902	1,426	1,308	447	701	747	906	421	569	900	747
Total industrial demand	5,597	4,526	4,378	3,078	3,172	3,455	3,410	2,930	3,125	3,710	3,612
Total U.S. primary demand	13,739	13,659	12,785	10,059	10,988	12,679	11,968	10,586	11,323	12,712	12,685

[1] Sulfur in all forms.

[2] The difference between total U.S. distribution of supply and total U.S. supply.

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 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.

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 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 man's 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 onwards, 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 1989, world sulfur production and consumption amounted to 58.3 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 over 1.2 million tons 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.

Economic Factors

Prices.—Over the past 20 years, world sulfur price leadership has shifted from dominance by the U.S. Frasch producers to the Canadian exporters. The transfer was aided in the 1980's by Canada's ability to export most of its production from the port of Vancouver and by its willingness to ship large volumes of sulfur from vatted stocks. The maturation of Sultran Ltd., dealing almost exclusively with sulfur destined for the offshore market, into a well organized and skilled transportation arm of the Canadian sulfur industry, aided immeasurably in Canada's ascension to world price leadership.

In the United States, the quoted liquid Frasch sulfur price, f.o.b. terminal Tampa, FL, is the benchmark price. Recovered sulfur producers, in many cases, consider the economic desirability of producing sulfur subordinate to the necessity of producing it. As a result, domestic recovered elemental sulfur producers normally offer sulfur at a price $5 to $15 per ton below the Tampa quote to ensure prompt sale and reduce storage costs. This marketing strategy has re-

TABLE 22

TIME-PRICE RELATION FOR SULFUR[1]

Year	Actual prices	Based on constant 1988 dollars
1970	22.17	65.76
1971	17.19	46.96
1972	16.76	43.72
1973	17.56	43.03
1974	28.42	63.84
1975	44.91	91.86
1976	45.72	87.89
1977	44.38	79.99
1978	45.17	75.89
1979	55.75	86.04
1980	89.06	126.06
1981	111.48	143.86
1982	108.27	131.33
1983	87.24	101.25
1984	94.31	106.22
1985	106.46	116.44
1986	105.22	112.15
1987	89.78	92.76
1988	85.95	85.95
1989	86.62	83.19

[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 1970-89.

TABLE 23

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1985	1986	1987	1988[p]	1989[e]
Algeria: Byproduct, natural gas and petroleum[e]	20	20	20	20	20
Australia:					
Byproduct:					
Metallurgy	190	174	194	[e]200	200
Petroleum	12	10	9	[e]9	10
Total	202	184	203	[e]209	210
Austria:					
Byproduct:					
Metallurgy	11	11	10	11	12
Natural gas and petroleum	24	29	25	36	36
Gypsum	27	24	13	([4])	—
Total[5]	62	64	48	48	48
Bahamas: Byproduct, petroleum[e]	1	—	—	—	—
Bahrain: Byproduct, petroleum	36	46	48	48	48
Belgium: Byproduct, all sources[e]	260	300	300	310	320
Bolivia: Native	3	5	9	7	[6]8
Brazil:					
Frasch	4	6	6	6	6
Pyrites	91	92	77	103	100
Byproduct:					
Metallurgy	79	100	153	152	155
Petroleum	55	74	77	61	70
Total	229	272	313	322	331
Bulgaria:[e]					
Pyrites	65	80	80	70	70
Byproduct, all sources	53	62	65	60	60
Total	118	142	145	130	130
Canada:					
Byproduct:					
Metallurgy	822	[r]873	783	856	831
Natural gas	5,306	5,161	5,268	5,437	5,153
Petroleum[e]	[r]125	[r]129	[r]142	[r]152	150
Tar sands	392	[r]424	426	485	[6]491
Total[e]	[r]6,645	[r]6,587	[r]6,619	[r]6,930	6,625
Chile:					
Native:					
Refined	15	13	15	17	16
From caliche	64	44	22	21	20
Byproduct, metallurgy	[r]120	[r]120	130	140	230
Total	[r]199	[r]177	167	178	266
China:[e]					
Native	300	300	300	300	300
Pyrites	2,200	2,500	3,700	3,900	4,000
Byproduct, all sources	400	300	500	550	600
Total	2,900	3,100	4,500	4,750	4,900
Colombia:					
Native	41	36	41	43	40
Byproduct, petroleum	10	[e]10	[e]10	8	8
Total	51	[e]46	[e]51	51	48

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]	1985	1986	1987	1988[p]	1989[e]
Cuba: Byproduct, petroleum[e]	5	5	5	5	5
Cyprus:[7] Pyrites	31	25	41	51	52
Czechoslovakia:[e]					
Native	[6]6	6	6	6	6
Pyrites	[6]62	60	60	60	60
Byproduct, all sources	[6]12	10	11	11	11
Total	[6]80	76	77	77	77
Denmark: Byproduct, petroleum	7	13	18	19	20
Ecuador:[e]					
Native	4	4	5	5	4
Byproduct:					
Natural gas	5	5	5	5	5
Petroleum	5	5	5	5	5
Total	14	14	15	15	14
Egypt: Byproduct, natural gas and petroleum[e]	7	7	8	8	8
Finland:					
Pyrites	248	275	311	[e]300	300
Byproduct:					
Metallurgy[e]	[6]257	260	220	240	240
Petroleum	45	42	[e]40	47	45
Total	550	577	[e]571	[r e]587	585
France:					
Byproduct:					
Natural gas	1,386	946	872	762	[6]636
Petroleum[e]	160	180	200	[r]226	235
Unspecified[e]	177	180	180	180	180
Total	1,723	1,306	[e]1,252	1,168	1,051
German Democratic Republic: Byproduct, all sources[e]	330	315	315	315	290
Germany, Federal Republic of:					
Byproduct:					
Metallurgy[e 8]	320	300	300	310	315
Natural gas	964	998	1,030	[e]1,000	1,050
Petroleum[e]	200	190	210	205	210
Unspecified[e]	285	285	285	280	310
Total[e]	1,769	1,773	1,825	1,795	1,885
Greece:[e]					
Pyrites	78	66	70	72	70
Byproduct:					
Natural gas	130	130	130	130	105
Petroleum	5	5	5	5	5
Total	213	201	205	207	180
Hungary:[e]					
Pyrites	2	1	1	1	1
Byproduct, all sources	9	10	10	10	10
Total	11	11	11	11	11

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]	1985	1986	1987	1988[p]	1989[e]
India:					
Pyrites	7	8	14	12	14
Byproduct:					
Metallurgy[e]	120	120	120	125	125
Petroleum	(9)	[e]1	—	[e]1	5
Total[e]	127	129	[r]134	[r]138	144
Indonesia:[7] Native	4	5	4	3	4
Iran:[e]					
Native	30	30	30	30	30
Byproduct, natural gas and petroleum	150	250	300	300	300
Total	180	280	330	330	330
Iraq:[e]					
Frasch	500	600	707	700	900
Byproduct, natural gas and petroleum	70	200	250	350	370
Total	570	800	[6]957	1,050	1,270
Israel: Byproduct, natural gas and petroleum	25	29	40	[e]50	50
Italy:					
Native	1	—	—	—	—
Pyrites	280	309	330	[r e]330	330
Byproduct, all sources[e 10]	[r]240	[r]370	[r]410	[r]500	500
Total[e]	[r]521	[r]679	[r]740	[r]830	830
Japan:					
Pyrites	253	158	79	70	63
Byproduct:					
Metallurgy	1,201	1,228	1,225	[e]1,300	1,300
Petroleum	1,044	985	1,012	1,077	[6]1,160
Total	2,498	2,371	2,316	[e]2,447	2,523
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	35	36
Total	90	90	90	90	91
Kuwait: Byproduct, natural gas and petroleum[e]	[6]238	260	310	360	575
Libya: Byproduct, natural gas and petroleum[e]	14	14	14	14	14
Mexico:					
Frasch	1,551	1,588	1,806	1,628	[6]1,531
Byproduct:					
Metallurgy[e]	[r]120	[r]134	[r]154	[r]240	280
Natural gas and petroleum	469	462	498	510	[6]556
Total[e]	[r]2,140	[r]2,184	[r]2,458	[r]2,378	2,367
Namibia: Pyrites	108	134	74	135	130
Netherlands: Byproduct, petroleum[e]	250	250	245	245	250
Netherlands Antilles: Byproduct, petroleum[e]	25	40	60	60	60
New Zealand: Byproduct, all sources	1	[e]1	[e]1	4	4

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]	1985	1986	1987	1988[p]	1989[e]
Norway:					
Pyrites	193	181	179	[e]170	170
Byproduct:					
Metallurgy	60	67	[e]80	[e]80	80
Petroleum[e]	[6]10	13	15	10	10
Total	263	261	[e]274	[e]260	260
Oman: Pyrites[e]	[r]14	[r]16	[r]17	[r]17	17
Pakistan:					
Native	1	1	1	1	1
Byproduct, all sources[e]	26	26	26	[r]25	25
Total[e]	27	27	27	[r]26	26
Peru:					
Native	(7)	(7)	(7)	(7)	(7)
Byproduct, all sources[e]	[6]68	66	66	66	66
Total[e]	[6]68	66	66	66	66
Philippines:					
Pyrites	108	113	158	[e]160	195
Byproduct, metallurgy[e]	100	120	140	150	185
Total[e]	208	233	298	310	380
Poland:[11]					
Frasch	4,326	4,437	4,410	[e]4,400	4,400
Native	657	550	694	[e]500	500
Metallurgy	170	170	170	150	150
Petroleum	30	30	30	20	20
Gypsum[e]	20	20	20	20	20
Total[e]	5,203	5,207	5,324	5,090	5,090
Portugal:					
Pyrites	155	144	[e]140	[r e]120	120
Byproduct, all sources[e]	5	5	5	5	5
Total[e]	160	149	145	[r]125	125
Qatar: Byproduct, natural gas	37	49	53	[r e]54	55
Romania:[e]					
Pyrites	200	150	150	150	150
Byproduct, all sources	150	140	130	120	120
Total	350	290	280	270	270
Saudi Arabia: Byproduct, natural gas and petroleum	1,100	1,446	1,432	1,450	1,400
Singapore: Byproduct, petroleum[e]	50	50	50	50	55
South Africa, Republic of:					
Pyrites	562	499	468	[e]470	470
Byproduct:					
Metallurgy	85	[e]108	105	[e]110	110
Petroleum[e 12]	100	110	110	120	120
Total[e]	747	717	683	700	700

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]	1985	1986	1987	1988[p]	1989[e]
Spain:					
Pyrites	1,231	1,195	960	[e]1,100	1,000
Byproduct:[e]					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	215	210	225	230	225
Petroleum	7	8	8	8	8
Total[e]	1,455	1,415	1,195	1,340	1,235
Sweden:					
Pyrites	210	227	[e]220	200	225
Byproduct:					
Metallurgy	123	125	[e]125	125	125
Petroleum	23	49	[e]50	45	50
Total	356	401	[e]395	370	400
Switzerland: Byproduct, petroleum	3	3	4	[e]4	4
Syria: Byproduct, natural gas and petroleum[e]	35	35	40	40	40
Taiwan: Byproduct, all sources	43	63	89	86	75
Trinidad and Tobago: Byproduct, petroleum[e]	([6 9])	5	5	5	5
Turkey:					
Native	44	41	39	33	20
Pyrites	11	4	22	[r e]25	25
Byproduct, all sources[e]	80	80	80	80	80
Total[e 5]	135	126	[r]141	[r]138	125
U.S.S.R.:[e]					
Frasch	960	1,100	1,100	1,100	1,100
Native	1,800	1,900	1,900	1,900	1,800
Pyrites	2,421	2,090	2,150	2,150	2,150
Byproduct:					
Metallurgy	[r]1,025	[r]1,050	[r]1,250	[r]1,375	1,350
Natural gas	[6]1,974	[r]1,625	[r]2,400	[r]3,290	2,500
Petroleum	350	400	450	450	450
Total	[r]8,530	[r]8,165	[r]9,250	[r]10,265	9,350
United Arab Emirates: Abu Dhabi:[e]					
Byproduct:					
Natural gas	104	104	97	[r]146	150
Petroleum	1	11	8	[r]19	25
Total	105	115	105	[r]165	175
United Kingdom:					
Byproduct:					
Metallurgy	69	[r]58	51	55	55
Petroleum	80	105	119	129	130
Total	149	[r]163	170	184	185
United States:					
Frasch	5,011	4,043	3,202	3,174	[6]3,888
Pyrites	W	W	W	W	W
Byproduct:					
Metallurgy	957	919	1,003	1,125	[6]1,190
Natural gas	2,373	2,246	2,536	2,501	[6]2,537
Petroleum	2,940	3,570	3,624	3,943	[6]3,973
Unspecified	328	309	173	3	[6]4
Total	11,609	11,087	10,538	10,746	11,592

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]	1985	1986	1987	1988[p]	1989[e]
Uruguay: Byproduct, petroleum[e]	2	2	2	2	2
Venezuela: Byproduct, natural gas and petroleum	88	99	[e]125	125	125
Yugoslavia:					
Pyrites and pyrrhotite	[r]218	[r]320	258	252	255
Byproduct:[e]					
Metallurgy	170	175	175	170	170
Petroleum	3	3	3	3	3
Total[e]	[r]391	[r]498	[r]436	[r]425	428
Zaire: Byproduct, metallurgy[e]	36	[r]39	[r]35	[r]35	35
Zambia:					
Pyrites	[r]12	[r]8	19	27	29
Byproduct, metallurgy[e]	79	74	74	74	74
Total[e]	[r]91	[r]82	[r]93	[r]101	103
Zimbabwe:[e]					
Pyrites	25	25	[r]21	[r]18	18
Byproduct, all sources	5	5	5	5	5
Total	30	30	[r]26	[r]23	23
Grand total[5]	[r]53,771	[r]53,601	56,068	58,096	58,348
Of which:					
Frasch	12,352	11,774	11,230	11,008	11,825
Native	2,970	2,935	3,066	2,865	2,749
Pyrites	[r]8,985	[r]8,881	9,800	10,163	10,214
Byproduct:					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	[r]6,414	[r]6,519	6,807	7,338	7,521
Natural gas	12,279	[r]11,264	12,392	13,325	12,191
Natural gas and petroleum, undifferentiated	2,240	[r]2,852	3,062	3,263	3,494
Petroleum	[r]5,618	[r]6,379	6,599	7,015	7,176
Tar sands	392	[r]424	426	485	491
Unspecified sources	[r]2,472	[r]2,527	2,651	2,611	2,665
Gypsum	47	44	33	20	20

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Byproduct: Unspecified sources."

[1]Table includes data available through May 16, 1990.

[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 People's Democratic 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]Revised to zero.

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

[6]Reported figure.

[7]In addition, may produce limited quantities of byproduct sulfur from oil refining.

[8]Includes only the elemental sulfur equivalent of sulfuric acid produced as a byproduct from metallurgical furnaces; additional output may be included under "Byproduct: Unspecified sources."

[9]Less than 1/2 unit.

[10]Includes recovery from gypsum, if any.

[11]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.

[12]Estimates for 1985–89 include byproduct production from synthetic fuels.

sulted 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 to its prior history (see figure 1.). The worldwide recession of 1982 and the U.S. Department of Agriculture PIK 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 nearly $37 during the same time period. Tampa prices were stable for about a 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 nearly $10 per ton. The price of sulfur decreased rapidly in mid-1989, as recounted earlier.

[1] Vasilyev, B. T., V. S. Sushev, Yu. V. Filatov, and V. M. Borisov. Current Status and Future Prospects for the Development of Sulfuric Acid Production in the U.S.S.R. KHIMICHESKAYA INDUSTRIYA, No. 11, Nov. 1989, pp. 817–823.

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TALC AND PYROPHYLLITE

By Robert L. Virta

Mr. Virta, a physical scientist with 14 years 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 Peter Roetzel, international data coordinator.

Domestic production of talc and pyrophyllite increased slightly from that of 1988 to 1,253,128 metric tons. Sales of crude and processed talc and pyrophyllite increased 10% to 1,145,097 tons and decreased slightly in value. Imports for consumption decreased 2% to 77,716 tons and decreased slightly in value to $12,128,000. Exports increased 23% in tonnage to 319,329 tons and 35% in value to $28,949,000. Over the past 10 years, talc and pyrophyllite production averaged 1,135,000 tons; sales, 1,071,000 tons; domestic consumption, 940,000 tons; exports, 243,000 tons; and imports, 44,000 tons. The major use for talc was in ceramics, which accounted for 32% of the domestic consumption, followed by paint, 15%; paper, 14%; roofing, 10%; plastics, 10%; and other, 19%. The major use for pyrophyllite was in ceramics, which accounted for 60% of the market followed by refractories, 18%; insecticides, 9%; and other, 13%.

DOMESTIC DATA COVERAGE

Domestic production and sales data for talc and pyrophyllite are developed by the Bureau of Mines from a voluntary survey of U.S. mines and mills. Survey forms were sent to 19 companies that operated 55 mines and mills. Fifteen companies that account for approximately 58% of the domestic production responded to the survey. Production data for one nonrespondent were obtained from a company annual report. Data for two nonrespondents that accounted for approximately 5% of the domestic production were estimated from reported prior-year production levels adjusted by trends in employment and other guidelines. Beginning in 1989, production and trade data for talc and pyrophyllite will be reported in metric units.

LEGISLATION AND GOVERNMENT PROGRAMS

The Occupational Safety and Health Administration (OSHA) extended through November 30, 1990, an administrative stay on its 1986 regulation governing worker exposure to the nonasbestiform varieties of actinolite, anthophyllite, and tremolite. 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 2 fibers per cubic centimeter will remain in effect during the stay.[1]

TABLE 1

SALIENT TALC AND PYROPHYLLITE STATISTICS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Mine production, crude:					
Talc	1,078	1,106	1,080	r1,136	1,172
Pyrophyllite	73	75	83	97	81
Total[1]	1,151	1,181	1,163	r1,234	1,253
Value:					
Talc	$27,768	$29,687	$27,265	r$29,364	$27,731
Pyrophyllite	1,420	1,540	1,607	1,820	W
Total	29,188	31,227	28,872	r31,185	2,27,731
Sold by producers, crude and processed:					
Talc	968	971	975	r940	1,065
Pyrophyllite	73	75	82	93	79
Total[1]	1,041	1,046	1,057	r1,033	1,145
Value:					
Talc	$114,542	$111,924	$113,394	r$115,899	$114,453
Pyrophyllite	3,273	3,366	3,712	r4,164	W
Total[1]	117,815	115,290	117,107	r120,063	2114,453
Exports[3] (talc)	215	212	r255	r260	319
Value	$14,282	$16,302	r$19,607	r$21,391	$28,949
Imports for consumption (talc)	43	47	48	80	78
Value	$9,532	$8,715	$10,348	$12,268	$12,128
Apparent consumption[4]	979	1,016	956	1,054	1,012
World: Production	r7,828	r7,697	7,804	p7,991	e7,980

e Estimated. p Preliminary. r Revised. W Withheld to avoid disclosing company proprietary data.

[1] Data may not add to total 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 changes. Does not include imported pyrophyllite.

OSHA revised its standards for exposures to talc and soapstone. The permissible 8-hour time weighted average exposure limit is 2.0 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.[2]

The Mine Safety and Health Administration proposed revisions to its air quality, chemical substances, and respiratory protection standards. The proposed permissible 8-hour time weighted average exposure limit is 2.5 mg/m^3 for talc (containing no asbestos), 3 mg/m^3 for respirable soapstone, and 6 mg/m^3 for total soapstone dust. The nonasbestiform varieties of tremolite, anthophyllite, and actinolite would be covered under the proposed respirable mine dust standard.[3]

ISSUES

The question of whether or not the nonasbestiform varieties of tremolite, anthophyllite, and actinolite pose a health risk continued to concern a portion of the talc industry. OSHA maintains that although nonasbestiform amphiboles may not pose as great a health risk as asbestos, the risk posed is great enough to warrant their regulation. Industry representatives believe that there are insufficient data to demonstrate a health risk and that a regulation is not required. Much of the controversy surrounds the choice of study and control populations, the mineralogy and concentration of airborne dusts at the time of exposure, prior worker exposure to carcinogens, and smoking patterns.

PRODUCTION

Talc

Fourteen companies, operating 23 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-Tile Inc. (Texas Talc), 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.

U.S. mine production of crude talc increased 3% in tonnage and decreased 6% in value. Mines that operated in Montana, New York, Texas, and Vermont accounted for 94% of domestic talc production. Montana led all States in the tonnage and value of talc produced.

Pfizer Inc. finalized plans and began construction of a talc beneficiation plant in Montana. The company will use flotation processing to remove impurities from the ore. The flotation process will permit the company to recover talc from pond tailings, mill rejects, and ore stockpiles and compete in markets that it did not previously service.[4]

Pyrophyllite

Pyrophyllite was produced by four companies operating five 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 bulldozers and scrapers or extracted using conventional open pit mining techniques. The ore was dried and then jaw crushers and gyratory crushers were used to reduce the size of the mill feed. Ball, pebble, or roller mills were used to produce the final product.

U.S. mine production of crude pyrophyllite decreased 17% in tonnage due primarily to the closure of one mine in North Carolina. North Caro-

TABLE 2

CRUDE TALC AND PYROPHYLLITE PRODUCED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1988		1989	
	Quantity	Value	Quantity	Value
Georgia (talc)	24	260	26	W
Montana (talc)	r415	r14,524	454	12,717
Texas (talc)	237	4,466	242	4,564
Other[1]	r558	r11,934	528	[2]10,338
Total[3]	r1,234	r31,185	1,253	[2]27,731

r Revised. W Withheld to avoid disclosing proprietary data; included under "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.

lina accounted for most of the domestic production.

CONSUMPTION AND USES

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.

U. S. consumption of talc increased 7% in 1989. The major consumer of talc was the construction industry, with applications in ceramic tiles and sanitary ware, joint compounds, paint, plastics, and roofing. The end-use distribution was ceramics, 32%; paint, 15%; paper, 14%; roofing, 10%; plastics, 10%; cosmetics, 5%; and insecticides, refractories, rubber, and other, 14%.

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 decreased 11% in tonnage in 1989. The largest portion, 60% of domestically produced ground pyrophyllite, was used in ceramics; 18% in refractories, 9% in insecticides, and 13% in paint, plastics, roofing, rubber, and other.

PRICES

Talc prices varied depending on the quality and on the degree and method of processing. The unit value of crude talc was $23 per ton. The average unit value of processed talc was $107 per ton. The average unit values of crude and processed pyrophyllite were slightly higher in 1989 than in 1988. Unit values for imported crude and ground talc ranged from $62 per ton to $278 per ton for quantities greater than 1,000 tons. The average unit value for all imported talc was $157 per ton. Unit values for exported talc ranged from $17 per ton to $162 per ton for quantities greater than 1,000 tons and averaged $90 per ton for all exports.

Prices, quoted by the American Paint & Coatings Journal, December 26, 1989, in U.S. dollars per metric ton for paint-grade talc in carload lots were as follows:

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

Approximate equivalents, in dollars per metric ton, of price ranges quoted in Industrial Minerals (London), December 1989, for talc, c.i.f. main European ports, were as follows:

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

TABLE 3

END USES FOR GROUND TALC AND PYROPHYLLITE

(Thousand metric tons)

Use	1988			1989		
	Talc[r]	Pyrophyllite	Total[r 1]	Talc	Pyrophyllite	Total[1]
Ceramics	279	73	354	308	70	377
Cosmetics[2]	44	—	44	50	—	50
Insecticides	1	9	10	—	11	11
Paint	131	—	131	143	—	143
Paper	125	—	125	138	5	143
Plastics	93	4	97	97	1	98
Refractories	1	18	19	1	21	21
Roofing	95	1	96	97	—	97
Rubber	18	(3)	19	20	(3)	21
Other[4]	81	27	107	100	10	109
Total[1]	868	[5]132	[5]1,001	953	[5]117	[5]1,070

[r]Revised.
[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.

FOREIGN TRADE

Beginning in 1989, the U. S. Bureau of the Census adopted the Harmonized System for reporting commodity imports and exports. Talc export categories under the Harmonized System were unchanged from those of previous years. All talc imports under the Harmonized System will be reported as crude, ground, or cut. The category "Talc, n.s.p.f." was discontinued.

Talc exports increased 23% in tonnage and 35% in value. Mexico remained the largest importer of talc, followed by Canada, Japan, and Belgium-Luxembourg. Talc imports decreased 2% in tonnage and 1% in value. Australia and Canada provided 77% of all talc imports.

TABLE 4

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
1985	5	373	73	4,864	16	1,422	98	4,492	22	3,131	215	14,282
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	r101	r4,182	47	5,538	r255	r19,607
1988	r27	r3,942	62	5,079	r30	r3,849	r97	r3,225	44	5,296	r260	r21,391
1989	30	4,766	81	5,614	35	4,710	107	6,601	65	7,258	319	28,949

r Revised.

[1] Excludes powders—talcum (in package), face, and compact.

[2] Probably includes shipments in transit through Canadian ports.

[3] Includes 55 countries in 1989.

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

Source: Bureau of the Census.

TABLE 5

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)
1987:	9,166	$916	36,999	$6,112	2,120	$2,017	$1,304	48,285	$10,348
1988:									
Australia	18,254	1,468	20	2	—	—	—	18,274	1,470
Brazil	—	—	493	88	185	59	36	678	184
Canada	365	36	42,007	6,384	100	149	40	42,472	6,609
China	8,279	599	—	—	697	435	342	8,976	1,376
Italy	630	95	736	330	17	24	66	1,383	515
Korea, Republic of	—	—	1,738	402	17	13	2	1,755	418
Other[2]	4,461	419	1,227	473	166	200	604	5,854	1,696
Total[1]	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	6,954
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[3]	4,084	533	2,871	881	188	695	NA	7,143	2,109
Total	16,416	1,460	60,115	9,265	1,185	1,404	NA	77,716	12,128

NA Not available.

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

[2] Includes 21 countries.

[3] Includes 19 countries.

Source: Bureau of the Census.

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 44% of the world's talc and pyrophyllite production.

Capacity

The data in table 6 are annual rated capacity for mines and refineries as of December 31, 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.

Austria

Talkumwerke Naintsch Ges.mbH, Osterreichische Talkumindustrie Ges.-mbH., and Naintsch Mineralwerke Ges.-mbH were reorganized as Naintsch Mineralwerke Ges.mbH. With the consolidation of these companies, Naintsch Mineralwerke Ges.mbH is the only operator in the Rabenwald talc district. Three mines and mills will be operated for a total production capacity of 150,000 tons per year. Markets include bitumen, ceramics, paints, paper, and plastics.[5]

China

The United Nations Fund for Natural Resources Exploration signed an agreement with China to explore for pyrophyllite deposits in Fujian province. The project will entail geological mapping, trenching and pitting, drilling, and sampling. Previous work indicated reserves of 19 million tons of pyrophyllite in the province.[6]

United Kingdom

The Shetland Islands Council granted permission to Shetland Talc Ltd. to begin mining a talc-magnesite deposit at Cunningsburgh. The deposit contains 19,000 tons of rock with a composition of 95% talc and whiteness of 90 to 92. Shetland Talc is a joint venture between Anglo-European Minerals Ltd. and Dalriada Mineral Ventures Ltd.[7]

TABLE 6

WORLD TALC AND PYROPHYLLITE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(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	181
Korea, Republic of	998
Other	82
Total	4,559
Oceania:	
Australia	227
World total	8,990

[1] Includes capacities of operating plants as well as plants on standby basis.

OUTLOOK

The average annual growth in domestic demand for talc and pyrophyllite was 1.4% between 1970 and 1989 and 0.4% between 1980 and 1989. 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 descending order. For pyrophyllite, the major domestic end uses will continue to be in ceramics and refractories.

[1] Federal Register. Occupational Safety and Health Administration (Dept. of Labor). Occupational Exposure to Asbestos, Tremolite, Anthophyllite, and Actinolite. V. 54, No. 139, July 21, 1989, pp. 30704–30705.

[2] ———. Occupational Safety and Health Administration (Dept. of Labor). Air Contaminants. V. 54, No. 12, Jan. 19, 1989, pp. 2332–2772.

[3] ———. Mine Safety and Health Administration (Dept. of Labor). Air Quality, Chemical Substances, and Respiratory Protection Standards. V. 54, No. 166, Aug. 29, 1989, pp. 35766–35852.

[4] Backus, P. Talc Firm Planning $8.5 Million Project. Montana (Butte) Standard, Aug. 4, 1989.

[5] Industrial Minerals (London). Talc Companies Consolidate. No. 266, Nov. 1989, pp. 8–9.

[6] ———. UN Pyrophyllite Search. No. 257, Feb. 1989, p. 11.

[7] ———. Go Ahead for Shetland Talc. No. 270, Mar. 1990, p. 147.

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TABLE 7

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina:					
Pyrophyllite	2,785	2,812	1,260	671	1,000
Steatite[e]	[3]280	300	300	250	250
Talc	15,944	22,353	27,103	26,028	25,000
Australia:					
Pyrophyllite	7,317	8,588	6,036	5,750	5,000
Talc	132,074	179,467	206,865	199,631	195,000
Austria: Steatite	131,454	133,319	129,959	132,974	135,000
Brazil:[4]					
Algomatolite	106,152	131,036	104,536	[e]120,000	120,000
Pyrophyllite	81,910	87,250	51,114	[e]75,000	75,000
Talc	356,333	336,706	425,513	[e]425,000	425,000
Burma: Steatite	128	56	22	[e]25	28
Canada (shipments): Pyrophyllite, soapstone, talc	126,860	123,037	141,223	134,000	[3]143,000
Chile: Talc	1,299	2,257	980	1,070	1,000
China: Unspecified[e]	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Colombia: Pyrophyllite, soapstone, talc	8,611	9,013	11,927	12,800	13,000
Egypt: Pyropyllite, talc, soapstone, steatite	7,700	8,800	[e]6,600	7,268	7,000
Finland: Talc	318,547	284,179	319,000	379,000	380,000
France: Talc	310,897	314,965	[e]328,800	[e]330,000	340,000
Germany, Federal Republic of: Talc (marketable)	20,716	21,884	19,785	[e]20,000	19,000
Greece: Steatite	1,725	17,310	1,507	[e]1,600	1,600
Hungary: Talc[e]	17,000	16,000	15,000	13,000	12,000
India:					
Pyrophyllite	53,741	53,005	51,724	58,789	60,000
Steatite	329,192	343,000	359,448	382,000	385,000
Iran: Talc[e]	[3]30,800	31,000	31,000	31,000	30,000
Italy: Steatite and talc	[r]132,614	151,206	150,718	158,722	155,000
Japan:					
Pyrophyllite	1,355,625	1,270,112	1,241,069	1,244,491	1,231,300
Talc	78,616	63,851	55,899	49,213	54,500
Korea, North: Unspecified[e]	170,000	170,000	170,000	170,000	170,000
Korea, Republic of:					
Pyrophyllite	738,304	587,049	690,819	673,776	640,000
Talc	194,174	210,631	161,052	146,478	160,000
Mexico: Talc	29,900	24,301	17,469	18,320	20,000
Nepal: Talc[5]	6,015	8,780	3,539	4,430	5,000
Norway: Talc[e]	100,000	100,000	100,000	100,000	100,000
Pakistan: Pyrophyllite	20,183	23,021	23,278	37,429	30,000
Paraguay: Unspecified	120	[r]130	180	150	[3]200
Peru:					
Pyrophyllite	—	7,354	705	[e]1,000	750
Talc	500	1,754	1,447	[e]1,500	1,250
Philippines: Talc	345	[e]1,000	—	—	—
Portugal: Talc	3,607	4,141	7,292	7,187	7,200
Romania: Talc[e]	65,000	65,000	65,000	65,000	60,000
South Africa, Republic of:					
Pyrophyllite	4,227	4,606	3,467	3,162	3,000
Talc	10,220	8,641	8,005	10,111	10,500

See footnotes at end of table.

TABLE 7—Continued

TALC AND PYROPHYLLITE: WORLD PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Spain: Steatite	88,776	81,476	75,307	[r e]80,000	80,000
Sweden: Talc and steatite	[r]14,400	[r]11,233	16,981	[r e]16,000	16,000
Taiwan: Talc	17,560	21,552	22,102	21,603	20,000
Thailand:					
Pyrophyllite	42,002	36,165	37,749	37,285	38,000
Talc	1,476	2,886	4,101	4,843	5,000
U.S.S.R.: Talc[e]	520,000	520,000	530,000	530,000	530,000
United Kingdom: Talc	20,000	[r]12,352	12,529	14,182	14,000
United States:					
Pyrophyllite	73,000	75,000	83,000	97,000	[3]81,301
Talc	1,078,000	1,106,000	1,080,000	1,140,284	[3]1,171,871
Uruguay: Talc	1,308	1,255	1,648	[e]1,600	1,600
Zambia: Talc	449	266	258	73	200
Zimbabwe: Talc	437	797	516	976	900
Total	[r]7,828,323	[r]7,696,896	7,803,832	7,990,671	7,980,450

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Table includes data available through May 11, 1990.

[2] In addition to the countries listed, Czechoslovakia and Turkey produce talc, but available information is inadequate to make reliable estimates of output levels.

[3] Reported figure.

[4] Total of beneficiated production, salable direct shipping production, and that consumed by consumers.

[5] Data based on Nepalese fiscal year beginning mid-July of year stated.

THALLIUM

By Thomas O. Llewellyn

Mr. Thomas O. Llewellyn is a physical scientist with the Branch of Nonferrous Metals. He has covered thallium for 3 years. Domestic survey data were prepared by Lura Nightlinger, Nonferrous Metals Data Section.

In 1989, domestic demand for thallium metal was met by imports.

Thallium is a trace element with an estimated average abundance of 2.2 parts per million in zinc sulfide ores, and is a byproduct recovered from flue dust and residues collected in the smelting of zinc as well as copper and lead ores. There are a number of rare thallium minerals found in nature, which have no commercial importance as sources of thallium metal.

CONSUMPTION AND USES

Based on import data and discussions with metal traders, the domestic consumption of thallium in 1989 was estimated to be 950 kilograms, about 5% higher than 1988. 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. Very few foreign countries used thallium sulfate as an ingredient in rodenticide. These countries were in the process of banning its use for such purposes because of its high toxicity to humans.

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 ranged from $170 per kilogram for 99.9%-pure thallium metal to about $230 per kilogram for 99.999%-pure metal. The average value per kilogram of unwrought thallium metal and waste and scrap imported into the United States was estimated to be about $105 per kilogram.

FOREIGN TRADE

Thallium materials were imported from Belgium, the Federal Republic of Germany, and Japan. Belgium remained the principal source of imported material and increased its share of total U.S. thallium imports from 72% in 1988 to approximately 95% in 1989.

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.

TABLE 1

U.S. IMPORTS FOR CONSUMPTION OF THALLIUM,[1] BY COUNTRY

Country	Compounds			Unwrought and waste and scrap	
	Gross weight (kilograms)	Content[2] (kilograms)	Value	Gross weight (kilograms)	Value
1988:					
Belgium	250	200	$36,955	306	$38,409
Germany, Federal Republic of	77	61	10,898	—	—
Japan	175	140	11,372	—	—
Total	502	401	59,225	306	38,409
1989:[3]					
Belgium	—	—	—	1,135	116,402
Germany, Federal Republic of	—	—	—	15	3,104
Japan	—	—	—	23	3,895
Total	—	—	—	1,173	123,401

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable to those in 1988.
[2] Estimated by the Bureau of Mines.
[3] Beginning in 1989, only data for unwrought and waste and scrap are available.

Source: Bureau of the Census.

WORLD REVIEW

Reserves

World production data for thallium were not available. The U.S. reserves in zinc ores were estimated to be 32,000 kilograms. Rest-of-world reserves were estimated to be 345,000 kilograms of thallium.

OUTLOOK

In the short-term, the United States is not expected to resume recovery of refined thallium. The toxicity of thallium is the factor that was expected to continue to influence domestic dependence on foreign sources for its supply.

BACKGROUND

Technology

In February 1988, University of Arkansas scientists were the first to report the use of thallium in bulk superconductor formulations. Superconductors are materials that have no resistance to electric currents, when they are cooled to a sufficiently low temperature, called the critical temperature. Current low-temperature superconductors, principally made from alloys of the metals niobium and titanium, become superconductors when chilled to a liquid-helium temperature of about 4 K (-269° C). The critical temperature of the thallium-based superconductors were among the highest of superconductors developed.

In 1989, scientists at the International Business Machines Corporation received the first patent in the United States for a high-temperature superconductor compound formulation using thallium.[1] The new high-temperature superconductors, principally made of ceramic materials such as oxides of thallium, barium, calcium, and copper, become superconductors when chilled to above liquid-nitrogen temperature of 77 K (-196° C). Liquid-nitrogen is easier to handle, cheaper to produce, and a much more efficient coolant than liquid-helium.

A survey study by the Argonne National Laboratory in Gaithersburg, MD, was made to determine whether future commercialization of superconductors could be impaired by price or availability of the constituent elements. This survey of the supply and demand factors affecting certain high-temperature superconductor materials, such as bismuth, barium, rare-earths, strontium, thallium, and yttrium lead the researchers to conclude that, only in the case of thallium were large price increases and shortages likely to occur.

Operating Factors

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.

[1] Engler, M. E., V. Y. Lee, A. I. Nazzal, and S. S. P. Parkin. Tl-Ca/Ba-Cu-O Compositions Electrically Superconducting Above 120 Degree K and Processes for Their Preparation. U.S. Patent 4,870,052, Sept. 26, 1989.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Thallium. Ch. in Mineral Commodity Summaries, annual.
Thallium. Ch. in Mineral Facts and Problems, 1985 ed.

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American Metal Market (daily paper).
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THORIUM

By James B. Hedrick

Mr. James B. Hedrick, a geologist and physical scientist with the Federal Government for 12 years, has been the commodity specialist for thorium since 1982. Domestic survey data were prepared by Mr. Kevin Bacon, mineral data assistant. International data tables were prepared by Mr. Harold Willis, international data assistant.

Domestic consumption of refined thorium products declined, according to the Bureau of Mines, U.S. Department of the Interior. Most thorium produced in the world was recovered as a byproduct of refining monazite for the rare earths. Thorium-bearing monazite was recovered primarily as a byproduct of mineral sands mined for titanium and zirconium minerals or tin minerals in Australia, Brazil, China, India, Malaysia, Republic of South Africa, Taiwan, 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 stockpiled material.

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 in refractory applications and mantles for incandescent lanterns. Thorium continued to be used as a source of nuclear energy at one electric powerplant in Colorado.

Thorium's natural radioactivity represented a significant problem to those companies involved in its mining, processing, and disposal.

TABLE 1

SALIENT U.S. REFINED THORIUM STATISTICS

(Metric tons of ThO_2, unless otherwise specified)

	1985[1]	1986	1987	1988	1989
Exports:[2]					
Metal, waste and scrap	1.64	17.01	20.41	2.74	NA
Compounds[3]	NA	NA	NA	NA	8.25
Imports:[2]					
Compounds, gas mantles, metals	69.34	19.71	30.69	13.23	33.34
Shipments from Government stockpile excesses	2.17	—	—	3.06	—
Consumption, reported nonenergy applications[4]	74.36	72.38	39.41	63.63	57.20
Prices, yearend, dollars per kilogram, ThO_2:[5]					
Nitrate, mantle-grade	$10.10	$13.60	$10.10	$13.80	NA
Oxide, 99% grade	$35.85	$40.00	$41.00	$45.00	NA

NA Not available.

[1] Some data reflects only refined products, excludes monazite concentrates.

[2] Because of the implementation of the Harmonized Tariff System begun in January 1989, import and export categories for 1989 are not necessarily comparable to those in previous years.

[3] Data not available prior to January 1989.

[4] 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.

[5] Source: Rhône-Poulenc, Inc.

LEGISLATION AND GOVERNMENT PROGRAMS

Public Law 100–180, the U.S. Department of Defense Authorization Act for Fiscal Years 1988 and 1989, authorized the disposal of 4,536 kilograms (10,000 pounds) of thorium nitrate from the National Defense Stockpile (NDS) in fiscal year 1989. In fiscal year 1990, Public Law 100–456, The National Defense Authorization Act of 1989, authorized the disposal of all stocks of thorium nitrate in excess of the NDS goal of 272,155 kilograms (600,000 pounds). Thorium nitrate in excess to goal at yearend 1989 totaled 2,973,752 kilograms (6,556,000 pounds).

PRODUCTION

Associated Minerals (USA) Ltd., a wholly owned subsidiary of the Australian-based firm of Renison Goldfields Consolidated Ltd. of Australia, was the principal producer of thorium-containing monazite in the United States. Monazite was produced by Associated Minerals as a byproduct of processing mineral sands mined for titanium and zirconium minerals at Green Cove Springs, FL. Imperial Mining Co., primarily an industrial sand and gold producer, recovered byproduct monazite as a constituent of a mixed heavy-mineral concentrate at Marion, NC.

CONSUMPTION AND USES

Domestic thorium producers reported consumption of an estimated 57.2 tons of thorium oxide equivalent in 1989, a decrease of 6.4 tons from the 1988

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.
Ceradyne Inc.	Santa Ana, CA	Produces advanced technical 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.
GA Technologies Inc.	San Diego, CA	Nuclear fuels.
W.R. Grace & Co., Davison Chemical Div.	Chattanooga, TN	Produces thorium 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 Inc.	Freeport, TX	Produces thorium nitrate from an intermediate compound of monazite.
Spectrulite Consortium Inc.	Madison, IL	Magnesium-thorium alloys.
Teledyne Cast Products	Pomona, CA	Magnesium-thorium alloys.
Teledyne Wah Chang	Huntsville, AL	Produces thoriated welding rods.
Union Carbide Corp., Nuclear Div.	Oak Ridge, TN	Nuclear fuels; tests quantities.
Wellman Dynamics Corp.	Creston, IA	Magnesium-thorium alloys.
Westinghouse Materials Co. of Ohio[1]	Cincinnati, OH	Produces compounds and metals; manages DOE thorium stocks.

[1] Manager of Department of Energy stocks.

level. Nonenergy uses accounted for most of the total consumption. The decrease was the result of lower demand in refractory and ceramic applications. The approximate distribution of thorium by end use, based on data supplied by producer, processors, and several consumers, was as follows: refractory applications, 75%; lamp mantles, 15%; aerospace alloys, special use light bulb elements, welding electrodes, and other applications, 10%.

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-strength, 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 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 quality 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 radar communication.

Thorium was used in other types of electron-emitting tubes, elements in special use light bulbs, high-refractivity glass, radiation detectors, computer memory components, catalysts, photoconductive films, target materials for X-ray tubes, and fuel-cell elements.

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's only domestic energy application was as a nuclear fuel in the thorium-232/uranium-233 fuel cycle at one commercial reactor at Fort St. Vrain, CO.

STOCKS

Government stocks of thorium nitrate in the NDS were 3,223,993 kilograms (1,541,810 kilograms of equivalent thorium oxide) on December 31, 1989. The NDS goal at yearend was 272,155 kilograms of thorium nitrate (130,153 kilograms of equivalent thorium oxide). All stocks in excess of goal were authorized for disposal.

The U.S. Department of Energy's inventory at yearend was 1,244,027 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.), as quoted in Australian dollars (A$)[1], increased from A$700–A$780 per ton at yearend 1988, to A$780–A$880 per ton at yearend 1989. Changes in the United States-Australia foreign exchange rate in 1989, resulting from the weakness of the Australian economy, caused the corresponding U.S. dollar to be up $0.06 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, increased from US$598–US$666[2] per ton in 1988 to US$616–US$695[3] per ton in 1989.

Thorium prices quoted by Magnesium Elektron, Flemington, NJ, at yearend 1989 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 continued its quest to gain approval for a rare-earth separation plant at Pinjarra, Western Australia. Environmental concerns related to the disposal of naturally radioactive thorium halted the project in 1988. Rhône-Poulenc proposed a new plan to dispose of the thorium nitrate by injecting it into deep wells drilled into a confined saline aquifer.[4]

Brazil

Production of thorium-containing monazite concentrates in 1987 was 4,332 tons: 177 tons from the State of Espírito Santo, a decrease from the 197 tons produced in 1986; 3,271 tons from the State of Rio de Janerio, a decrease from the 1986 production of 3,421 tons; and 884 tons from the State of Bahia, which produced no monazite in 1986.

Measured reserves of monazite were 36,806 tons. Estimated thorium content of these reserves was 2,400 tons of thorium oxide equivalent. Monazite reserves were located in the States of Bahia, Espirito Santo, Minas Gerais, and Rio de Janeiro.[5]

Madagascar

QIT-Fer et Titane Inc. (QIT) announced it would delay development of its joint-venture heavy-mineral sands project at least until 1995. Planned monazite capacity of the project was 6,000 tons per year.

South Africa, Republic of

General Mining Corp. Ltd. continued to produce byproduct monazite from its Naboomspruit fluorspar operations in the Transvaal. Monazite is reportedly removed during processing by wet high-intensity magnetic separators to lower the undesirable phosphate levels in the final fluorspar product.[6]

Taiwan

Pacific Ocean Rare Earth Industry Co. (POR), continued production of heavy minerals, including monazite, on the west coast of Taiwan from Taichung to Tainan. Reserves of monazite in Yuanlin and Chiai Counties were reported at 50,000 tons. Ore from the area is shipped to Hsinchu for processing and separation of the rare earths from monazite. Monazite capacity of the Hsinchu plant is 1,000 tons per year.

[1] Metal Bulletin (London). Non-ferrous Ores in Europe. No. 7445, Dec. 29, 1989, p. 28.

[2] Values have been converted from Australian dollars (A$) to U.S. dollars (US$) at the exchange rate of A$1.1710=US$1.00 based on yearend 1988 foreign exchange rates reported in the Wall St. J.

[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 St. J.

[4] Industrial Minerals (London). Rhône Poulenc RE Interest. No. 267, Dec. 1989, p. 68.

[5] Anuário Mineral Brasileiro 1988. Monazita. Pp. 264–265.

[6] Griffiths, J. South Africa's Minerals: Diversity in Adversity. Ind. Min. (London), No. 263, Aug. 1989, p. 30.

TABLE 3

U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS[1]

(Quantity in kilograms unless otherwise specified)

	1987		1988		1989		Principal destinations and sources, 1989
	Quantity	Value	Quantity	Value	Quantity	Value	
EXPORTS							
Thorium ore, monazite, concentrate	582,995	$427,838	e490,314	$310,384	e50,000	$29,780	France 50,000.
Metals[2]	17,961	402,370	2,406	54,271	NA	NA	
Compounds[3]	NA	NA	NA	NA	8,247	221,323	Israel 7,652; Japan 228; Tunisia 227; Canada 60; Taiwan 23; Australia 22; Other 35.
IMPORTS							
Thorium ore, monazite, concentrate metric tons	1,121	627,312	1,924	1,154,498	774	530,294	Indonesia 594; Australia 180.
ThO_2 content	89,680	XX	127,220	XX	48,240	XX	
Compounds	46,322	1,046,526	20,001	380,255	33,344	943,692	France 32,274; Netherlands 677; United Kingdom 371; Other 22.
Oxide equivalent, in gas mantles[e 4]	1,824	606,344	862	284,673	NA	NA	
Other	656	250,355	663	213,677	NA	NA	
Metals and alloys	22,019	NA	15,167	NA	NA	NA	
Unwrought, waste and scrap	1,149	37,999	77	2,550	NA	NA	

[e] Estimated. NA Not available. XX Not applicable.

[1] Because of the implementation of the Harmonized Tariff System begun in January 1989, import and export categories for 1989 are not necessarily comparable to those in previous years or may no longer be available.

[2] Unwrought, wrought, waste and scrap.

[3] Data unavailable prior to January 1989.

[4] Based on the manufacture of 2,205 gas mantles per kilogram of thorium oxide.

Sources: Bureau of the Census and a producer.

TABLE 4

MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Australia	18,735	14,822	12,813	11,872	13,500
Brazil	1,895	1,947	1,560	[r e]1,600	1,600
India[e]	4,000	4,000	4,000	4,000	4,000
Malaysia	5,808	5,959	2,908	2,920	3,100
Mozambique[e]	4	[r]3	([3])	([3])	—
South Africa, Republic of[e]	1,000	1,000	1,200	1,200	1,250
Sri Lanka[e]	200	200	200	200	200
Thailand	663	1,609	458	590	600
United States	W	W	W	W	W
Zaire	—	7	97	168	200
Total	32,305	[r]29,547	23,236	22,550	24,450

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] Table includes data available through Apr. 20, 1990.

[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.

[3] Revised to zero.

TIN

By James F. Carlin, Jr.

Mr. Carlin is a physical scientist with the Branch of Nonferrous Metals. He has covered tin for 10 years. Domestic survey data were prepared by Regina R. Coleman, Nonferrous Data Section. International data tables were prepared by Harold Willis and Giovanni Jacarepaqua, International Data Section.

For the ninth consecutive year, there was a world excess of tin, largely due to increased production from several major producers. The excess narrowed somewhat, but was believed to be about 30,000 metric tons at yearend. Repercussions from the exhaustion of the International Tin Council (ITC) fund to support the tin price in late 1985 continued throughout 1989. Legal actions continued against the London Metal Exchange (LME) and the ITC. The actions were brought by the tin dealers and banks who had alleged monetary losses due to activities of the LME and ITC in late 1985. The various parties involved in the legal conflicts showed a willingness to compromise, and toward yearend it appeared that an out-of-court settlement was imminent. The tin contract was reintroduced to trading on the LME after being suspended for 3 years.

The price of tin rose considerably during the first 4 months of 1989, but then declined to levels around those of January for the balance of the year as increased mine production from some leading producers aggravated an oversupply situation. World tin mine and smelter output rose slightly as the higher prices at the start of the year encouraged production. In the United States, there was increased interest in detinning used tin cans because of dwindling dumpsites and new detinning technology. A major detinning facility was started in 1989, while another one neared completion; both were intended to process mostly used tin cans. A meeting was held in Geneva, Switzerland, March 29 through April 7, attended by the world's major tin producers and users. At this meeting, the terms of reference were adopted for a proposed International Tin Study Group (ITSG).

TABLE 1

SALIENT TIN STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Mine	W	W	W	W	W
Smelter	e3,000	3,213	1 3,905	1 1,467	e 1,000
Secondary	14,109	14,850	r 16,159	e r 15,249	e 15,213
Exports [2] [3]	1,478	1,547	1,318	1,209	904
Imports for consumption: [3]					
Metal	33,830	35,768	41,150	43,493	33,988
Ore (tin content)	1,616	3,936	2,953	2,837	216
Consumption:					
Primary	36,524	33,327	35,620	r 37,529	36,518
Secondary	12,145	10,197	8,599	r 8,072	9,853
Stocks, yearend, U.S. industry	12,359	13,857	r 14,464	r 15,023	14,662
Prices, average cents per pound:					
New York market	525.90	294.12	309.01	r 330.91	397.28
Metals Week composite	4 595.95	4 383.22	418.78	441.42	520.18
London	4 556.26	NA	NA	NA	NA
Kuala Lumpur [5]	4 540.70	4 272.26	303.45	319.86	387.12
World: Production:					
Mine	r 180,725	r 172,471	178,131	p 200,150	e 216,457
Smelter:					
Primary	r 192,990	r 184,239	189,276	p 215,133	e 222,418
Secondary	17,545	15,591	16,238	p 19,491	e 19,409

e Estimated. p Preliminary. r Revised. NA Not available; the tin contract was suspended from London Metal Exchange trading on Mar. 12, 1986. W Withheld to avoid disclosing company proprietary data; U.S. mine production for 1985–89 was negligible.

[1] Reported figure.

[2] Exports (excluding reexports).

[3] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, export/import categories for 1985–88 are not necessarily comparable with those in 1989.

[4] Prices quoted for 10 months only.

[5] Beginning in 1985, Kuala Lumpur replaced Penang as the reference market.

LEGISLATION AND GOVERNMENT PROGRAMS

The National Defense Stockpile (NDS) was managed by the Secretary of Defense for the first full year, with day-to-day operations guided by the Defense Logistics Agency.

The Department of Defense sold 2,775 tons of tin in 1989, all of which represented payment for the Department of Defense's Ferroalloy Upgrading Program, which started on April 11, 1984. At yearend, the NDS inventory was 171,233 tons; the stockpile goal was 42,674 tons.

Federal laws provided a depletion allowance of 22% for domestic operations and 14% for U.S. companies producing in other countries.

PRODUCTION

One mine operating in Alaska produced tin concentrates. Total output amounted to only a small fraction of domestic tin requirements.

The only domestic tin smelter, Tex-Tin Corp., in Texas City, TX, recovered tin primarily from imported and domestic concentrates, secondary tin-bearing materials, and its own stockpile of tin residues and slags. The smelter's main source of tin concentrate was Peru. The facility also produced a line of solder. At midyear, the smelter ceased tin production for the balance of the year and converted its equipment to processing copper scrap, from which it produced copper blister.

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 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 categories of consumption and was a major source of material for the solder and the brass and bronze industries. The Steel Can Recycling Association in Pittsburgh, PA, funded and operated by five domestic tinplate producers, sought to advance the collection, preparation, and transportation of can scrap. Also, they began 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 tin cans, was detinned. This was mostly due to technical difficulty in processing the cans. In recent years, new scrap preparation procedures were developed, especially a new shredding method, that permitted detinning of used tin cans. These developments, combined with increased incentives for municipal recycling of trash due to a lack of landfill space, set the stage in 1989 for large-scale detinning of used tin cans. The domestic detinning industry responded with several startups and plant constructions. Late in the year, 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 tin-plated 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 product was sold to various tin refiners for refining. Plans called for the detinned bales of high-quality scrap-steel to be processed by Buffalo Steel Co., a proposed $260 million minimill joint venture of Proler and two other companies. Buffalo Steel planned to locate the new steel mill near Houston, TX, and intended to purchase the former USX Corp. facilities at Baytown, TX, for its operation, provided all permits could be obtained.

AMG Resources Corp. was completing construction of a plant at St. Paul, MN, to recycle cans. This facility would have an electrolytic detinning system to process up to 40,000 tons of tin cans annually. The extracted tin was to be utilized in the chemical industry, and the scrap steel was to be shipped to steel mills and foundries. AMG also was completing a detinning plant near Princeton, NJ, that was designed to process mostly used tin cans.

In future years, these developments should provide increased tonnages of secondary tin and should augment the supply of domestic scrap steel, which has recently been in short supply.

CONSUMPTION AND USES

Primary tin consumption decreased slightly from that of 1988. The decline tended to affect several usage categories modestly and was most pronounced in brass and bronze, solder, and chemicals. The declines were attributable to increased usage of secondary tin by the brass and bronze and solder makers because of a sharp tin price increase in the first half of the year. Tinplate replaced solder as the largest application for primary tin, followed by chemicals. Although the number of tinplate cans increased absolutely in 1989, tinplate continued to lose market share to aluminum in the metal can category. Tin-plated steel and tin-free steel accounted for 29% of the 120 billion cans shipped domestically and aluminum accounted for 71%; in 1988, when steel accounted for 30% and aluminum for 70%, 114 billion cans were shipped. Aluminum held an overwhelming segment of the beverage can market, while steel predominated in the food can and the general line markets.

PRICES

The price of tin metal, as published in Metals Week, rose steadily during the first 4 months of the year. It peaked in April, then steadily declined the balance of the year, finishing the year at a lower price than in January.

TABLE 2

SECONDARY TIN RECOVERED FROM SCRAP PROCESSED AT DETINNING AND OTHER PLANTS IN THE UNITED STATES

		1988	1989
Tinplate scrap treated	metric tons	W	W
Tin recovered in the form of:			
Metal	do.	578	569
Compounds (tin content)	do.	W	W
Total	do.	578	569
Weight of tin compounds produced	do.	W	W
Average quantity of tin recovered per metric ton of tinplate scrap used	kilograms	2.07	1.98
Average delivered cost of tinplate scrap	per metric ton	$57.13	$60.41

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	1988[r]	1989
Tin metal[1]	578	569
Bronze and brass[e 2]	9,939	10,305
Lead and tin alloys:		
Antimonial lead	902	952
Babbitt	112	116
Solder	3,619	3,225
Type metal	70	46
Other alloys[3]	29	W
Total	4,732	4,339
Tin content of chemical products	W	W
Grand total	[e]15,249	[e]15,213
Value (thousands)[e 4]	$148,398	$174,463

[e] Estimated. [r] Revised. 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.

After being suspended from LME trading since early 1986 because of problems related to the late 1985 tin market "collapse," tin was reintroduced to daily LME trading on June 1. The new LME contract was quoted in U.S. dollars and was for high-grade tin. Also, a new futures contract for tin metal was available for up to 15 months.

The Kuala Lumpur Commodities Exchange (Malaysia) continued as an active tin trading medium.

FOREIGN TRADE

In 1989, the United States implemented the Harmonized Tariff System (HTS), which resulted in changes in classifications for some materials.

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
1987[r]									
Copper-base scrap	10,113	143,005	11,385	132,475	143,860	9,258	480	5,149	5,629
Brass mills[2]	2,464	32,720	W	W	30,708	4,476	467	—	467
Foundries and other plants	5,451	26,303	7,525	19,177	26,702	5,052	356	830	1,186
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	1,303	5,979	7,282
Lead-base scrap	29,584	893,252	68,586	818,429	887,015	35,821	1,800	5,406	7,206
Tin-base scrap[3]	21	347	W	W	W	20	1,501	77	1,578
Grand total	XX	XX	XX	XX	XX	XX	4,604	11,462	16,066
1988									
Copper-base scrap	9,258	155,726	14,709	141,350	156,059	8,925	594	5,492	6,086
Brass mills[2]	4,476	W	W	W	W	4,769	633	—	633
Foundries and other plants	5,052	19,579	W	W	19,852	4,779	W	604	604
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	1,227	6,096	7,323
Lead-base scrap	35,821	895,088	59,428	843,604	903,032	27,877	1,560	5,134	6,694
Tin-base scrap[3]	20	102	W	64	W	27	1,174	58	1,232
Grand total	XX	XX	XX	XX	XX	XX	3,961	11,288	15,249
1989									
Copper-base scrap	8,925	145,771	10,844	138,396	149,240	5,456	449	5,324	5,773
Brass mills[2]	4,769	41,314	41,314	—	41,314	4,833	584	—	584
Foundries and other plants	4,779	12,394	W	W	15,975	1,198	W	294	294
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	1,033	5,618	6,651
Lead-base scrap	27,877	1,013,055	67,444	946,422	1,013,866	27,066	1,770	5,290	7,060
Tin-base scrap[3]	27	119	W	110	110	W	W	103	103
Grand total[4]	XX	XX	XX	XX	XX	XX	4,202	11,011	15,213

[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)

	1985	1986	1987[r]	1988[r]	1989
Stocks, Jan. 1[1]	8,430	9,336	9,876	10,217	9,242
Net receipts during year:					
Primary	38,006	35,475	38,401	39,421	37,670
Secondary	8,904	11,636	11,707	12,472	10,901
Scrap	7,471	6,346	6,635	6,707	8,168
Total receipts	54,381	53,457	56,743	58,600	56,739
Total available	62,811	62,793	66,619	68,817	65,981
Tin consumed in manufactured products:					
Primary	36,524	33,327	35,620	37,529	36,518
Secondary	12,145	10,197	8,599	8,072	9,853
Total	48,669	43,524	44,219	45,601	46,371
Intercompany transactions in scrap	214	354	512	630	424
Total processed	48,883	43,878	44,731	46,231	46,795
Stocks, Dec. 31 (total available less total processed)	13,928	18,915	21,888	23,586	19,186

[r] Revised.
[1] Includes tin in transit in the United States.

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)
1985	146,041	2,215,042	9,321	4.2
1986	120,186	2,068,246	8,660	4.2
1987	141,842	2,302,173	10,357	4.5
1988[r]	149,054	2,375,809	11,582	4.9
1989	153,542	2,263,769	11,764	5.2

[r] Revised.
[1] Includes small tonnage of secondary tin and tin acquired in chemicals.

Some data that were aggregated under one category in the Tariff Schedule of the United States (TSUS) classification system were separated under the HTS, and some data that were separated in the TSUS system were aggregated in the HTS. Consequently, trade data that can be identified specifically with one commodity may have changed, and data for 1989 were not comparable with that of 1988 and previous years.

Imports for consumption of tin concentrate declined sharply, reflecting the reduced activity at the TexTin smelter. Imports of tin metal declined substantially, indicating that consumers were drawing down stocks and also utilizing tin metal from NDS releases. Brazil remained the major source for imported tin metal, followed by Indonesia, Bolivia, and China.

Imports of tin in all forms (ore and concentrate, metal, and waste and scrap) remained free of U.S. duty.

WORLD REVIEW

The Sixth International Tin Agreement, which commenced on July 1, 1982, officially ended on July 1, 1989. In reality, ITC ceased functions a year earlier when it exhausted operating funds and ceased publications. The United States was not a member of the agreement.

Legal actions continued on behalf of tin dealers and banks that had lost money, allegedly because of activities of the LME and the ITC in late 1985, when the ITC exhausted its credit to support the price. Throughout the year, meetings were held between the various parties involved in the lawsuits to reach an out-of-court settlement. Toward yearend, considerable progress was reported toward such an agreement on a basis that would award the injured parties a financial settlement that was only a fraction of the value originally sought.

The Association of Tin Producing Countries (ATPC), headquartered in Kuala Lumpur, Malaysia, and composed of seven major producer nations—Australia, Bolivia, Indonesia, Malaysia, Nigeria, Thailand, and Zaire—completed its fifth year. Two major tin producing countries, Brazil and China, continued to decline ATPC membership, although each one nominally assented to cooperate with most ATPC goals. ATPC maintained its Supply Rationalization Scheme, basically export controls, for member countries during the year. This was aimed at trying to reduce the long-standing world excess tin supply. Industry sources estimated the world tin surplus at about 30,000 tons at yearend 1989.

During March 29 to April 7, 1989, meetings were held in Geneva, Switzerland, under the auspices of the United Nations Conference on Trade and Development (UNCTAD) to further explore the possibility of establishing the ITSG. These meetings, at which the United States was represented, made considerable progress, and terms of reference for the proposed organization were adopted. To bring the ITSG into being, countries representing at least 70% of world tin trade must ratify the terms of reference.

Australia

The Renison Bell Mine in Tasmania, owned by Renison Consolidated Goldfields Ltd., remained the largest tin mine, accounting for about 90% of 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. The entire output of tin concen-

TABLE 7

U.S. CONSUMPTION OF TIN, BY FINISHED PRODUCT

(Metric tons of contained tin)

Product	1988[r]			1989		
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous)[1]	W	W	W	W	W	W
Babbitt	719	207	926	511	283	794
Bar tin	557	—	557	619	—	619
Bronze and brass	1,890	2,044	3,934	1,575	2,118	3,693
Chemicals	W	W	W	W	W	W
Collapsible tubes and foil	W	W	W	W	W	W
Solder	11,078	4,210	15,288	10,806	5,564	16,370
Tinning	1,406	W	1,406	1,509	W	1,509
Tinplate[2]	11,582	W	11,582	11,764	W	11,764
Tin powder	W	W	W	711	W	711
Type metal	W	W	W	W	W	W
White metal[3]	1,131	W	1,131	1,074	W	1,074
Other	9,166	1,611	10,777	7,949	1,888	9,837
Total	37,529	8,072	45,601	36,518	9,853	46,371

[r] Revised. 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)

	1985	1986	1987[r]	1988[r]	1989
Plant raw materials:					
Pig tin:					
Virgin[1]	5,712	5,754	6,466	7,013	6,801
Secondary	2,342	3,021	2,333	1,440	2,253
In process[2]	1,342	1,377	1,289	1,056	1,032
Total	9,396	10,152	10,088	9,509	10,086
Additional pig tin:					
Jobbers-importers	1,642	1,272	1,890	3,387	3,536
Afloat to United States	1,321	2,433	2,486	2,127	1,040
Total	2,963	3,705	4,376	5,514	4,576
Grand total	12,359	13,857	14,464	15,023	14,662

[r] Revised.
[1] Includes tin in transit in the United States.
[2] Data represent scrap only, tin content.

trate from Renison was believed to have been toll-smelted in Malaysia. Renison continued direct sales of refined tin to large U.S. user firms from an affiliate office in Green Cove Springs, FL.

Renison was considering construction of a new tin smelter. Australia's only tin smelter, in Sydney, closed in the late 1980's when tin prices declined sharply.

Greenbushes Ltd. continued to mine tin and tantalum near Perth. This operation usually produces about 200 to 300 tons of tin concentrate annually, which the firm planned to boost over the next few years as part of its goal of increasing tantalum output.

Bolivia

The tin industry continued to recover from the low production levels of 1986 and 1987, when low tin prices caused a massive restructuring of the mine and smelter sector.

Historically, the Huanuni tin mine, located in the Department of Oruro, has been the richest underground tin mine. The mine was closed in 1986 but reopened in mid-1988 following modernization. The modernization program included construction of a new 1,000-ton-per-day treatment plant, opening up new crosscuts and drifts, and improvements to the ventilation and pumping systems. During 1989, capacity of the mine was 3,600 tons of tin-in-concentrates annually, with the output being delivered to Corporación Minera de Bolivia's (COMIBOL) metallurgical complex at Vinto. COMIBOL was reportedly seeking a joint-venture partner for Huanuni.

The Bolivar tin-zinc-silver mine, located in the Department of Oruro, operated at a loss in 1989. Recently, this operation was the subject of a favorable feasibility study by Preussag of the Federal Republic of Germany. Development work was proceeding to attempt to increase the reserves. Funding was assisted by a $12 million loan from the Federal Republic of Germany. In addition, installation of a 750-ton-per-day concentrator was planned at a cost of $30 million. The new concentrator was expected to be funded by the West German Government, the International Development Bank, and COMIBOL.

The Caracoles tin mine, located in the Department of LaPaz, reportedly operated profitably in 1989, and a rich new vein of tin ore was found that averaged 7% across a 1-meter band.

The Catavi-Siglo tin mine, located in the Department of Potosi, was leased by COMIBOL to four cooperatives employing 4,500 miners. The cooperatives produced about 3,600 tons. COMIBOL was reportedly reevaluating the tin tailings at Catavi and seeking a joint-venture partner to assess the possibility of producing tin concentrates from them; these tailing dumps reportedly contain about 35 million tons grading about 0.3% tin. A Spanish firm, ERAL, was also preparing a pilot project for testing various treatment processes.

The Government-owned Vinto tin smelter, since reopening in 1987, continued to be profitable. With a capacity to treat 20,000 tons of tin ore annually, Vinto officials were reportedly attempting to attract foreign tin ore.

TABLE 9

MONTHLY COMPOSITE PRICE OF STRAITS TIN FOR DELIVERY IN NEW YORK

(Cents per pound)

Monthly	1988			1989		
	High	Low	Average	High	Low	Average
January	430.88	422.00	426.59	471.75	458.59	464.35
February	424.00	417.48	419.50	522.38	470.72	491.66
March	425.78	422.22	424.07	567.27	511.28	543.09
April	424.62	421.02	422.95	647.85	583.57	642.13
May	432.63	421.42	425.00	643.34	590.16	621.18
June	442.50	434.07	439.84	624.31	593.67	607.96
July	452.53	438.42	446.11	585.18	552.47	569.10
August	465.54	452.43	457.70	561.55	427.97	517.89
September	471.85	455.38	463.05	512.87	482.35	493.57
October	461.54	448.89	454.32	501.62	448.91	477.14
November	460.34	454.05	457.67	437.78	402.63	418.80
December	465.51	458.28	460.24	428.82	339.68	413.34
Average	XX	XX	441.42	XX	XX	520.18

XX Not applicable.

Source: Metals Week.

During 1989, there was reportedly an active market in smuggling tin concentrates from Brazil into Bolivia; the concentrates apparently were included in Bolivian production data.

Brazil

Brazil was the world's leading tin producer for the second consecutive year. Tin mine and smelter production was 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. The company owned and operated five tin mines. The mines were Capipore, in

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TIN, TIN MANUFACTURERS, TINPLATE AND TERNEPLATE, AND TINPLATE SCRAP[1]

Year	Miscellaneous tin and tin manufactures			Tinplate and terneplate		Tin compounds		Tinplate scrap	
	Tinfoil, tin powder, flitters, metallics, tin and manufactures, n.s.p.f.	Dross, skimmings, scrap, residues, tin alloys, n.s.p.f.		Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
	Value (thousands)	Quantity (metric tons)	Value (thousands)						
1987	$1,854	2,270	$9,241	329,783	$193,110	838	$5,162	2,543	$380
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

[1] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, categories for 1987 and 1988 are not necessarily comparable with those in 1989.

Source: Bureau of the 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)
1987	209,526	$106,156	1,318	$9,456	28,989	$13,549
1988	297,629	295,002	1,209	9,838	43,297	r21,848
1989	178,884	101,279	904	8,915	100,703	54,135

r Revised.

[1] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, export categories for 1987 and 1988 are not necessarily comparable with those in 1989.

[2] Tinplate circles, strips, and cobbles are included with exports of tinplate and terneplate in 1987 and 1988.

[3] Ingots and pigs only in 1989; not to include bars.

[4] Including bars, rods, profiles, wire, powders, flakes, tubes, and pipes in 1989.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY[1]

Country	Quantity (metric tons)	Value (thousands)
1988		
Concentrates (tin content):		
Bolivia	923	$2,313
China	—	—
Peru	1,914	5,600
Total	2,837	7,913
Metal (unwrought tin):		
Australia	1,342	9,460
Austria	—	—
Bolivia	3,926	27,643
Brazil	16,213	114,411
Canada	101	758
Chile	238	1,771
China	6,223	34,838
Colombia	—	—
Germany, Federal Republic of	1	7
Hong Kong	98	754
India	100	706
Indonesia	5,334	38,147
Italy	—	—
Japan	70	480
Malaysia	5,317	36,786
Mexico	583	4,125
Netherlands	—	—
Nigeria	41	286
Poland	98	684
Singapore	1,342	9,954
South Africa, Republic of	—	—
Switzerland	379	3,015
Thailand	670	8,466
Turkey	20	129
United Arab Emirates	40	266
United Kingdom	1,354	10,304
Venezuela	—	—
Total	43,493	[2]302,991
1989		
Concentrates (tin content):		
China	67	$459
Peru	149	1,479
Total	216	1,938
Metal (unwrought):		
Australia	1,420	11,079
Austria	100	773

See footnotes at end of table.

TABLE 12—Continued

U.S. IMPORTS FOR CONSUMPTION OF TIN, BY COUNTRY[1]

Country	Quantity (metric tons)	Value (thousands)
Metal (unwrought)—Continued		
Bolivia	4,795	$40,019
Brazil	10,572	86,827
Canada	123	1,060
Chile	464	4,100
China	4,793	42,485
Colombia	81	763
Germany, Federal Republic of	1	6
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
Netherlands	20	181
Singapore	456	3,726
South Africa, Republic of	10	95
Switzerland	60	447
Thailand	180	1,803
United Arab Emirates	22	182
United Kingdom	391	3,559
Venezuela	39	195
Total	33,988	[2]288,118

[1] Because of the implementation of the Harmonized Tariff System beginning in Jan. 1989, import categories for 1988 are not necessarily comparable with those in 1989.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

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; Sao Raimundo, in the State of Para; and Iarape Preto and Pitinga, both in the State of Amazonas.

Pitinga, the country's largest tin mine, used four Elliot bucketwheel 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. Total investment at Pitinga was about $115 million. Management was in the process of developing mining of a soft weathered tin ore, separate from the alluviumat, at the Pitinga deposit. Officials also were studying the feasibility of constructing a tin smelter at Pitinga.

Tin mining activity by "garimpeiros" or independent miners increased. Estimated to number 10,000 individuals, "garimpeiros" worked an area about 6 by 12 kilometers in the State of Rondônia, with no specific limits to each person's mining area and with only limited local government control.

Government officials believed that large quantities of tin ore were being smuggled out of the country and indicated that the problem was centered in the Western Amazon State of Rondônia, where tin ore was being trucked to the Madeira and Marmore Rivers, then barged across these rivers to neighboring Bolivia. Thus, some Brazilian tin mine production eventually surfaced as Bolivian production.

Canada

The East Kemptville Tin Corp. Ltd., owned by Rio Algom Ltd., continued tin mining operations at its open pit 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 is complex and concentration by gravity and magnetic methods was reportedly difficult. In recent years, Rio worked to improve the tin recovery rate by improving the grinding, dewatering, and gravity equipment, and by installing a new flotation circuit. In 1989, Rio sought to improve recovery of copper and zinc and planned to install column flotation cells.

Cominco Ltd. produced a small quantity of tin-lead alloy at its Trail, British Columbia, smelter as a byproduct of the production of indium.

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. The high-grade alluvial deposits, after 100 years of exploitation, were virtually de-

pleted. In 1989, low-grade alluvial tin ores of fine particle size, tailings, and the underground lode were the main sources.

For smelting and refining, Yunnan used reverberatory smelting of tin concentrate; pyrometallurgical refining of tin metal; electrolytic separation of tin-lead alloy; and tin slag fuming. Yunnan developed a continuous electrothermal crystallizer designed to remove lead and bismuth using the different melting points and specific gravities of tin and lead-tin alloy; direct recovery of tin was increased by 6% over former methods, and manning levels reduced by 50% in 1989. Several other tin smelters around the world utilized Yunnan crystallizer technology.

The DaChang Tin Mining Bureau Mine, located in the southwest region of Guangxi, China, was being expanded and was expected to become the country's largest tin mine in a few years.

India

Hindustan Zinc Co. announced plans to build a 3,000-ton-per-year domestic tin smelter to meet part of the country's demand.

Indonesia

Tin mining occurred predominantly at offshore locales, with large-scale dredging the preferred method. 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.

Timah announced that it intended to direct the extra revenue from sharply higher tin prices in early 1989 toward ensuring long-term growth in tin production, and they increased maintenance, development, and exploration expenditures.

The other leading tin producer was Kobe Tin, owned by Renison Consolidated Goldfields Ltd. (Australia). Kobe also reportedly experienced production gains and invested substantially in tin facilities.

Malaysia

Malaysia Mining Corp. remained the largest tin-producing organization in the world. A total of 338 tin mines were in operation in 1989, compared with about 800 in 1980. During 1989, 41 gravel pump mines reopened, and 1 dredge restarted due to the impetus of the early 1989 tin price rise. Gravel pump mines accounted for 41% of output, up from 34% in 1988. Dredges accounted for 37% of Malaysia's tin output.

Two large tin smelters on the island of Penang, one owned by Datuk Keramat Sdn. Bhd. and the other owned by Malaysia Smelting Corp. Sdn. Bhd., operated at fairly high levels and made smelter production in Malaysia the largest in the world. Both smelters depended on toll-smelting of imported tin concentrates, especially from Australia, Bolivia, and China.

Mexico

Tin was mined in the three adjoining States of Durango, Zacatecas, and San Luis Potosí in north-central Mexico. 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 Río S.A. All four smelters processed imported tin concentrates, primarily from Canada and China, as well as domestic concentrates.

Namibia

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), was the largest producer. Concentrates 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.

Nigeria

Five tin-mining companies operated in Nigeria. They were Amalgamated Tin Mines of Nigeria (Holdings) Ltd., Bisichi-Jantar Nigeria Ltd., Kaduna Prospecting Nigeria Ltd., Ex-Lands Nigeria Ltd., and Gold & Base Metal Mines of Nigeria Ltd. All tin concentrates were smelted domestically by Makeri Smelting Co. Ltd. at Jos, Plateau State.

Peru

The only tin mine in Peru was the San Rafael Mine, near Juliaca, owned by Minsur S.A. The mine was within the northern extension of the Bolivian tin belt. Tin grades averaged 1.8%. Peru remained the major supplier of tin concentrate to the United States.

Portugal

The new Neves Corvo Mine, in its second year as a copper producer, was planning to begin tin production in 1990. This mine was developed by Socieded Minera de Neves Corvo (SOMINCOR), owned 51% by the Government-controlled Empresa de Desenvolvimento Mineiro E.P. and 49% by RTZ Corp. PLC. RTZ announced 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 plans to produce 2,200 tons of tin in 1990 and 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.

Beralt Tin & Wolfram Co., headquartered in Lisbon, produced tin, tungsten, and copper concentrates at its underground and processing plants at Minas de Panasqueira in central Portugal. Decades ago, the firm was only a tin producer, but in recent years tin output has declined and tungsten has become its primary product. In 1989, output was about 60 tons of tin concentrate.

Thailand

Tin remained the principal mineral product and export; but, in 1989, tin fell in relative importance as other industries gained. The number of operating tin mines was about 200, located chiefly in the Phang-Nga, Phuket, and Ranong regions. About 60% of the tin was mined with offshore dredges.

Most of the onshore tin mines were idle in 1989. Aokam Tin Co. and Tongkha Harbor Tin Co. continued to operate dredges 10 months per year in the Phuket Bay area, where the dredges were sheltered from monsoons. The largest dredge, Bor Dan, was operated by the Government-owned Offshore Mining Enterprise.

Most domestic tin concentrates were

smelted by the Thaisarco smelter. Because it was not being operated at capacity, it experimented with some foreign concentrates, mostly from China.

United Kingdom

The cost of tin mining in the Cornwall district reportedly was among the highest in the world. Most tin concentrates were shipped to the Billiton smelter in the Netherlands.

The restructuring and downsizing of the Capper Pass tin smelter, owned by RTZ, returned the operation to profitability. Increasingly, the feed came from imported low-grade and complex primary and secondary materials. The plant was also an important producer of byproduct metals such as bismuth and indium.

The attempted purchase by Minorco S.A., based in Luxembourg, of London-based Consolidated Goldfields PLC, was blocked on legal grounds. However, shortly thereafter, Hanson Trust PLC, a British conglomerate, purchased Consolidated for about $4.8 billion. The purchase was the largest merger in British history. Consolidated operated tin mines in Australia and Indonesia accounting for about 10% of Western World tin output.

Throughout the year, London, as the base for the now defunct ITC and the LME, was the hub of activity related to the numerous lawsuits connected with the 1985 tin market "collapse." Repeated efforts, often clandestine, were made to resolve the conflicts out of court.

CURRENT RESEARCH

Dan Engineering Corp., Denmark, developed a new vacuum distillation furnace for the refining of tin. The furnace reportedly had unique advantages, whether utilized with a primary tin smelter or a secondary recovery facility, for extracting certain impurities or coalloy metals. Dan Engineering indicated the vacuum distillation process was a relatively low-cost procedure effective for high levels of impurities. The furnace was adaptable to handle small quantities in batches or large tonnages continuously. There was no dross from anode or cathode melting; the byproducts were obtained in metallic form and there were no environmental hazards.[1]

Work at the International Tin Research Institute (ITRI) resulted in advances for tin compounds used as fire retardants and smoke suppressants in various substrates, especially unsaturated polyesters, rigid polyvinylchloride, natural fibers, and wool.[2]

Cooperative research by British Steel Corp., Hoogovens IJmuiden (The Netherlands), and Rasselstein A.G., resulted in the development of a nondetachable beverage can end, made from tinplate. Development took place at the Rasselstein Tin Mill in Andernach, Federal Republic of Germany, on a production line capable of producing 200 million can ends annually. This new style end has two buttons etched into it, which are depressed to open the can—one for flow of the beverage, the other for venting. The end remains attached to the can. The new end was commercially available and competed with the traditional aluminum ring-pull end. If commercially successful, this new style end could result in substantial increases in tinplate demand.[3]

TABLE 13

TIN: WORLD ANNUAL MINE AND PRIMARY SMELTER CAPACITY, BY CONTINENT AND COUNTRY, DECEMBER 1989

(Metric tons)

Continent and country	Mine capacity	Smelter capacity
North America:		
Canada	5,000	—
Mexico	600	7,000
United States	300	8,000
South America:		
Argentina	1,000	1,000
Bolivia	20,000	16,000
Brazil	60,000	50,000
Peru	8,000	—
Europe:		
Czechoslovakia	1,000	—
German Democratic Republic	2,000	4,000
Portugal	6,000	1,000
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	30,000	35,000
Indonesia	35,000	32,000
Japan	—	2,000
Korea, Republic of	100	2,000
Laos	1,000	—
Malaysia	45,000	120,000
Thailand	33,000	44,000
Vietnam	1,000	1,000
Oceania:		
Australia	10,000	2,000
Total	[1]301,000	383,000

[1] Data do not add to total shown because of indpendent rounding.

OUTLOOK

Domestic demand for primary tin has been growing slowly during most of the 1980's, and this trend was expected to continue over the next few years. Since 1987, the consumption of tin for tinplate has increased significantly, partly because of higher aluminum prices and partly because of increased recycling of used tin cans using new recovery technologies. This trend also was expected to continue.

There were no known new uses for tin that hold promise for significant future consumption growth.

BACKGROUND

The late 1980's witnessed the disintegration of one of the most enduring and critical components of the tin industry, the ITC, based in London, England. The ITC's demise, the repercussions involving the LME, and subsequent lawsuits, comprised perhaps one of the most significant news events in the entire metals

TABLE 14

TIN: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina	451	379	186	446	400
Australia	6,363	8,508	7,691	7,009	[2]7,776
Bolivia	16,136	[r]10,462	8,128	10,573	[2]15,858
Brazil	26,514	26,246	27,364	44,102	[2]50,161
Burma	1,751	1,495	939	529	400
Burundi[e]	—	—	1,000	1,000	1,000
Cameroon	9	9	8	5	5
Canada	120	2,485	3,397	[e]3,300	3,300
China[e]	15,000	15,000	20,000	25,000	25,000
Czechoslovakia	250	[e]200	550	515	500
German Democratic Republic[e]	2,800	2,800	3,000	[r]2,800	2,500
Indonesia	[r]21,722	[r]24,497	26,093	29,590	[2]31,263
Japan	510	500	86	—	([2])
Korea, Republic of	[r]31	1	3	([3])	—
Laos[e]	[2]540	550	550	[2]300	400
Malaysia	36,884	29,135	30,388	28,866	31,000
Mexico	380	585	369	274	230
Namibia	984	880	1,097	1,182	1,200
Niger	134	80	94	119	100
Nigeria	[e]1,500	630	844	432	450
Peru	3,807	4,817	5,263	4,378	[2]5,053
Portugal	263	196	64	81	90
Rwanda	813	29	—	—	—
South Africa, Republic of	2,153	2,054	1,438	1,377	[2]1,306
Spain	637	296	71	[e]50	50
Tanzania[e]	[2]2	[r]5	[r]4	[r]4	3
Thailand	16,864	17,066	15,006	14,225	14,500
Uganda[e]	18	18	10	10	10
U.S.S.R.[e]	13,500	14,500	16,000	16,000	16,000
United Kingdom	5,204	4,276	4,003	3,454	3,200
United States	W	W	W	W	W
Vietnam[e]	600	650	680	700	700
Zaire[4]	3,100	2,650	2,378	2,688	2,700
Zambia[e]	[r]15	[r]2	[r]17	[r]1	2
Zimbabwe[e]	1,670	1,470	1,410	[r]1,140	1,300
Total	[r]180,725	[r]172,471	178,131	200,150	216,457

[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 6, 1990.

[2] Reported figure.

[3] Revised to zero.

[4] Nonduplicated total of content of concentrates plus smelter production.

field since World War II.

The ITC, the latest of several similar tin industry organizations dating back to the turn of the century, was created in 1956. Historically, it had been composed of about 20 to 25 producer and consumer countries, each with voting rights in the council approximating that country's tonnage of either tin production or consumption. The goal of the ITC was to stabilize tin supply-demand and tin prices, and to ensure producers a decent profit and users an adequate tin supply at fair prices.

The ITC operated under a complex set of rules. A key feature that allowed it to play a major role in the tin market was the ITC buffer stockpile. The ITC used this stockpile to influence tin prices by selling tin to protect a predetermined "ceiling" price or by buying tin in another part of the market cycle to protect a predetermined "floor" price. During the 1960's and 1970's, the ITC did a remarkable job in protecting the "floor" prices but was generally unsuccessful in protecting the "ceiling" prices. This was attributed to the relatively small size of the ITC stockpile.

During the 1980's, when the world tin market was generally in an oversupply situation and tin prices weakened, the ITC borrowed funds extensively to support the tin price. Finally, in October 1985, the over-extended ITC exhausted available funds to support the tin price, and lenders would not advance any more credit. This triggered an immediate "collapse" of the world tin market, and by early 1986, trading on the LME was suspended. The crisis soon spread to other metals because many brokers who held tin trading seats on the LME also held positions in metals like aluminum, lead, and zinc. Following this "collapse," the price of tin dropped sharply and remained at historically low levels through 1986, 1987, and 1988.

The collapse was followed by a myriad of lawsuits brought by the creditors, mostly brokers and banks who had loaned or lost money, against the ITC and the LME. The legal actions, mostly centered in London, sought to recover an estimated $1.5 billion. The ITC, composed of 22 member Governments, denied responsibility for any losses and opposed the legal actions for several years. The U.S. Government was not a party to the matter because it had only been a member of the ITC for one term, the duration of the 5th International Tin Agreement, from 1976–81. The ITC, hampered by lack of operating funds, ceased operations in 1988. Toward the end of 1989, negotiations for an out-of-court settlement of the tangled legal actions were taking place, and a settlement on a reduced value basis was imminent. The LME resumed daily tin trading in early 1989.

One of the most important impacts of the collapse of the tin market was the resultant sharp decline in price for tin metal, which dropped to about one-half of its "precollapse" price by early 1986 and remained low essentially through

TABLE 15

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Argentina:					
Primary	238	230	240	280	280
Secondary[e]	135	135	100	100	100
Total[e]	373	365	340	380	380
Australia:					
Primary	2,683	1,399	563	439	[2]424
Secondary	409	320	320	300	300
Total	3,092	1,719	883	739	724
Belgium: Secondary	2,304	2,712	3,900	4,972	5,000
Bolivia: Primary	12,859	7,673	2,667	5,461	[2]9,705
Brazil:					
Primary	24,702	27,427	29,365	41,857	43,450
Secondary[e]	200	200	200	250	250
Total[e]	24,902	27,627	29,565	42,107	43,700
Burma: Primary	388	322	649	[r e]300	200
Canada: Secondary[e]	180	200	200	200	200
China: Primary[e]	15,000	15,000	20,000	[r]29,500	29,500
Czechoslovakia: Primary	507	240	500	500	500
Denmark: Secondary[e]	100	100	100	100	100
German Democratic Republic:					
Primary[e]	3,300	3,300	3,400	3,300	3,000
Germany, Federal Republic of:					
Secondary[e]	1,000	350	250	150	150
Greece: Secondary[e]	40	40	40	40	40
India: Secondary	100	100	100	200	200
Indonesia: Primary	20,909	22,080	24,200	28,365	[2]29,916
Japan: Primary	1,391	1,280	895	846	[2]808
Korea, Republic of: Primary[e]	300	300	400	400	800
Malaysia: Primary	45,500	43,788	44,363	49,945	[2]50,874
Mexico: Primary	[r]1,533	[r]1,488	1,730	1,514	1,500
Netherlands:					
Primary	5,312	5,104	3,834	3,478	4,900
Secondary	200	214	194	189	200
Total	5,512	5,318	4,028	3,667	5,100
Nigeria: Primary	1,079	91	560	566	575
Norway: Secondary[e]	60	60	60	55	100
Portugal: Primary	483	184	48	58	110
Rwanda: Primary[e]	800	—	—	—	—
Singapore: Primary[e]	4,000	500	1,000	1,000	800
South Africa, Republic of:					
Primary	2,069	2,001	1,508	1,389	1,307
Secondary[e]	350	350	350	400	400
Total[e]	2,419	2,351	1,858	1,789	1,707
Spain:					
Primary	3,531	1,965	1,671	656	650
Secondary[e]	200	200	200	200	200
Total[e]	3,731	2,165	1,871	856	850
Thailand: Primary	17,996	19,672	15,438	14,675	[2]14,571

See footnotes at end of table.

1989. These historically low prices caused a market-driven restructuring of the world's tin mining industry. High-cost, low-grade tin mines could not operate profitably and hundreds ceased operation. Although most of the 35 tin producer countries suffered economic hardship during this restructuring, the historically low tin prices offered opportunity to the world's scores of tin consumer countries.

The ATPC, founded in 1983, emerged as a force in the tin world by the mid-1980's as the influence of the ITC was waning. The ATPC started with five charter members: Bolivia, Indonesia, Malaysia, Thailand, and Zaire. Later, Australia and Nigeria joined. Two of the world's largest producers, Brazil and China, did not join, thereby weakening the ATPC's potential influence. The announced goals of the ATPC were to obtain fair returns for tin producers and adequate and stable supplies for tin consumers at reasonable prices, to facilitate cooperation in the marketing of tin, and to enhance the growth of tin usage.

Although the ATPC membership included 7 major producers, effectiveness was weakened by the fact that about 30 countries in the world that mined or smelted tin were not members. Nevertheless, the ATPC tackled rather effectively the estimated oversupply of 100,000 tons of tin that existed during most of the 1980's. The ATPC utilized a series of schemes for the rationalization of supply, in effect imposing export controls on member countries to restrain tin production. By 1989, the world tin oversupply had diminished to an estimated 30,000 tons.

The 1980's also witnessed the rise of Brazil and China as major world tin producers from modest levels just 10 years earlier. This phenomenon was fueled by discoveries of new high-grade, low-cost tin deposits and commitments by the Governments of the two countries to facilitate tin mining and smelting. Although neither country was a member of the ATPC, each generally agreed to cooperate with the spirit of the ATPC's supply rationalization strategies. Tin production levels in both countries became so large that, without their cooperation, the ATPC export controls would not have been effective in reducing the world oversupply of the late 1980's.

Brazil's tin mine production in 1979

TABLE 15—Continued

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
U.S.S.R.:[e]					
Primary	16,000	16,000	[r]18,500	[r]18,500	18,000
Secondary	3,700	3,800	4,000	4,000	4,000
Total	19,700	19,800	22,500	22,500	22,000
United Kingdom:					
Primary	7,548	9,227	12,135	9,014	8,000
Secondary	7,265	5,676	4,871	7,757	7,600
Total	14,813	14,903	17,006	16,771	15,600
United States:					
Primary	[e]3,000	3,213	3,927	1,467	1,000
Secondary	1,302	1,134	1,353	578	569
Total	4,302	4,347	5,280	2,045	1,569
Vietnam: Primary[e]	570	620	645	600	600
Zaire: Primary	85	56	—	168	100
Zimbabwe: Primary	1,207	1,079	1,038	855	[2]848
Grand total	210,535	199,830	205,514	234,624	241,827
of which:					
Primary	192,990	184,239	189,276	215,133	222,418
Secondary	17,545	15,591	16,238	19,491	19,409

[e]Estimated. [p]Preliminary. [r]Revised.

[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. Table includes data available through June 8, 1990.

[2]Reported figure.

was 7,000 tons; in 1989 it was an estimated 50,000 tons. During the decade, considerable exploration occurred and resulted in the discovery of numerous high-grade, mostly alluvial, tin deposits. Most tin discoveries were part of the same geological belt or trend extending up from Bolivia into the far southwestern extremes of Brazil. The Brazilian mines were generally low-cost operations, often the lowest cost in the world, a fact which came to the fore after the late-1985 tin market "collapse." The collapse resulted in a historically low tin price, a price at which the Brazilian mines were among the few in the world that could operate at a profit. Unlike many tin mines in the world, Brazil's tin mines were generally privately owned, sometimes by foreign firms.

It was estimated that tin mine production in China rose sharply from about 15,000 tons in 1979 to an estimated 25,000 tons in 1989. It was believed that most tin mines in China were underground lode operations in the same geological trend extending from Malaysia, Burma, and Thailand into southwest China. All Chinese tin mines are Government-owned and often named for the province in which they are located. Although China has numerous tin smelters, in recent years considerable tin ore has been shipped to smelters in Malaysia. In recent years, China has emerged as the second leading supplier of tin metal to the United States, after Brazil.

The transactions of the NDS in the United States, administered by the Department of Defense in 1989, have been a major factor in the tin industry. Almost immediately after the creation of the NDS following World War II, tin became the largest dollar volume holding in the entire stockpile of some 80 nonfuel mineral materials. The U.S. Government purchased the tin for the NDS primarily from foreign producers at the then prevailing market prices of well below $1 per pound. The tin was stored at several warehouses around the country in proximity to industries that could require the tin in wartime. By 1960, the NDS stockpile reached its peak quantity of 358,149 tons and the Nation's consumer and defense-related tin requirements began to decline. Beginning in 1962, stockpile tin that was excess to the goal was offered for sale. Sales, or later swap programs, were elaborately designed to avoid significantly affecting the world tin market.

The immensity of the NDS holdings of tin can be measured by noting that at yearend 1989, after almost 30 years of almost continuous stockpile sales, the stockpile tin inventory of 171,233 tons was still by far the largest dollar volume holding of all the nonfuel mineral materials in the stockpile.

Even though Defense plans call for an eventual tin stockpile of 42,674 tons, it probably will take many decades to sell the excess down to that level, given the legislative processes needed to authorize disposals and the sometimes conflicting aims of avoidance of undue market disturbance and maximization of income from disposals.

Technology

For most of this century, one of the major worldwide uses for tin has been for tinplate, most of which is used for tin cans. Even though tinplate has lost most of the beverage market in the United States to aluminum during the past 25 years, tinplate has continued to dominate the food can market. Until the late 1980's, used tin cans were generally not recycled; when used by the consumer, they were usually taken via trash collection vehicles to municipal landfills. Also, until the late 1980's, technology did not exist for economically removing the tin coating from the base steel (tinplate is 99% steel) on the required volume and speed basis necessary for treating large volumes of cans.

During the late 1980's, new procedures for effectively separating the tin from the base steel were developed so each metal could be reused as scrap. One such technique involved a shredding process that permitted more effective chemical reaction with the tin surfaces. Also during the late 1980's, many of the Nation's landfills were nearing capacity and became a major environmental concern, leading to municipal policies and actions to encourage or mandate household trash recycling programs. This movement started to generate a significant supply of used

tin cans that could be treated by the new detinning technology. In 1989, the impact of both of these developments created a new industry for the collection and detinning of used tin cans, and several new detinning plants were under construction.

[1] Dan Engineering ApS. Presentation at Metal Bulletin's First International Tin Conference, Penang, Malaysia, June 1989.

[2] Tin and Its Uses. No. 161, 1989, p. 2.

[3] Non Detach Steel Easy Open End. British Steel Hoogovens IJmuiden-Rasselstein, Corporate Promotion Brochure, 1989, available from British Steel Corp.

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TITANIUM

By Langtry E. Lynd and Ruth A. Hough

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U.S. production of titanium dioxide (TiO_2) pigments increased about 8% to a little over one million metric tons in 1989, reaching a record-high level for the seventh consecutive year. However, domestic consumption of TiO_2 pigments dropped about 4%, reflecting an easing of the very tight supply-demand balance that had existed for several years. Exports of TiO_2 pigments increased markedly while imports decreased.

U.S. production of titanium sponge metal rose 13% to 25,200 tons, 5% higher than was reached in the previous record-high year of 1981. Demand for titanium mill products also increased, mainly because of the continued boom in orders for new commercial airliners.

Consumption of titanium concentrates, (ilmenite, high-TiO_2 slag, rutile, and synthetic rutile), also increased, in line with the rising production of titanium metal and TiO_2 pigments. Imports again supplied about three-quarters of U.S. requirements for TiO_2 in concentrates.

TABLE 1

SALIENT TITANIUM STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Ilmenite concentrate:					
Imports for consumption	459,765	422,401	307,515	394,170	411,751
Consumption	685,896	731,436	744,266	679,008	659,584
Titanium slag:					
Imports for consumption	264,742	328,285	408,785	434,641	386,146
Consumption	228,635	250,677	251,423	300,013	414,830
Rutile concentrate, natural and synthetic:					
Imports for consumption	162,988	158,595	197,937	231,124	264,895
Consumption	276,944	298,601	320,505	352,356	366,143
Sponge metal:					
Production	21,098	15,787	17,849	22,270	25,225
Imports for consumption	[1] 1,558	1,475	924	1,364	903
Consumption [e]	19,601	17,680	17,973	21,003	24,927
Price, Dec. 31, per pound	$3.50–$4.00	$3.90–$4.30	$4.00–$4.20	$4.25–$4.75	$4.80–$5.30
Titanium dioxide pigment:					
Production	783,393	844,274	878,558	926,746	1,006,581
Imports for consumption	178,001	183,862	174,219	185,466	166,346
Consumption, apparent [2]	893,195	908,055	966,169	991,536	947,259
Price, Dec. 31, cents per pound:					
Anatase	72.0	77.0	77.0	95.0	102.0
Rutile	78.0	82.0	82.0	97.0	105.0
World: Production: (rounded)					
Ilmenite concentrate [3]	3,456,767	3,419,500	3,878,869	[p] 4,002,538	[e] 4,213,200
Rutile concentrate, natural [3]	373,407	393,860	439,366	[p] 433,520	[e] 475,690
Titaniferous slag	1,280,000	1,285,000	1,575,000	[p] 1,725,000	[e] 1,765,000

[e] Estimated. [p] Preliminary.

[1] Excludes sponge imported for the national stockpile.

[2] Production plus imports minus exports plus stock decrease or minus stock increase.

[3] Excludes U.S. production data to avoid disclosing company proprietary data.

LEGISLATION AND GOVERNMENT PROGRAMS

The International Trade Administration (ITA) of the Department of Commerce tentatively decided to revoke an antidumping duty order on titanium sponge manufactured by Osaka Titanium Co. Ltd. of Japan because it had found Osaka's dumping margin for the period November 1, 1985, to October 31, 1986, to be 0.0% rather than the 0.3% found in a preliminary review in July 1988. ITA rejected a request from Toho Titanium Co. Ltd. for revocation of an antidumping duty order after determining that its dumping margin for the same period was 0.83%.

In furtherance of the Department of Defense Appropriations Act of 1990 (PL 101-165, H. R. 3072-13), the Bureau of Mines was preparing to initiate the Soledad Canyon Demonstration Project in Los Angeles County, CA, to develop a reliable supply of titanium ore from ilmenite. The project is concerned with titanium resources in the vicinity of Soledad Canyon and adjacent areas of Angeles National Forest. It will involve a total resource evaluation, bulk sample recovery, evaluation of beneficiation potential, and determination of response to technology to produce synthetic rutile, titanium metal, and TiO_2 pigment. Six million dollars was made available for the project through September 30, 1993.

STRATEGIC CONSIDERATIONS

Security of Supply

Although imports supply a very large proportion of domestic demand for 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 1989 has been in the 70% to 80% range. Import reliance for rutile declined from about 90% in 1980 to about 60% in 1983 and later years because of increased domestic production of synthetic rutile. However, this decline was at the expense of increased import reliance for ilmenite, because the domestic synthetic rutile was made from Australian ilmenite.

Dependence on foreign rutile sources could be eased or eliminated in an emergency in two ways, using current commercial processing methods: (1) synthetic rutile could be made from domestic ilmenite now being mined in Florida, or ilmenite that could be mined from other deposits, such as the Tennessee ilmenite sand deposits, and (2) titanium tetrachloride ($TiCl_4$) for metal production could be made directly from ilmenite, as is done by E. I. du Pont de Nemours & Co. Inc. (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 1989, 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 between 0% and 16% in the period 1980 to 1989. 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 National Defense Stockpile (NDS) from domestic producers and from producers in Japan and the United Kingdom. Rutile for the stockpile 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 Annual Materials Plan for fiscal year 1991 includes a proposal to acquire 2,722 tons of titanium sponge metal for the stockpile. 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 sponge and a large part of the world's TiO_2 pigment, prefer rutile or synthetic rutile over ilmenite as plant feed material. Possible ways of better utilizing U.S. ilmenite resources and reducing U.S. dependence on foreign sources of titanium concentrates are discussed in the Strategic Considerations section.

Fluctuations in Metal Demand

A major problem affecting the titanium industry is the wide fluctuation 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 1989 were Associated Minerals (USA) Ltd. Inc. (AMU) at Green Cove Springs, FL, and Du Pont at Starke and Highland, FL. P. W. Gillibrand Co., Simi Valley, CA, reported initial commercial shipments of several thousand tons of ilmenite, produced as a coproduct of its rock, sand, and gravel operations.

In December, Nord Resources Corp. announced that production of heavy minerals had begun at the newly completed processing facility of Nord Ilmenite Corp. near Lakewood, NJ. This operation will reclaim zircon, ilmenite, and rutile from tailings at a previously mined mineral sands deposit. The first shipments of zircon were made in early December.

AMU was again the only U.S. producer of natural rutile. Kerr-McGee Chemical Corp. was the sole domestic producer of synthetic rutile, at Mobile, AL.

Du Pont announced plans to begin mining ilmenite at a new location in Florida by 1992. The new mine site is at Maxville, on the northern extension of Trail Ridge, about 15 kilometers (km) north of Du Pont's current operations on Trail Ridge. A Du Pont spokesperson said the new mine site will support the company's plans to expand TiO_2 production capacity by 50% to about 900,000 tons per year by the mid-1990's. Du Pont said it will close portions of one of the two Trail Ridge mine sites now in use when operations at the new site begin.

Renison Goldfields Consolidated Ltd. (RGC), Mineral Sands Div.-USA, was evaluating a mineral sand deposit located in Dinwiddie and Sussex Counties, VA. The deposit was said to contain 7.3 million tons of recoverable heavy minerals, with ilmenite, leucoxene, rutile, and zircon making up nearly 80% of the heavy mineral concentrate. Heavy mineral content in the deposit reportedly averages about 7%. Mining could begin in about 3 to 5 years.

South East Tisand, a joint venture between Becker Minerals Inc. of England and Consolidated Rutile Ltd. of Australia, was investigating a similar mineral sand deposit in the Greensville County area, VA. Other companies exploring for heavy mineral sand deposits in the southern Virginia-eastern North Carolina area included Du Pont and Piedmont Mining Co. Inc.

Ferrotitanium

Ferrotitanium was produced by Ashland Chemical Co., Columbus, OH; HTP Co., Sharon, PA; Reactive Metals and Alloys Corp., West Pittsburg, PA; and Shieldalloy-GFE Corp., Newfield, NJ. Most of the production consisted of the 70%-titanium grades.

Metal

Oregon Metallurgical Corp. (Oremet) completed construction of an eighth reduction furnace, bringing its sponge production capacity to 5,400 tons per year. Oremet planned further expansion of capacity to 8,000 tons per year by March 1991. In November, RMI Co. completed expansion of sponge production capacity at its Ashtabula, OH,

TABLE 2

U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1989

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	5,400	10,000
RMI Co.	USX Corp., 50%; Quantum Chemical Co., 50%.	Ashtabula, OH Niles, OH	10,900 —	— 16,300
Teledyne Allvac	Teledyne Inc.	Monroe, NC	—	3,600
Teledyne Wah Chang Albany	do.	Albany, OR	—	900
Titanium Metals Corp. of America	Baroid Corp., 70%; Allegheny International Inc., 30%.	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			29,000	66,700

[1] Based on 7-days-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 5,000 tons was single-melt electron-beam capacity for remelt electrodes nd commercially pure ingot and slab.
[2] Single melt only.

facilities from 9,500 tons per year to about 11,000 tons per year. In December, Titanium Metals Corp. of America (TMCA) and a Japanese group signed a memorandum of understanding providing for the financing, design, and construction of a 10,000-ton-per-year titanium sponge plant utilizing proven vacuum-distillation technology. The parties expected to, and did, reach a definitive agreement during the first quarter of 1990. The Japanese group, which will provide advanced technology and financing for the project, consists of Toho Titanium Co. Ltd. and its primary shareholders, Nippon Mining Co. Ltd., Mitsui and Co. Ltd., and Mitsui and Co. (U.S.A.) Inc. After production startup, expected by 1993, the Japanese group will have the option to acquire 25% of TMCA's common stock. The new sponge plant will be operated by TMCA in conjunction with its existing titanium sponge, ingot, and research facilities in Henderson, NV.

RMI was making trial runs in its pilot plant for producing titanium metal by the Ginatta electrolytic process. RMI reported that initial results from the extensively automated processing system were promising, yielding products with low levels of oxygen and metallic impurities.

Teledyne Allvac, Monroe, NC, announced in August that it had broken ground for a continuous automated bar mill in Chester County, about 48 km from Monroe. Allvac said the mill is to be on-line in the fourth quarter of 1990 and will be used to roll the superalloys and titanium alloys that the company produces. Allvac believes that when this project is completed, it will have the industry's most cost-effective capability to meet increasingly demanding requirements for the most consistent, highest quality, superalloy and titanium rod and bar products.

Titanium Dioxide Pigments

Supply and demand for TiO_2 pigments remained in close balance, and production facilities were generally operated at full capacity. U.S. producers increased capacity by about 125,000 tons per year, using process optimization as well as major expansions.

Kemira Inc., Savannah, GA, completed a 50% expansion of its TiO_2 capacity to 145,000 tons per year.

TABLE 3

COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND

(Metric tons)

Component	1985	1986	1987	1988	1989
Production:					
Sponge	21,098	15,787	17,849	22,270	25,225
Ingot	32,103	31,836	33,762	38,856	41,306
Mill products	NA	NA	NA	27,837	29,946
Exports:[1]					
Sponge	46	63	85	80	136
Other unwrought	164	188	204	210	1,173
Scrap	6,133	5,809	5,083	5,989	5,474
Ingot, slab, sheet bar, etc.	2,039	1,922	2,467	2,083	2,702
Other wrought	1,041	1,027	1,801	2,679	NA
Other articles of titanium	NA	NA	NA	NA	3,857
Total[2]	9,423	9,008	9,640	11,041	13,342
Imports:[1]					
Sponge	[3]1,558	1,475	924	1,364	903
Scrap	1,936	2,155	2,218	4,235	5,308
Ingot and billet	162	96	68	237	190
Other unwrought	NA	NA	NA	NA	119
Other wrought (mill products)	1,315	986	892	822	1,049
Other articles of titanium	NA	NA	NA	NA	200
Total[2]	4,970	4,712	4,101	6,658	7,770
Stocks, yearend:					
Government: Sponge (total inventory)	33,413	33,413	33,413	33,413	33,413
Industry:					
Sponge	4,314	2,885	2,272	2,439	2,114
Scrap	10,601	10,485	9,212	8,596	8,028
Ingot	3,629	3,719	4,044	3,933	3,548
Other	31	30	14	8	7
Total industry[2]	18,575	17,119	15,542	14,977	13,697
Reported consumption:					
Sponge	19,601	17,680	17,973	21,003	24,927
Scrap	13,354	14,957	16,363	18,058	17,956
Ingot	31,770	30,664	32,260	35,556	31,396
Mill products (net shipments)	20,648	18,908	20,218	22,558	24,997
Forging and extrusion billet	11,188	9,637	10,968	10,694	11,742
Rod and bar	2,889	2,732	2,932	3,528	3,566
Other[4]	6,571	6,539	6,318	8,336	9,689
Castings (shipments)	348	385	431	[r]473	485

[r] Revised. 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 with those in 1988.

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

[3] Excludes sponge imported for the national stockpile.

[4] Data for sheet and strip, plate, extrusions (other than tubing), pipe and tubing, and other have been combined to avoid disclosing company proprietary data.

Du Pont was on schedule with its addition of 110,000 tons per year of new capacity at De Lisle, MS, to be completed in 1990. Du Pont was also planning a 24,000-ton-per-year expansion of its Altamira, Mexico, TiO_2 plant in 1990, and construction of new 60,000-ton-per-year plants during the next few years in Brazil, the Republic of Korea, and Taiwan.

Kronos Inc. (formerly NL Chemicals Inc.) was proceeding with construction of a new 82,000-ton-per-year chloride-process TiO_2 plant at Lake Charles, LA, scheduled for completion in 1991.

In December, Kerr-McGee announced plans to build a new 54,000-ton-per-year chloride-process TiO_2 plant at a U.S. site to be determined later. Completion is planned for yearend 1992.

SCM Chemicals Inc. announced around midyear plans to expand production at its Ashtabula, OH, plant by about 53,000 tons per year.

TABLE 4

CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON DECEMBER 31, 1989[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	—	155,000
Edge Moor, DE	—	127,000
New Johnsonville, TN	—	280,000
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	—	109,000
Baltimore, MD	63,000	49,000
Total	117,000	943,000

[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.

CONSUMPTION AND USES

Concentrates

Total U.S. consumption of TiO_2 in concentrates increased about 10%, in line with the increase in production of TiO_2 pigment and titanium metal. Ilmenite consumption decreased slightly, while slag consumption increased 38% and rutile consumption rose 4%. 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 for the manufacture of steel and other alloys was about the same as that of 1988. After rising appreciably in 1988, demand for ferrotitanium continued to rise early in 1989, but declined later in the year.

Metal

Net shipments of mill products increased 11% and reached a record-high level, exceeding the previous record set in 1980 by about 380 tons. Sponge production also reached a new high, surpassing the previous peak reached in 1981. Consumption of scrap for remelting dropped slightly and supplied a calculated 43.5% of ingot feedstock compared with 46.2% in 1988. Castings shipments increased 2.5%.

Mill product shipments by product type were 47% forging and extrusion billet; 39% sheet, strip, plate, extrusions and other; and 14% rod and bar. Estimated U.S. mill product usage by application was commercial aircraft,

TABLE 5

COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND

(Metric tons unless otherwise specified)

Component	1986		1987		1988		1989	
	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content
Production	844,274	784,880	878,558	r820,810	926,746	858,166	1,006,581	935,919
Shipments:[1]								
Quantity	984,372	919,050	1,043,129	977,424	1,097,481	1,020,517	1,126,622	1,046,633
Value thousands	$1,530,225	$1,530,225	$1,700,644	$1,700,644	$1,954,656	$1,954,656	$2,352,390	$2,352,390
Exports	101,811	e92,992	108,889	e99,748	118,422	e107,409	212,197	e193,311
Imports for consumption	183,863	e170,928	174,219	e162,767	185,468	e171,743	166,346	e154,669
Stocks, yearend	69,759	e64,851	47,478	e44,358	49,734	e46,053	63,205	e58,768
Consumption, apparent[2]	908,055	e845,176	966,169	e904,322	991,536	e920,805	947,259	e884,562

e Estimated. r Revised.

[1] Includes interplant transfers.

[2] Production plus imports minus exports plus stock decrease or minus stock increase.

Sources: Bureau of the Census and Bureau of Mines.

TABLE 6

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]
1985	685,896	436,366	228,635	181,083	276,944	259,898
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:						
Alloys and carbide	(3)	(3)	(4)	(4)	—	—
Pigments	678,169	429,147	300,013	242,594	279,591	262,998
Welding-rod coatings and fluxes	(3)	(3)	—	—	3,946	3,737
Miscellaneous[5]	839	590	(4)	(4)	68,819	64,641
Total[6]	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[6]	659,584	419,743	414,830	335,395	366,143	345,989

[e] Estimated.
[1] Includes a mixed product containing rutile, leucoxene, and altered ilmenite.
[2] Includes synthetic rutile made in the United States.
[3] Included with "Miscellaneous" to avoid disclosing company proprietary data.
[4] Included with "Pigments" to avoid disclosing company proprietary data.
[5] Includes ceramics, chemicals, glass fibers, and titanium metal.
[6] Data may not add to totals shown because of independent rounding.

42%; military aerospace, 38%; chemical industry, including pulp and paper, 10%; powerplant condensers, 5%; naval and other marine uses, 2%; medical implants, 1%; and other uses, mainly oil drilling, flue-gas desulfurization, and automotive, 2%.

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 in various engines. Major nonaerospace industrial uses are mainly those requiring superior resistance to corrosion.

Pigment

Apparent domestic consumption of TiO_2 pigments was about 947,000 tons, 4.5% less than in 1988, despite full-

TABLE 7

U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS, TITANIUM DIOXIDE CONTENT, BY INDUSTRY[1]

(Percentage)

Industry	1985	1986	1987	1988	1989
Ceramics	W	W	W	0.4	0.4
Coated fabrics and textiles	0.4	0.4	0.3	W	.4
Floor coverings	W	.9	1.2	1.2	1.1
Paint, varnish, lacquer	54.3	52.6	49.5	48.1	50.0
Paper	20.5	20.7	24.3	24.2	25.8
Plastics	16.2	15.8	17.0	17.0	16.3
Printing ink	1.0	1.4	1.2	1.7	.8
Roofing granules	W	.4	.4	.4	.3
Rubber	1.7	2.0	1.8	1.7	1.4
Other	5.9	5.8	4.3	5.3	3.5
Total	100.0	100.0	100.0	100.0	100.0

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1] Data coverage beginning in 1986 was extended to include additional major importers.

TABLE 8

U.S. CONSUMPTION OF TITANIUM PRODUCTS[1] IN STEEL AND OTHER ALLOYS

(Metric tons)

	1985	1986	1987	1988	1989
Carbon steel	438	664	711	877	W
Stainless and heat-resisting steel	1,909	1,982	2,229	2,742	2,647
Other alloy steel (includes HSLA)	445	269	325	249	149
Tool steel	W	W	W	W	W
Total steel[2]	2,792	2,916	3,265	3,868	2,796
Cast irons	21	59	W	W	W
Superalloys	596	572	625	642	800
Alloys, other than above	324	292	290	1,552	873
Miscellaneous and unspecified	16	32	41	54	1,600
Total consumption[2]	3,749	3,871	4,221	6,116	6,069

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.

capacity operation of U.S. TiO_2 pigment plants. The slight easing of domestic demand made a larger part of production available for exports.

STOCKS

A 39% increase in the TiO_2 content of ilmenite stocks was largely offset by a 25% decrease in stocks of titanium slag. Stocks of rutile rose 33%, so that total stocks of TiO_2 in concentrates rose 15%. Stocks of TiO_2 pigment increased 27% to about 63,000 tons, a 24-day supply.

PRICES

Prices of ilmenite rose slightly, and rutile prices increased about 2.5% in 1989, compared with increases in 1988 of 42% and 24%, respectively. Titanium slag prices rose about 10%.

Prices of titanium sponge increased about 12%, while those of titanium mill products rose by an average of about 10%. Titanium scrap prices rose early in the year, but fell considerably in the second half in response to declining demand for ferrotitanium.

Titanium dioxide pigment prices increased 5 cents to 6 cents per pound in the second quarter, and edged a little higher by yearend. There were reports of "gray-market" sales at much higher prices in response to the continued high demand, but the volume of material sold at these inflated prices was believed to be relatively small. Titanium dioxide pigment prices were reportedly significantly higher in other countries than in the United States.

TABLE 9

U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT, DECEMBER 31

(Metric tons)

	Gross weight	TiO_2 content
Ilmenite:[1]		
1987	198,094	120,016
1988	173,372	98,772
1989	236,679	137,643
Titanium slag:[1]		
1987	119,554	96,994
1988	129,537	105,429
1989	96,067	78,078
Rutile:[1]		
1987	107,642	99,987
1988	117,751	108,339
1989	155,024	144,618
Titanium pigment:[2]		
1987	47,478	e44,358
1988	49,734	e46,053
1989	63,205	e58,767

e Estimated.
[1] Producer, consumer, and dealer stocks.
[2] Bureau of the Census. Producer stocks only.

FOREIGN TRADE

Exports of TiO_2 increased an unprecedented 73%, making the United States a net exporter of TiO_2 for four consecutive quarters. Net exports of TiO_2 were about 46,000 tons, amounting to 4.5% of production. The record-high exports were made possible by recent increases in production capacity and a slight easing of domestic demand, with high prices in other countries providing extra incentive.

WORLD REVIEW

World production of TiO_2 in concentrates rose about 6% in 1989. Several heavy mineral projects were announced, and progress was made on projects already underway. World demand for TiO_2 pigments remained at record-high levels, estimated at about 3.0 million tons, and estimated production capacity increased about 5%.

Titanium metal production in the market economy countries increased 19% to nearly 48,000 tons, reflecting continued growth in demand in the United States, Europe, and Japan.

Industry Structure

The titanium industry is moderately integrated from raw materials to semifinished products. The world's largest TiO_2 producer, Du Pont, obtains ilmenite, rutile, and leucoxene from its own mines in Florida and from various suppliers in other countries, mainly Australia. NL Industries (formerly National Lead Co.) 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. From 1942 through 1983, NL Industries operated an ilmenite mine at Tahawus, NY, that supplied its two U.S. pigment plants, one of which was closed in 1978 and the other in 1982. 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

TABLE 10

PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS

		1988[1]	1989[1]
Concentrates:			
Ilmenite, f.o.b. eastern U.S. ports	per metric ton	(2)	(2)
Ilmenite, f.o.b. Australian ports	do.	$64.00–$77.00	$67.00–$75.00
Ilmenite, large lots, bulk, f.o.b. U.S. east coast	do.	NA	NA
Rutile, bagged, f.o.b. Australian ports	do.	547.00–572.00	553.00–632.00
Rutile, bulk, f.o.b. Australian ports	do.	499.00–542.00	514.00–553.00
Rutile, large lots, bulk, f.o.b. U.S. east coast	do.	NA	540.00–550.00
Synthetic rutile, f.o.b. Mobile, AL	do.	NA	NA
Titanium slag, 80% TiO_2, f.o.b. Sorel, Quebec[e]	do.	235.00–255.00	260.00–280.00
Titanium slag, 85% TiO_2, f.o.b. Richards Bay, Republic of South Africa[e]	do.	250.00–275.00	275.00–300.00
Metal:			
Sponge, reported sales	per pound	4.25– 4.75	4.80– 5.30
Sponge, Japanese, under contract, c.i.f. U.S. ports, including import duty	do.	No quotation	No quotation
Mill products:			
Bar	do.	10.50– 11.50	12.56– 16.54
Billet	do.	7.75	8.87– 12.96
Plate	do.	10.70– 12.50	13.07– 15.20
Sheet	do.	8.75– 9.25	10.50– 11.03
Strip	do.	10.25– 10.60	10.50– 11.32
Scrap:			
Cuttings, commercially pure	do.	2.50– 2.65	4.50– 4.66
Turnings, commercially pure	do.	2.50– 2.60	4.02– 4.18
Turnings, unprocessed	do.	2.40– 2.50	2.73– 3.05
Pigment:			
Titanium dioxide pigment, f.o.b. U.S. plants, anatase	do.	.92– .95	1.01– 1.02
Titanium dioxide pigment, f.o.b. U.S. plants, rutile	do.	.95– .97	1.04– 1.05

[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.

Ltd., the major producer of titanium minerals in Australia. Also in 1989, a joint venture between Minproc Holdings and Kerr-McGee 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 the U.S.S.R. or China 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 25% of the world's sponge production capacity. Major U.S. sponge and ingot producers during 1989, their ownership, location, and approximate annual capacities are shown in table 2.

Overseas sponge producers and their shares of the total world capacity of about 116,000 tons in 1989 were the U.S.S.R., 45%; Japan, 23%; the United Kingdom, 4%; and China, 3%.

Titanium dioxide pigment output in 27 countries in 1989 came from about 60 separate facilities ranging in annual capacity from a few thousand tons to 280,000 tons. The United States accounted for 33% of the world's TiO_2 pigment capacity, followed by the Federal Republic of Germany, 10%; Japan, 9%; the United Kingdom, 8%; 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 an annual capacity of about 650,000 tons; Tioxide, with two plants in the United Kingdom and facilities in Australia, Canada, France, Italy, Spain, and South Africa, and an annual capacity of 510,000 tons; SCM Chemicals, with plants in the United States, the United Kingdom, and Australia, and an annual capacity of 430,000 tons; and Kronos Inc., with plants in Belgium, Canada, the Federal Republic of Germany, and Norway, and an annual capacity of 310,000 tons.

U.S. companies, mainly Du Pont, SCM, Kronos, and Kerr-McGee, own or control nearly half of the world productive capacity for TiO_2 pigments. Tioxide controls about 16%. An estimated 7% is owned by Governments of countries with centrally planned economies. The remaining 30% is principally owned 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.

Major U.S. producers of TiO_2 pigments during 1989, their ownership, annual capacities, and plant locations are shown in table 4.

Capacity

The data in table 15 are rated capacities for mines and benefication plants, sponge metal facilities, and TiO_2 pigment plants as of December 31, 1989. Rated capacity is defined as the maxi-

TABLE 11

U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS[1]

Class	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Metal:						
Sponge	85	$746	80	$574	136	$910
Scrap	5,083	9,721	5,989	23,374	5,474	22,909
Ingots, billets, slabs, etc.	2,467	44,203	2,083	33,312	NA	NA
Other unwrought	204	2,254	210	1,480	NA	NA
Billet	NA	NA	NA	NA	1,128	21,765
Blooms and sheet bars	NA	NA	NA	NA	1,240	27,630
Ingot	NA	NA	NA	NA	334	5,471
Other	NA	NA	NA	NA	1,173	8,906
Wrought	1,801	40,534	2,679	71,958	NA	NA
Bars and rods	NA	NA	NA	NA	1,848	49,969
Other	NA	NA	NA	NA	2,009	60,542
Total[2]	9,640	97,458	11,041	130,698	13,342	198,102
Ores and concentrates	4,023	1,395	9,368	3,729	19,832	5,900
Pigment and oxides:						
Titanium dioxide pigments	108,889	181,707	118,422	219,237	68,485	141,359
Titanium oxides	NA	NA	NA	NA	143,712	296,286
Titanium compounds, except pigment-grade	11,819	28,478	4,478	14,885	NA	NA
Total[2]	120,708	210,185	122,900	234,122	212,197	437,645

NA Not available.

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, export categories for 1989 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.

mum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and temporarily closed facilities that, in the opinion of the author, can be brought into production within a short period of time and with minimum capital expenditure.

Mine and mill capacity for the production of titanium concentrates, metal production plant capacity, and TiO_2 pigment plant capacity are generally based on close to 365-days-per-year operation, three shifts per day. Capacity figures are based on information obtained from the producing companies, from news items, and from Bureau of Mines estimates.

Reserves

U.S. and world reserves and reserve base data for titanium are shown in tables 16 and 17. U.S. reserves of 7.8 million tons of TiO_2 in ilmenite and 300,000 tons of TiO_2 in rutile occur mainly in ancient beach sand deposits in Florida. Ilmenite concentrates from the U.S. sand deposits contain about 60% to 65% TiO_2, while those from rock deposits contain 45% to 50% TiO_2. The U.S. reserve base of 34.7 million tons of TiO_2 occurs as 23.5 million tons in ilmenite, 9.8 million tons in perovskite ($CaTiO_3$), and 1.4 million tons in rutile.

Other U.S. resources include additional rock deposits of ilmenite in California, Minnesota, New York, and Wyoming, and sand deposits of ilmenite and/or rutile in Georgia, Idaho, New Jersey, North Carolina, Oregon, and South Carolina, as well as large quantities of accessory rutile in porphyry copper ores and mill tailings.

The Bureau of Mines is compiling a computerized file of worldwide mineral deposit data called the Minerals Availability System (MAS). Most of the resource data in table 16 and 17 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 Rension Goldfields Consolidated Ltd., Consolidated Rutile Ltd., Westralian Sands Ltd., and Cable Sands Ltd. Reserves at Allard Lake, Quebec, Canada, are held by QIT-Fer et Titane Inc. (QIT), now a subsidiary of RTZ Corp. PLC. QIT also has a 50% interest in Richards Bay mineral sands deposits in the Republic of South Africa. Major deposits in Brazil, India, and Sri Lanka are held by the respective Governments. NL Industries controls Titania/AS, owner of the large hardrock deposit at Tellnes, Norway.

Adequacy of Reserves

U.S. reported consumption of TiO_2 in concentrates in 1989 was 1,101,000 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, at the current level of import reliance, 71% of reported consumption, these reserves would provide a 25-year supply of titanium. The U.S. reserve base of 35 million tons TiO_2 content is equivalent to 32 times the 1989 domestic consumption level.

Production and consumption of TiO_2 in concentrates in 1989 in the rest of the world was about 4.1 million tons. World reserves of TiO_2 shown in table 17 total 289 million tons, or 70 times 1989 world consumption.

Australia

RGC announced that its subsidiary, AMC Mineral Sands Ltd., will develop the Enneaba West mineral sands deposit 5 km west of AMC's Enneaba operations in Western Australia. Annual production is expected to be 180,000 tons of ilmenite, 41,000 tons of rutile, and 68,000 tons of zircon, with plant startup planned for early 1991. AMC also planned to expand synthetic rutile production capacity at its Narngulu facility from 112,500 tons per year to 260,000 tons per year by 1992.

Partners Kerr-McKee and Minproc Holdings Ltd. were proceeding with the Cooljarloo Joint Venture in Western Australia. The project will involve operations at three separate locations: mining and wet concentration of the ore at Cooljarloo, 170 km north of Perth, which began in late 1989; a dry-separation plant and a synthetic rutile plant at Muchea, to begin operation in the first half of 1990; and a TiO_2 pigment plant at Kwinana, scheduled for completion in early 1991. Planned annual production capacities were 130,000 tons of synthetic rutile and 54,000 tons of TiO_2 pigment.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES, BY COUNTRY[1]

Concentrate and country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ilmenite:						
Australia	302,567	$10,640	348,364	$16,657	317,835	$20,335
Ghana[2]	—	—	3,291	178	—	—
India	4,948	1,341	—	—	—	—
Sierra Leone	—	—	21,516	1,625	52,261	2,895
Sri Lanka	—	—	21,000	1,029	30,400	1,672
St. Pierre and Miquelon[2]	—	—	—	—	11,255	598
Total[3]	307,515	11,981	394,170	19,489	411,751	25,500
Titanium slag:						
Canada	199,004	41,625	222,626	48,597	117,609	25,260
South Africa, Republic of	209,781	41,381	212,015	44,292	268,537	59,851
Total	408,785	83,006	434,641	92,889	386,146	85,111
Rutile, natural:						
Australia	102,284	41,199	99,934	44,546	108,380	54,213
Canada	—	—	—	—	82	28
Mexico	—	—	—	—	1,050	35
Sierra Leone	17,318	6,668	36,165	16,163	32,793	17,294
South Africa, Republic of	26,204	9,542	18,051	6,167	46,252	19,591
Other	5	3	198	23	68	554
Total[3]	145,812	57,412	154,348	66,899	188,625	91,715
Rutile, synthetic:						
Australia	46,014	12,021	62,281	20,462	64,190	22,517
China	92	34	32	13	—	—
India	2,927	1,127	8,007	3,203	9,101	4,179
Japan	3,085	1,497	6,456	3,372	2,979	1,515
Netherlands	6	22	—	—	(4)	2
Total[3]	52,125	14,701	76,776	27,050	76,270	28,213
Titaniferous iron ore:[5]						
Canada	11,928	757	24,802	1,534	37,922	1,876

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 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 Bureau of Mines.

Brazil

Compania Vale Do Rio Doce was progressing with plans to construct a plant to produce 300,000 to 500,000 tons per year of 90%-TiO_2 anatase concentrate. A large part of the anatase plant product was reportedly committed to Du Pont, including feed for a proposed 60,000-ton-per-year TiO_2 pigment plant in Brazil to be completed in 1993–94.

Canada

At yearend, QIT announced that it will increase its production capacity of 80%-TiO_2 slag at Sorel, Quebec, to about 1.1 million tons per year by September 1990.

Japan

ISK, the largest TiO_2 producer in Japan, was reportedly expanding its facilities in Yokkaichi by a few percent to about 50,000 tons per year by the chloride process and 96,000 tons by the sulfate process.

Japan has been outstanding in the development of innovative, nonaerospace applications for titanium. In early 1989, Suisman Titanium Corp. published a review and listing of titanium usage in Japanese buildings, which totalled about 180,000 kilograms in 1987 and 113,000 kilograms in 1988.[1]

Titanium sponge metal production in Japan rose 17% to about 21,000 tons. At yearend, producers were planning further increases in production rates.

Madagascar

QIT's plans for development of a mineral sands deposit near Fort Dauphin were extended somewhat, with mining expected to begin in 1993–94.

Malaysia

Tioxide was on schedule with plans for construction of a 50,000-ton-per-year TiO_2 pigment plant in Malaysia, to be completed by yearend 1991.

Mexico

Du Pont announced plans for a 24,000-ton-per-year expansion of its chloride-process TiO_2 pigment plant in Altamira. Completion is scheduled for 1990, with plant capacity of 79,000 tons per year.

Mozambique

Kenmore Resources PLC, Dublin, Ireland, was progressing with plans to develop a mineral sands deposit 15 km north of Angoche. Initial production was expected in the spring of 1992, with annual production of about 420,000 tons of ilmenite, 8,000 tons of rutile, 37,000 tons of zircon, and about 1,000 tons of monazite.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY COUNTRY

(Metric tons)

Country	1989	
	Quantity (metric tons)	Value (thousands)
80% or more titanium dioxide:		
Australia	1,281	$2,281
Belgium	7,663	12,047
Canada	25,608	38,081
China	1,434	1,867
Finland	2,432	4,536
France	3,015	6,108
Germany, Federal Republic of	20,555	35,109
Japan	3,932	7,731
Netherlands	1,611	3,002
Norway	744	1,044
Singapore	4,323	6,241
United Kingdom	956	1,883
Other	435	863
Total	73,989	120,793
Other titanium dioxide:		
Belgium	1,601	2,618
Canada	3,629	5,904
France	15,352	21,365
Germany, Federal Republic of	5,220	11,885
Italy	6,075	10,717
Norway	2,802	3,420
South Africa, Republic of	906	1,522
Spain	16,020	27,673
United Kingdom	7,125	12,489
Other	327	825
Total	59,057	98,418
Titanium oxide:		
Australia	225	409
Belgium	100	249
Canada	15,752	24,777
China	553	908
Finland	860	1,546
France	5,058	9,056
Germany, Federal Republic of	121	993
Japan	709	1,781
Mexico	671	1,789
United Kingdom	8,770	15,237
Yugoslavia	274	711
Other	207	473
Total	33,300	57,929
Grand total	166,346	277,140

Source: Bureau of the Census.

Sierra Leone

In May 1989, International Gold and Minerals NL and MC Mining NL of Australia signed an agreement with the Government of Sierra Leone to develop a rutile-bearing mineral sand deposit about 60 km east of Freetown. A preliminary feasibility study was said to indicate possible production of 56,000 tons per year of rutile, 83,000 tons per year of ilmenite, and 6,000 tons per year of zircon. Reserves of 146 million tons of ore grading 0.6% rutile, 0.8% ilmenite, and 0.06% zircon were delineated in the 1970's by a joint-venture partnership between Bayer AG and Preussag AG, Federal Republic of Germany, when mineral sand markets were depressed.

Singapore

In April, ISK began operation of the first phase of its new chloride-process TiO_2 plant at Tuas, Singapore. Initial production capacity is 36,000 tons per year, and ISK was reportedly considering a second phase of plant construction that would double capacity to 72,000 tons per year.

Spain

Tioxide approved expansion of its TiO_2 plant at Huelva, Spain, operated by Tioxide Espana SA, from 60,000 to 80,000 tons per year, in response to demands from the domestic market.

CURRENT RESEARCH

As part of a Bureau of Mines program to develop a more continuous titanium metal process that utilizes domestic resources, a study was made of the kinetics of hydrofluoric acid (HF) leaching of New York rock ilmenite. The leaching rate was found to be linearly dependent on the HF concentration and inversely proportional to the average starting diameter of the ilmenite particle. Using 19 molar HF at 45° C, 99% of the titanium and 100%

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY[1]

Class and country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought:						
Sponge:						
China	16	$54	390	$2,656	225	$1,709
Japan	907	6,252	949	7,668	649	6,203
United Kingdom	—	—	23	172	9	109
Other	(2)	15	3	27	20	160
Total[3]	924	6,321	1,364	10,523	903	8,181
Waste and scrap:						
Austria	281	673	433	1,597	142	1,209
Belgium-Luxembourg[4]	135	206	63	175	8	50
Canada	142	280	345	1,539	480	3,517
China	64	112	145	981	173	1,225
France	212	631	180	1,157	216	1,451
Germany, Federal Republic of	193	694	406	2,609	303	2,719
Japan	547	1,893	1,903	10,181	2,121	15,482
Salvador	—	—	—	—	111	736
Sweden	—	—	—	—	87	587
United Kingdom	467	1,641	557	3,619	919	9,204
U.S.S.R.	—	—	—	—	524	4,007
Other	176	449	204	1,005	224	1,711
Total[3]	2,218	6,579	4,235	22,863	5,308	41,898
Ingot and billets:						
Germany, Federal Republic of	13	245	17	629	—	—
Hong Kong	—	—	—	—	86	713
Israel	11	338	11	342	—	—
Japan	42	436	61	740	36	527
United Kingdom	1	29	137	1,300	68	862
Other	r2	r63	r11	r152	—	—
Total[3]	69	1,111	237	3,011	190	2,102
Powder:						
Israel	NA	NA	NA	NA	31	887
Other	NA	NA	NA	NA	6	374
Total	NA	NA	NA	NA	37	1,261
Other:[5]						
China	NA	NA	NA	NA	35	95
United Kingdom	NA	NA	NA	NA	33	433
Other	NA	NA	NA	NA	14	4,445
Total	NA	NA	NA	NA	82	4,973
Wrought titanium:[6]						
Canada	351	7,112	298	5,548	638	14,693
France	—	—	—	—	17	516
Germany, Federal Republic of	42	463	78	1,012	25	792
Japan	435	6,683	355	6,117	474	11,671
Sweden	—	—	—	—	16	3,165
United Kingdom	39	790	65	1,884	56	1,584
Other	24	698	26	1,178	24	1,664
Total[3]	891	15,747	822	14,743	1,250	34,085

r Revised. NA Not available.
[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable with those in prior years.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.
[4] For 1987 Belgium and Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.
[5] Includes blooms, sheet bars, slabs, and other unwrought.
[6] Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strips, tubes, wire, and other.

Source: Bureau of the Census.

TABLE 15

WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand metric tons of TiO_2 content of concentrates, gross weight of sponge (over 99% Ti), and gross weight of pigment [average about 95% TiO_2])

	Ilmenite	Rutile	Rutile, synthetic	Sponge metal	TiO_2 pigment		
					Sulfate[1]	Chloride[2]	Total
North America:							
Canada	[3]830	—	—	—	74	38	112
Mexico	—	—	—	—	—	55	55
United States	210	26	100	29	117	943	1,060
Total	1,040	26	100	29	191	1,036	1,227
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	—	—	—	—	38	—	38
Norway	450	—	—	—	27	—	27
Poland	—	—	—	—	36	—	36
Spain	—	—	—	—	65	—	65
U.S.S.R.	250	10	—	52	100	—	100
United Kingdom	—	—	—	5	136	128	264
Yugoslavia	—	—	—	—	28	—	28
Total	700	10	—	57	1,142	208	1,350
Africa:							
Sierra Leone	35	120	—	—	—	—	—
South Africa, Republic of	[5]640	56	—	—	35	—	35
Total	675	176	—	—	35	—	35
Asia:							
China	90	—	—	3	25	—	25
India	200	19	138	—	12	22	34
Japan	—	—	46	27	256	44	300
Korea, Republic of	—	—	—	—	18	—	18
Malaysia	275	—	46	—	—	—	—
Singapore	—	—	—	—	—	36	36
Sri Lanka	80	13	—	—	—	—	—
Taiwan	—	—	—	—	10	—	10
Thailand	16	—	—	—	—	—	—
Total	661	32	230	30	321	102	423
Oceania: Australia	1,100	260	250	—	63	70	133
World total (may be rounded)	4,260	520	580	116	1,800	1,420	3,220

[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.

Source: Technical publications, especially Industrial Minerals; industry contacts; and Bureau of Mines estimates.

TABLE 16

U.S. TITANIUM RESERVES AND RESERVE BASE IN 1989

(Thousand metric tons of TiO_2 content)

	Reserves			Reserve base[1]		
	Ilmenite	Rutile	Total	Ilmenite and perovskite[2]	Rutile and anatase[3]	Total
Arkansas	—	—	—	—	200	200
California	—	—	—	600	—	600
Colorado	—	—	—	9,800	—	9,800
Florida	7,800	300	8,100	7,800	300	8,100
New York	—	—	—	7,900	—	7,900
Tennessee	—	—	—	5,600	900	6,500
Virginia	—	—	—	1,600	—	1,600
Total United States	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.

of the iron in the ilmenite were leached in 40 minutes.[2] The HF leach solution was treated by solvent extraction to remove iron, and calcium carbonate was added to form calcium fluorotitanate ($CaTiF_6$), which was precipitated by evaporation. Limited reduction tests were carried out on the $CaTiF_6$ in induction slag casting and melting furnaces. Complete reduction to metallic titanium and calcium fluoride was achieved, with the metallic titanium finely disseminated throughout the slag.[3]

The Bureau of Mines studied a sulfate-fluoride system to process Colorado perovskite to recover potassium fluorotitanate. This double salt, after washing and drying, was subjected to

TABLE 17

WORLD TITANIUM RESERVES AND RESERVE BASE IN 1989

(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	8,000	33,300	1,400	35,000
Total	35,000	300	35,000	106,300	1,400	108,000
South America:						
Brazil	1,600	66,000	68,000	1,600	86,000	88,000
Europe:						
Finland	1,400	—	1,400	1,400	—	1,400
Italy	—	—	—	9,000	21,000	30,000
Norway	32,000	—	32,000	90,000	—	90,000
U.S.S.R.	5,900	2,500	8,400	13,000	2,500	16,000
Total	39,000	2,500	42,000	113,000	24,000	137,000
Africa:						
Egypt	—	—	—	1,400	—	1,400
Madagascar	—	—	—	15,000	—	15,000
Mozambique	2,300	100	2,400	2,300	100	2,400
Sierra Leone	1,000	2,000	3,000	1,000	2,000	3,000
South Africa, Republic of	36,000	3,600	40,000	45,000	4,500	50,000
Total	39,000	5,700	45,000	65,000	6,600	72,000
Asia:						
China	30,000	—	30,000	41,000	—	41,000
India	31,000	4,400	35,400	31,000	4,400	35,000
Malaysia	—	—	—	1,000	—	1,000
Sri Lanka	3,600	800	4,400	3,800	800	4,600
Total	65,000	5,200	70,000	77,000	5,200	82,000
Oceania:						
Australia	24,000	5,300	29,000	45,000	14,000	59,000
World total	204,000	85,000	289,000	407,000	139,000	545,000

[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.

TABLE 18

TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE, AND TITANIFEROUS SLAG), BY COUNTRY[1]

(Metric tons)

Concentrate type and country	1985	1986	1987	1988[p]	1989[e]
Ilmenite and leucoxene:[2]					
Australia:					
Ilmenite	1,418,867	1,237,694	1,498,087	1,610,175	1,764,000
Leucoxene	13,809	14,143	11,290	11,742	12,000
Brazil	76,354	75,472	111,649	134,580	135,000
China[e]	140,000	140,000	140,000	150,000	150,000
Finland	53,000	—	—	—	—
India[e 3]	[4]143,000	140,000	140,000	140,000	160,000
Malaysia	314,736	414,941	509,202	486,305	497,000
Norway	735,842	803,622	852,322	[e]875,000	880,000
Portugal	227	232	141	59	110
Sierra Leone	—	—	5,600	42,118	[4]62,310
Sri Lanka	114,854	129,907	128,500	74,305	75,000
Thailand	1,078	13,489	27,078	18,254	17,800
U.S.S.R.[e]	445,000	450,000	455,000	460,000	460,000
United States	W	W	W	W	W
Total	3,456,767	3,419,500	3,878,869	4,002,538	4,213,220
Rutile:					
Australia	211,615	215,774	246,263	230,637	266,000
Brazil	713	495	511	1,142	1,000
India[e 3]	[4]6,800	7,000	7,000	[r]5,000	5,000
Sierra Leone	80,611	97,100	113,300	126,358	[4]128,340
South Africa, Republic of[e]	55,000	55,000	55,000	55,000	60,000
Sri Lanka	8,558	8,443	7,200	5,255	5,200
Thailand	110	48	92	128	150
U.S.S.R.[e]	10,000	10,000	10,000	10,000	10,000
United States	W	W	W	W	W
Total	373,407	393,860	439,366	433,520	475,690
Titaniferous slag:					
Canada[e 5]	845,000	850,000	925,000	1,025,000	1,040,000
South Africa, Republic of[e 6]	435,000	435,000	650,000	700,000	725,000
Total	1,280,000	1,285,000	1,575,000	1,725,000	1,765,000

[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: 1985—2,596,122; 1986—2,772,082; 1987—3,344,318; 1988—3,400,000; and 1989—3,500,000(estimated). This material reportedly contains 20% TiO_2. Table includes data available through June 13, 1990.

[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] Data are for fiscal year beginning Apr. 1 of year stated.

[4] Reported figure.

[5] Contains 80% TiO_2.

[6] Contains 85% TiO_2.

metallothermic reductions with either potassium or aluminum to produce titanium metal. Potassium reduction produced titanium metal of fine particle size, with oxygen content of 1%. Aluminum reduction in a molten zinc bath produced titanium metal with only 7% aluminum.[4]

The Bureau of Mines investigated the properties of ceramic particulate composites made from titanium nitride (TiN), alumina (Al_2O_3), and aluminum nitride (AlN) as part of a program to meet the high-performance demands on structural materials for new and emerging technologies. The best test results were obtained on a mixture of 40% TiN, 30% Al_2O_3 and 30% AlN.[5]

Bureau of Mines researchers measured the solubility of $TiCl_4$ in supercritical, liquid, and gaseous carbon dioxide (CO_2). $TiCl_4$ proved to be highly soluble in supercritical CO_2, and the two compounds were completely miscible near 1,500 pounds per square inch between 32° and 50° C. The $TiCl_4$ solubilities measured during this investigation are relevant to processes for recovering or purifying $TiCl_4$.[6]

The U.S. Geological Survey published results of a study on the geologic evolution of the Trail Ridge heavy-mineral sand deposit in Florida. Trail Ridge apparently represents a coast-parallel transgressive dune complex, analogous to younger dunes elsewhere that have become completely decoupled from parental shorelines.[7]

Research continued on titanium aluminides, especially Ti_3Al (α_2), which was already in limited use in aircraft turbine engines. Addition of stabilizing elements, particularly niobium, was the most successful approach to improving ductility. Properties were also improved by rapid solidification processing. Titanium aluminides have lower density and better resistance to creep and high-temperature oxidation than conventional titanium alloys.[8] Rapidly solidified titanium aluminide alloys are among the major potential materials needed for the National Aerospace Plane (NASP). NASP materials must combine the use-temperature capability of superalloys with the density of titanium alloys.[9]

Researchers at Sandia National Laboratories, Albuquerque, NM, reported significant progress in the use of solar energy to decompose organic pollutants in water. The promising results were achieved by testing the breakdown of an organic acid with a TiO_2 catalyst. Using concentrated solar power to speed up the reaction makes the process more commercially attractive. A Sandia representative said they believe the process will destroy most organic materials.[10]

OUTLOOK

World production and demand for titanium sponge metal in 1989 is estimated at about 96,000 tons. Demand is expected to grow at 3% to 5% per year during the next several years. Titanium demand is being driven mainly by the record-high level of orders for commercial airliners, as well as gradually increasing requirements for other industrial uses. The growth in demand for commercial aircraft is expected to more than offset anticipated cutbacks in military aircraft programs. Recently completed and announced future expansions of U.S. titanium sponge production capacity are believed to be sufficient to take care of increasing titanium demand for the next several years.

World TiO_2 pigment production and demand in 1989 are estimated at about 3.0 million tons. Industry sources project the growth of world TiO_2 demand at about 3% per year. Annual growth in demand by market area is expected to be about 5% in Asian countries bordering the Pacific Ocean, 3% in North America and Europe, and 2% in the rest of the world. If all of the planned TiO_2 pigment projects are completed, it is believed that demand can be supplied with a moderate capacity surplus, at least through 1994. The magnitude of the capacity surplus will depend mainly on economic conditions during that period.

If plans for all of the announced titanium raw material projects are implemented, an additional 1.2 million tons per year or more of TiO_2 in concentrates could be produced by 1995. At 3% annual growth in demand for TiO_2 pigments and 5% for titanium metal, additional annual demand for TiO_2 in concentrates by 1995 would be about 800,000 tons. The supply of TiO_2 in concentrates is, therefore, likely to be adequate through 1995.

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 crystallities, 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 1989 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, 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 titanium tetrachloride 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 addi-

TABLE 19

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
Qxygen	.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.

tions. Specifications for titanium sponge for the National Defense Stockpile are given in table 19.

Titanium dioxide pigment is characterized by its purity, high refractive index, fine 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 as an opacifier in paper.

Specifications for natural rutile for the National Defense Stockpile are shown in table 20. There are no rigid specifications for raw materials to be used as feed for making $TiCl_4$ for metals or pigment manufacture or for ilmenite or slag to be used in the sulfate pigment process. However, certain impurities such as chromium, columbium, manganese, phosphorus, and vanadium can seriously impair pigment properties, so these impurities are an important consideration in the selection of concentrates for pigment production. Concentrates to be used for making $TiCl_4$ should be low in calcium and magnesium, which form high-boiling-point chlorides that cause trouble in fluid-bed chlorinators. Chemical compositions of typical commercial titanium concentrates are shown in table 24.

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 located near continental margins where erosion of regional granitic and metamorphic rocks contain-

TABLE 20

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.

ing 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, hardpan, roots, stumps and other organic material, as well as the depth of the water table.

Approximate minimum requirements for an economic sand deposit of titanium minerals include reserves of 300,000 to 1 million tons of TiO_2 content in rutile or ilmenite and heavy mineral content in the ore of 1% to 5%, depending on the mix of ilmenite, rutile, and other valuable minerals.

Mining and Concentration.—For mining sand deposits of titanium minerals, a dredge is usually used. This may be bucket-ladder type, but is more likely to be suction type. The dredge floats in its own pond, digging forward and stacking tailings aft.

Rough concentration, the separation of heavy minerals from the lighter quartz-feldspar-mica fraction, is usually accomplished by wet-gravity methods. The Humphreys spiral has been standard for this separation since its introduction about 1940, but pinched-sluice separators of various designs 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.

TABLE 21

COMPOSITION OF TYPICAL COMMERCIAL TITANIUM CONCENTRATES

(Weight percentage)

	Ilmenite				Slag		Rutile	Synthetic rutile		
	United States		Norway, Tellnes	Australia, Bunbury	Canada, Sorel	Republic of South Africa, Richards Bay	Australia, East Coast	United States, Kerr-McGee	Australia, Western Titanium	Japan, Isihara
	New York	Florida								
TiO_2 (total)	46.1	64.0	45.0	54.4	80.0	[1]85.0	95.2	94.15	92.0	96.1
Ti_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	—
P_2O_5	.008	.12	.04	.02	—	—	.8	—	—	.17
ZrO_2	.01	—	—	—	—	—	.2	—	—	.15
Nb_2O_5	.01	.10	.01	.14	—	—	.03	—	—	.25
Ignition loss	1.3	—	—	0.4	—	—	.1	.6	—	—

[1]Minimum.
[2]Maximum.

Source: Technical publications and industry contacts.

TABLE 22

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
1969	0.48	1.21	1.32	3.32
1970	0.45	1.07	1.32	3.14
1971	0.45	1.01	1.32	2.97
1972	0.45	0.97	1.32	2.84
1973	0.50	1.01	1.42	2.87
1974	0.72	1.33	2.25	4.17
1975	0.73	1.23	2.70	4.55
1976	0.78	1.24	2.70	4.28
1977	0.81	1.20	2.98	4.43
1978	0.85	1.18	3.28	4.54
1979	0.98	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

The rutile fraction is further cleaned by screening and additional electrostatic separation. Zircon and monazite products are recovered from the nonconductor fraction of the wet-mill concentrate by a combination of gravity, electrostatic, and high-intensity magnetic separation.

Ilmenite is also mined from two hard-rock deposits, one in Canada, and one in Norway. The ore bodies are massive, and open pit mining is practiced.

At Tellnes, Norway, the ore is crushed, ground, and subjected to wet-magnetic separation to recover magnetite. An ilmenite concentrate containing about 44.5% TiO_2 is recovered by flotation of the nonmagnetic portion, as was formerly done at the MacIntyre Development, Tahawus, NY, where ilmenite-mining ceased in 1982.

At Allard Lake, Quebec, ore at 32% to 36% TiO_2 is shipped from the mine to the beneficiation plant at Sorel, Quebec; some of the ore is shipped to steel companies as a substitute for fluorspar flux. For upgrading to slag, the ore is crushed and ground, concentrated by gravity methods, roasted to remove sulfur, mixed with a reducing agent, and smelted in an electric arc furnace. A high-purity pig iron is produced. The titanium is concentrated in the slag, known as Sorelslag, which contains 80% TiO_2. Because the iron content of the slag is low, its use reduces the quantity of iron sulfate in the liquid effluent of sulfate process pigment plants. Because of its relatively high content of magnesium and calcium, which cause operating problems during chlorination, Sorelslag is not used to make $TiCl_4$.

At Richards Bay, Republic of South Africa, both rutile and ilmenite are produced from heavy mineral sand deposits. The ilmenite, containing about 50% TiO_2, is relatively low in magnesium and calcium and is smelted with carbon in an electric furnace to produce an 85% TiO_2 slag. Because of its low content of the above previously mentioned impurities, the Richard Bay (RB) slag is acceptable for manufacturing $TiCl_4$ and is also a feed material for the sulfate pigment process.

Pigment Production.—Titanium dioxide pigment is produced commercially by two methods that require different raw materials. In the sulfate process, ilmenite or titanium slag is reacted with sulfuric acid; a portion of the iron sulfate formed may be crystallized and removed, and titanium hydroxide is precipitated by hydrolysis, filtered, and calcined. In the chloride process, rutile is converted to $TiCl_4$ by chlorination at 850° to 950° C in the presence of petroleum coke. All U.S. commercial chloride-process plants use fluid-bed chlorinators, although static-bed systems can be used for this purpose.

Titanium tetrachloride so prepared may be used either in making pigment or, with additional purification, for reduction to metal. In making pigment, the $TiCl_4$ is oxidized with air or oxygen at about 1,000° C, and the resulting fine-size TiO_2 is calcined at 500° to 600° C to remove residual chlorine and any hydrochloric acid that may have formed in the reaction. Aluminum chloride is added to the $TiCl_4$ to ensure that virtually all of the titanium is oxidized in the rutile crystalline form.

Recoveries of TiO_2 in pigment are approximately 90% and 80% to 85% for chloride process and sulfate process plants, respectively.

Metal Production.—Feed materials needed for metal production are the same as those for chloride-process pigment because formation of $TiCl_4$ is required in both cases. Rutile and rutile substitutes are the only titanium raw 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

TABLE 23

U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1989	Jan. 1, 1989
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 val.	30.0% ad val.
Waste and scrap metal	8108.10.1000	Free.	Free.
Unwrought metal, including sponge	8108.10.50	15.0% ad val.	25.0% ad val.
Wrought metal: Articles of titanium	8108.90.30	5.5% ad val.	45.0% ad val.
Other	8108.90.60	15.0% ad val.	45.0% ad val.
Titanium dioxide pigments	3206.10.00	6.0% ad val.	30.0% ad val.
Titanium oxides	2823.00.0000	6.0% ad val.	30.0% ad val.

scrap and alloying additions, and made into ingot by two or more successive vacuum-arc melting operations.

Recycling.—Scrap titanium generally accounts for 40% to 50% of ingot production. Scrap is generated by producers of ingot and mill products and by consumers of mill products in fabricating finished products or components. It is estimated that up to 75% of titanium ingot metal becomes scrap during processing to finished parts. However, the proportion of scrap is gradually being lowered because of increased use of castings and other near net-shape technologies.

Clean and well-segregated scrap, processed to remove impurities, is blended with sponge metal and alloying constituents and remelted to ingot. Remelting is mainly by vacuum-arc consumable-electrode processing. Electron-beam and plasma-arc cold-hearth melting is also used, especially for chips and turnings. Cold-hearth melting is very effective in ensuring removal of high-density inclusions, such as tungsten carbide tool particles, which settle 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. In 1988–89, annual use of titanium scrap for remelting to ingot was about 18,000 tons; for use in steel and superalloys, 4,500 tons; and in aluminum alloys, 500 tons.

Economic Factors

Prices.—The price of rutile pigments and titanium sponge in constant dollars decreased 20% and 14%, respectively, from 1969 through 1972, as shown in table 22. Reflecting a sharp increase in pigment demand, the constant dollar price rose 32% in 1974. The rutile price did not surpass that level until 1989, following 6 consecutive years of record-high demand. 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. Published prices of titanium concentrates and products in 1988–89 are listed in table 10.

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 23 reflect results of the Tokyo Round of Multilateral Trade Negotiations completed in 1979 under which tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1, 1987.

Depletion Provisions.—The depletion allowance for ilmenite and rutile is 22% when mined from domestic deposits and 14% from foreign deposits.

Operating Factors

Environmental Requirements.—Heavy mineral sand mining presents few serious environmental hazards. The land is restored by returning the bulk of the sand after removal of the ore minerals and may even be improved in low, flat areas. Dune areas can be left in nearly their original form, and the sand can be stabilized by seeding and replanting.

The major environmental problem in the titanium industry is the disposal of wastes from pigment-producing processes that use ilmenite, generating up to 3.5 tons of waste per ton of product. Solutions to this problem required the development of methods to neutralize and control the effluent now produced by the sulfate pigment process, mainly a solution of waste sulfuric acid and ferrous sulfate heptahydrate. Deep well disposal has been used for waste ferric chloride produced when ilmenite is used to make $TiCl_4$. In processes for making synthetic rutile, the effluent solutions are treated to regenerate the original leaching agent, such as hydrochloric acid, which is recycled, and to form useful byproducts such as sodium sulfate, ammonium sulfate, and iron oxide. In sulfate-process technology, there is a strong trend away from disposal of waste materials in streams or in the ocean. Both U.S. sulfate-process producers now are using waste treatment plants that neutralize acid effluent with limestone and lime and produce gypsum and iron oxide byproducts. Such neutralization processes add about $100 per ton to the cost of the TiO_2 pigment product. The sale of all byproducts 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.[11] 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.[12] 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 TiO_2 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 Bureau of Mines, energy requirements for alluvial mine production are about 5.1 million British thermal units (Btu) per ton of TiO_2 in concentrate. Production of pigment requires about 75 to 112 million Btu per ton of TiO_2, depending on the process and feed material used. Titanium sponge production uses from 408 to 466 million Btu per ton of metal, of which about 248 to 270 million Btu is required to regenerate the reductant and chlorine. The conversion of sponge metal to titanium ingot requires an additional 46 million to 57 million Btu per ton of titanium ingot.[13]

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TUNGSTEN

By Gerald R. Smith

Mr. Smith, a physical scientist with 26 years of research and commodity experience with the 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, Branch of Technical Analysis.

Average prices for tungsten concentrate remained essentially unchanged during 1989 compared with those of 1988, thus preventing any significant resumption of U.S. tungsten mining. Dependence upon China as a predominant source of concentrate continued during the year, increasing from 51% of total U.S. imports of concentrate in 1988 to 69% in 1989. In spite of the decrease in imports of ammonium paratungstate (APT) and tungstic acid (TA) from China as a result of the Orderly Marketing Agreement (OMA) signed in 1987, China's share of all U.S. tungsten imports reached 61% in 1989. The total annual domestic tungsten activity, based upon concentrate consumption, production of APT, and net production of intermediate products remained at about the same level as in 1988.

DOMESTIC DATA COVERAGE

Domestic production data for tungsten are developed by the 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 45 operations to which survey requests were sent, all responded, representing 100% of the total production shown in table 1.

LEGISLATION AND GOVERNMENT PROGRAMS

Physical disposals of tungsten from the National Defense Stockpile totaled 466,000 kilograms during the year. The tungsten, contained in nonstockpile-grade ores and concentrates, was released as payment material in support of the Defense Logistics Agency's ferroalloy upgrading program, under the National Defense Authorization Act. Disposals of all tungsten remaining for release, under existing authorization within this program, were completed by the end of fiscal year 1989. The Defense Authorization Act for fiscal year 1990, beginning October 1, 1989, included no further authority for disposal of tungsten.

In the Report of the Secretary of Defense to the Congress on National Defense Stockpile Requirements, presented in April 1989, a recommendation was made that the stockpile goal for tungsten be raised by about 9,180,000 kilograms. The recommendation, based upon a revised assessment of military requirements, would, if implemented, effectively raise the

TABLE 1

SALIENT TUNGSTEN STATISTICS

(Metric tons of tungsten content unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Concentrate:					
Mine production	996	780	34	W	W
Mine shipments	983	817	34	W	W
Value thousands	$9,143	$5,774	$216	W	W
Consumption	6,838	4,804	5,506	7,832	7,725
Shipments from Government stocks	902	301	708	524	466
Exports	124	34	2	r172	203
Imports for consumption	4,746	2,522	4,414	8,045	7,896
Stocks, Dec. 31:					
Producer	60	21	21	21	10
Consumer	1,077	502	329	r499	1,261
Ammonium paratungstate:					
Production	6,527	5,604	5,336	8,357	7,831
Consumption	7,941	6,475	6,363	8,014	8,493
Stocks, Dec. 31: Producer and consumer	1,056	468	292	r1,016	915
Primary products:					
Production	8,219	6,408	7,424	8,068	8,749
Consumption	8,096	7,214	7,228	8,298	7,990
Stocks, Dec. 31:					
Producer	1,968	1,484	1,646	1,890	1,562
Consumer	1,206	860	787	930	761
World: Concentrate:					
Production	r46,579	43,344	42,177	p42,604	e43,280
Consumption	r47,804	44,406	41,427	p42,850	e41,516

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

goal for all tungsten materials to near the existing inventory level and essentially eliminate the need for future tungsten disposals.

The Environmental Protection Agency (EPA) eliminated tungsten sludges that were produced in ore leaching and waste treatment processes from its original list of mineral processing wastes considered for exclusion from the Resource Conservation and Recovery Act guidelines. This was effectively accomplished in an April 17, 1989 Notice of Proposed Rulemaking (54 FR 15316), in which EPA proposed to remove all but 39 mineral processing streams from consideration. By further applying high-volume, low-toxicity criteria to the remaining process streams, the list was reduced to 26 on September 1, 1989, (54 FR 36592).

The EPA announced final amendments to Clean Water Act regulations affecting nonferrous manufacturing that included the secondary tungsten and cobalt subcategory along with five other subcategories. Notice of these amendments, published October 30, 1989, (54 FR 45299), were in response to settlements with six petitioners regarding regulations in 40 CFR 421 promulgated September 20, 1985, (50 FR 38276). The amendments to the secondary tungsten and cobalt subcategory (40 CFR 421.310–40 CFR 421.317) affect only cobalt effluents but are an obvious integral step in the secondary recovery of cemented carbide components.

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 armor plate. 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. The Department of Defense (DOD) relies heavily on the maintenance of a broad domestic production base to cover mobilization contingencies. The entire tungsten industry, from mined ore to manufactured products, thus represents an important component of the U.S. defense policy. The DOD continually assesses the U.S. ability to produce tungsten, in order 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 proposed to be maintained at a level exceeding 32,000,000 kilograms.

TABLE 2

U.S. GOVERNMENT TUNGSTEN STOCKPILE MATERIAL INVENTORIES AND GOALS

(Metric tons of tungsten content)

Material	Goals	Inventory by program, Dec. 31, 1989		
		National stockpile	DPA[1] inventory	Total
Tungsten concentrate:				
Stockpile grade	25,152	24,503	72	24,575
Nonstockpile grade	—	10,055	5	10,060
Total	25,152	34,558	77	34,635
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

[1] Defense Production Act (DPA) of 1950.

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
1985	123,944	983	$9,143	$73.77	$9.30
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	—	—

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.

ISSUES

The world tungsten market became increasingly more dependent on supplies of tungsten materials from China during 1989. Concentrate prices re-

mained low and appeared to be dominated primarily by the production, distribution, and pricing strategies of the Chinese, who possess about 47% of the world's tungsten reserves. As a result, most tungsten mines in the United States and other market economy countries remained closed or were operated at reduced capacity during the year. In addition, little or no economic incentive existed to explore or develop other tungsten resources.

PRODUCTION

Releases of tungsten concentrate from the National Defense Stockpile, in support of the ferroalloy upgrading program, provided about 6% of the supply consumed in domestic processing.

Curtis Tungsten Inc., Upland, CA, completed its sale of the initial offering of common stock on June 28, 1989. Revenues realized from this sale enabled production to begin at a relatively low level during the last quarter of the year. A company representative indicated that the annual production capacity of the mine and mill was about 360 metric tons (mt)[1] by yearend. The company continued to modify and adjust its milling operation to ensure the quality of their product. No material was offered for sale on the world market in 1989.

U.S. Tungsten Corp., Bishop, CA, continued as the only other company producing tungsten concentrate. The Pine Creek Mine and mill was operated on an intermittent basis at levels below capacity in order 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. operated its Fort Madison, IA, APT conversion facility at near capacity levels during 1989, following the plant's reopening in August 1988. The company began selling all of its product on the open market upon completion of the tolling contract with Bomar Resources Inc. in July 1989. The tolling agreement had utilized about 70% of the plant's capacity.

TABLE 4

MAJOR PRODUCERS OF TUNGSTEN CONCENTRATE AND PRINCIPAL TUNGSTEN PROCESSORS IN THE UNITED STATES IN 1989

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.

CONSUMPTION AND USES

Total domestic consumption of tungsten in primary end-use categories decreased by about 4% in 1989 compared with that of 1988. Demand for cemented carbides in the combined cutting tool, mining tool, and wear-resistant component industries was strong during the first 8 months of the year but began to decrease in the final months, showing a small gain for the year. This gain was more than offset, however, by a moderate decline in the demand for other tungsten products, including specialty steels, superalloys, chemicals, and mill products made from metal powder. Demand for tungsten in the oil and gas drilling industry weakened during the first half of the year. The number of active drilling rigs in the United States declined steadily from 940 at the end of 1988 to 737 by the end of May 1989. This trend was reversed during the remainder of the year, reaching 1,061 active rigs by yearend.

PRICES

Average prices for wolframite and scheelite concentrate increased by 7% and 1%, respectively, in 1989, according to quotations published in Metal Bulletin.

Government representatives of tungsten producing and exporting countries met in Sydney, Australia in October 1989 to discuss the world tungsten market. Particular emphasis was placed on the supply-demand balance and prices of tungsten materials. Delegates recognized that price targets for concentrates and intermediate materials set at the September 1988 meeting in Changsha, China had not been met. They agreed that these price objectives, averaging

TABLE 5

PRODUCTION, DISPOSITION, AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1989

(Metric tons of tungsten content)

	Hydrogen-reduced metal powder	Tungsten carbide powder		Chemicals	Other	Total
		Made from metal powder	Crushed and crystalline			
Gross production during year	8,016	4,258	W	W	3,563	15,837
Used to make other products listed here	4,258	W	W	W	2,785	7,043
Net production	3,758	W	W	W	5,036	8,794
Producer stocks, Dec. 31	850	467	W	78	167	1,562

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

TABLE 6

CONSUMPTION AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1989, BY END USE

(Metric tons of tungsten content)

End use	Ferro-tungsten	Tungsten metal powder	Tungsten carbide powder	Scheelite (natural-synthetic)	Tungsten scrap[1]	Other tungsten materials[2]	Total[3]
Steel:							
Stainless and heat-resisting	62	—	—	W	W	—	62
Alloy	W	—	—	W	—	W	W
Tool	290	—	—	W	W	—	290
Superalloys	W	21	W	W	237	W	258
Alloys (excludes steels and superalloys):							
Cutting and wear-resistant materials	—	75	4,798	—	145	W	5,018
Other alloys[4]	W	6	(5)	—	W	—	7
Mill products made from metal powder	—	1,828	W	—	—	W	1,828
Chemical and ceramic uses	—	—	—	—	—	52	52
Miscellaneous and unspecified	89	(5)	58	139	51	138	476
Total[3]	442	1,930	[6]4,856	139	433	190	7,990
Consumer stocks, Dec. 31, 1989	45	19	[6]561	24	72	40	761

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 1989

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	57.43	69.00	63.22	57.35	55.43	64.00	59.72	54.17	52.00	56.00	54.00	59.52	60.77	55.13
February	57.00	69.00	63.00	57.15	55.00	64.00	59.50	53.98	51.25	56.00	53.63	59.11	60.70	55.07
March	57.25	69.63	63.44	57.55	55.00	64.50	59.75	54.20	48.40	55.40	51.90	57.21	61.29	55.60
April	58.63	71.50	65.07	59.03	55.00	65.00	60.00	54.43	47.50	53.00	50.25	55.39	61.35	55.66
May	59.00	72.00	65.50	59.42	52.50	64.50	58.50	53.07	46.00	51.00	48.50	53.46	61.87	56.13
June	59.78	73.33	66.56	60.38	51.00	64.00	57.50	52.16	47.60	52.20	49.90	55.01	62.60	56.79
July	60.00	74.00	67.00	60.78	50.11	63.22	56.67	51.41	47.00	53.00	50.00	55.12	59.59	54.06
August	59.14	74.00	66.57	60.39	48.00	62.00	55.00	49.90	45.40	53.00	49.20	54.23	62.88	57.04
September	59.00	74.00	66.50	60.33	48.00	62.00	55.00	49.90	43.00	53.00	48.00	52.91	59.33	53.80
October	58.78	74.00	66.39	60.23	45.78	60.67	53.23	48.28	40.00	48.00	44.00	48.50	60.38	54.78
November	56.00	72.00	64.00	58.06	44.00	59.67	51.84	47.02	40.00	45.60	42.80	47.18	59.70	54.16
December	56.00	72.00	64.00	58.06	43.43	60.71	52.07	47.24	39.00	45.50	42.25	46.57	58.96	53.49

[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 $65.10 for 1989. The average equivalent price per short ton unit of WO_3 was $59.06 for 1989.
[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 $56.57 for 1989. The average equivalent price per short ton unit of WO_3 was $51.31 for 1989.
[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 $48.70 for 1989. The average equivalent price per metric ton unit of WO_3 was $53.69 for 1989.
[4] Weighted average price per metric ton unit of WO_3 was $60.79 for 1989. The equivalent weighted average price per short ton unit of WO_3 was $55.14 for 1989.

TABLE 8

U.S. EXPORTS OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content [1] (metric tons)	Value (thousands)
Austria	—	—	42	$320
Canada	—	—	8	62
Germany, Federal Republic of	140	$1,604	31	231
Japan	—	—	29	221
Mexico	r1	8	(2)	4
Pakistan	r14	104	—	—
Singapore	r17	100	86	648
Turkey	—	—	6	49
South Africa, Republic of	—	—	(2)	4
Total [3]	172	1,815	203	1,539

r Revised.
[1] Calculated based upon an estimated value of $60 per metric unit WO_3.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1988			1989		
	Gross weight (metric tons)	Tungsten content [1] (metric tons)	Value (thousands)	Gross Weight (metric tons)	Tungsten content [1] (metric tons)	Value (thousands)
France	1	(2)	$5	—	—	—
Germany, Federal Republic of	58	41	365	6	4	$71
Hungary	10	7	73	10	7	83
Japan	8	6	93	50	36	376
Luxembourg	110	78	599	—	—	—
Mexico	(2)	(2)	2	14	10	121
Netherlands	—	—	—	14	10	123
South Africa, Republic of	2	1	31	1	1	10
Sweden	—	—	—	14	10	123
United Kingdom	48	34	398	69	49	595
Venezuela	10	7	37	—	—	—
Total [3]	246	174	1,601	178	127	1,503

[1] Tungsten content estimated by multiplying gross weight by 0.7066.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

about $71.00 and $78.00 per metric ton unit (mtu)[2] for wolframite and scheelite, respectively, should remain essentially the same. Consideration was given to certain practical measures that individual countries could take to achieve these objectives in a reasonable period of time. Specifically, the delegates stated that there was a need for the producers and exporters to be responsible and economically rational in their production and marketing policies. They further agreed to carefully examine their sales practices on an individual basis, so as to ensure the consistency of price and supply. Recognizing the importance of the relationship between the price of concentrates and tungsten intermediates, the Chinese delegation stated its intention to coordinate the respective price levels. This would be accomplished by enhancing the administration of its export licensing system for tungsten and tungsten products.

Domestic APT prices decreased about 25% during the year from a range of $87.63 to $88.74 per mtu in January 1989 to a range of $66.41 to $67.79 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.

FOREIGN TRADE

Total U.S. imports of tungsten materials decreased about 6% in 1989. China continued to be the dominant supplier, providing nearly 61% of all imported tungsten materials. Restrictions in the imports of APT and TA from China, in accordance with the OMA, were offset, as in 1988, by significant imports of concentrates, oxides, and sodium tungstate. Imports of concentrate from China increased by 34% compared with those of 1988. China's share of the total U.S. imports of concentrate increased from 51% in 1988 to 69% in 1989.

U.S. processors of tungsten voiced concern during the year that the OMA limitation of imports of APT and TA from China was being circumvented by the import of tungsten oxides. Although total imports of APT and TA from China in 1989 were about 244 mt less

than the OMA quota of 622 mt, the combined imports of APT, TA, and oxides exceeded the quota by about 80 mt.

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 the centrally planned economy countries where capacity information is either incomplete or unavailable.

United Nations Conference on Trade and Development (UNCTAD)

The UNCTAD Committee on Tungsten convened its 21st session in Geneva, Switzerland, in December 1989. A Secretariat paper and national statements presented to the Sessional Working Group provided a review of current market conditions. The Secretariat noted strong economic growth in tungsten-consuming countries, as well as increased trade, but continued low prices. Tungsten mines in many market economy countries continued to remain closed as a result of these low prices. Such actions as China's licensing system to control tungsten exports, the OMA signed between China and the United States, and efforts by individual producer nations to achieve higher prices, had little or no effect on the market. The statements of delegates from several producing countries were consistent with the Secretariat's analysis. Remarks by the Chinese delegation suggested that the market condition was due to a general economic slowdown, a stronger U.S. dollar, and psychological pressure from the overhang of material in the U.S. Defense Stockpile.

As part of the Sessional Working Group, a representative from Metal Bulletin presented a detailed description of the derivation of the publication's quoted tungsten concentrate prices. It was noted that several questions were under review regarding the manner in which prices were quoted. These included the relevance of the present European trading prices as a basis; the need for continuing separate scheelite and wolframite prices, and the importance of initiating individual quotations, namely, one reflecting the trading of Chinese materials, and the other reflecting those of the rest of world.

TABLE 10

U.S. EXPORTS OF TUNGSTEN CARBIDE POWDER, BY COUNTRY

Country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Argentina	1	$25	(1)	$16
Australia	41	944	27	576
Austria	4	113	84	1,202
Belgium	6	243	21	784
Brazil	2	79	17	530
Canada	150	4,366	253	4,448
Chile	1	24	1	29
Denmark	1	31	29	599
Finland	(1)	13	4	97
France	1	43	82	1,866
Germany, Federal Republic of	149	3,445	196	4,699
Hong Kong	1	22	2	56
India	1	24	(1)	19
Ireland	(1)	7	(1)	6
Israel	3	63	(1)	5
Italy	50	2,052	146	4,345
Japan	64	1,372	88	1,291
Korea, Republic of	1	72	8	410
Luxembourg	(1)	7	5	159
Malaysia	1	20	—	—
Mexico	23	450	34	626
Netherlands	9	460	32	889
Singapore	1	17	(1)	12
South Africa, Republic of	3	82	45	573
Spain	6	146	(1)	10
Sweden	(1)	10	80	1,101
Switzerland	5	101	29	621
Taiwan	10	265	5	116
United Kingdom	85	802	169	2,087
Venezuela	—	—	(1)	4
Other	1	40	3	33
Total[2]	618	15,340	1,360	27,209

[1] Less than 1/2 unit.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF TUNGSTEN AND TUNGSTEN ALLOY POWDER, BY COUNTRY

Country	1988			1989		
	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)
Australia	26	20	$647	35	28	$477
Austria	29	23	630	85	68	923
Belgium	7	6	135	1	1	18
Brazil	8	7	220	7	6	210
Canada	70	56	1,630	36	29	790
Denmark	23	19	478	1	1	43
Finland	28	22	443	16	13	314
France	57	46	1,051	15	12	436
Germany, Federal Republic of	138	110	3,841	135	108	3,214
India	1	(2)	23	9	7	153
Israel	101	81	1,249	103	82	1,214
Italy	55	44	1,149	4	3	117
Japan	10	8	200	28	22	695
Korea, Republic of	1	1	18	(1)	(1)	9
Luxembourg	5	4	113	—	—	—
Mexico	5	4	181	7	6	173
Netherlands	227	182	2,620	365	292	4,470
Pakistan	2	1	41	(1)	(1)	8
Singapore	22	18	360	20	16	302
South Africa, Republic of	13	10	206	2	1	53
Sweden	68	54	1,206	19	15	153
Switzerland	31	25	544	7	6	234
Taiwan	7	6	162	21	17	538
Turkey	3	2	96	2	1	42
United Kingdom	14	11	367	32	26	865
Other	(2)	(2)	5	4	2	103
Total[3]	948	759	17,616	954	762	15,554

[1] Tungsten content estimated by multiplying gross weight by 0.80.
[2] Less than 1/2 unit.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

During the discussions on statistics and market developments, the Secretariat made a strong request for more complete reporting of statistics and for participation by all countries in the reporting of data. The lack of data from the major producing countries with centrally planned economies was of continued concern.

The issue of market stabilization and the need for a commodity agreement to increase prices was again raised by the Chinese delegation. After additional remarks from delegates of producing and consuming countries, this discussion was ended without evidence of any progress toward an agreement. Suggestions to remove such discussions from the agenda or to modify the words in the agenda for the next meeting received support, but a consensus of the full committee could not be reached.

The Secretariat reported that efforts during the year to survey Research and Development (R&D) activities in tungsten resulted in only limited response. To further this effort, a sample questionnaire was introduced by the Secretariat for consideration, suggestions, and comments by each of the countries' delegates. On the basis of these replies, it was anticipated that the Secretariat would then be able to accumulate additional R&D information through the country delegations and to report such results at the next UNCTAD meeting.

European Communities (EC)

As a result of its investigation into complaints that China and the Republic of Korea were dumping tungsten materials into the EC, the EC Commission proposed that specific duties be applied. In August 1989, the Commission recommended imposing duties of 40% on ores and concentrates, 30% on APT, and 40% on tungsten oxides and tungstic acid imported from China. The question of the dumping of APT and tungsten carbide powder by the Republic of Korea was dismissed from further consideration by the Commission. After further responses from EC members, the Commission also terminated its investigation into claims that APT and tungsten metal powder were being dumped by China. By yearend, debate was continuing, however, regarding the imposition of duties on imports of Chinese ores and concentrates, tungstic acid, tungsten oxides, and tungsten carbide powder.

International Tungsten Industry Association (ITIA)

The ITIA held its 2nd Annual Meeting in Tokyo, Japan, in October 1989. After election of a new president and vice president, the secretary-general presented a detailed market report, supported by statistics, elaborating on several aspects of the tungsten market. These included trade patterns, supply-demand conditions, actions regarding the U.S. National Defense Stockpile, price trends, and the status of the European Commission's antidumping investigation. On the basis of this information, part of the subsequent discussions focused on attempting to understand the reasons for the low tungsten prices amid a relatively strong demand during the year.

Membership in the ITIA was increased by two; the Association gained four members but lost two of its original members. The new members included one each from the United States and Canada, and two from Japan. The departing members were Eurotungstene

Poudres of France and China National Nonferrous Metals Import and Export Corp. The latter's official reason for its resignation was that the ITIA, which is essentially an industry, consumer-based association, already had one of its subsidiaries, Zhuzhou Cemented Carbide, as a member.

China

The midyear political unrest had little effect on the production and shipment of tungsten materials. Although some brief delays and inconveniences were reported by buyers, there was essentially an uninterrupted flow of material.

Efforts were made by China to gain a share of the market for drill bits used in the mining and oil drilling industries. A private Norwegian company, Bjorn Hansen AS, reportedly was to sell the bits that are to be produced at the Shanghai No. 1 petroleum machinery works. The cost of these bits was said to be considerably less than similar items manufactured in the United States and Europe.

France

Bureau de Recherches Géologiques et Minières (BRGM), through its subsidiary, Cofromines, ceded its 51.15% interest in Eurotungstene Poudres. The latter specializes in the production of tungsten carbide powder, tungsten metal powder and intermediate products of tungsten. The majority of the interest ceded by Cofromines was acquired by Cie Metallurgique et Minière.

Israel

Construction of a tungsten metal powder and tungsten carbide powder production plant began in Ramat Hovav. According to projections, the facility would be in operation in about 2 years at a production capacity of 300 mt per year. After 3 years, the capacity was expected to be doubled. Feedstock will consist of scrap tungsten that is to be processed using a newly developed grinding and purification procedure.

Japan

The Japanese Government added 2.8 days of domestic consumption of tungsten to its ferroalloys stockpile. The private sector was expected to follow the Government's action by increasing its stockpiles of tungsten by 1.2 days. Reportedly, the Government will sus-

TABLE 12

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire:				
Argentina	5	$491	(1)	$8
Belgium	1	149	(1)	23
Brazil	9	635	4	293
Bulgaria	2	257	—	—
Canada	28	3,125	9	953
Colombia	2	310	(1)	29
Costa Rica	1	244	(1)	27
France	2	248	3	249
Germany, Federal Republic of	22	2,250	1	316
Hong Kong	1	114	1	63
India	15	943	19	1,158
Israel	1	119	—	—
Italy	7	662	7	622
Japan	19	1,933	10	954
Korea, Republic of	5	653	6	589
Mexico	8	725	9	810
Netherlands	1	146	1	127
Poland	2	102	(1)	24
Switzerland	1	125	(1)	38
Taiwan	8	567	12	797
United Kingdom	9	1,132	6	849
Venezuela	7	1,388	2	474
Other	1	158	4	246
Total[2]	153	16,475	94	8,649
Unwrought tungsten and alloy in crude form, waste, and scrap:				
Australia	—	—	3	81
Austria	12	266	(1)	3
Belgium	4	136	—	—
Canada	53	506	30	602
Chile	1	23	7	211
France	1	33	(1)	2
Germany, Federal Republic of	214	2,362	406	8,377
Israel	27	257	29	684
Japan	4	102	(1)	16
Korea, Republic of	3	17	1	43
Sweden	25	307	11	122
Taiwan	1	37	12	269
United Kingdom	1	42	12	286
Other	(1)	8	16	277
Total[2]	346	4,098	527	10,973
Other tungsten metal:				
Australia	1	$215	8	$217
Austria	2	85	(1)	3
Belgium	2	210	—	—
Brazil	(1)	87	8	631

See footnotes at end of table.

TABLE 12—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten metal—Continued				
Canada	23	3,101	46	2,371
Colombia	1	151	(1)	15
France	3	564	9	341
Germany, Federal Republic of	6	856	25	1,056
Hong Kong	(1)	59	1	81
India	1	116	2	99
Ireland	1	138	32	4,124
Italy	1	95	5	411
Japan	14	3,523	40	4,081
Korea, Republic of	2	457	3	358
Mexico	1	252	10	630
Netherlands	1	378	1	174
Singapore	1	92	2	122
South Africa, Republic of	1	107	1	40
Spain	1	65	2	94
Sweden	(1)	24	2	161
Switzerland	3	329	9	97
Taiwan	2	376	3	219
Thailand	1	52	1	68
United Kingdom	7	817	9	792
Venezuela	(1)	50	(1)	4
Other	1	108	11	408
Total	76	12,307	230	16,597
Other tungsten compounds:[3]				
Australia	1	$21	—	—
Austria	2	40	—	—
Belgium	(1)	10	—	—
Brazil	1	111	—	—
Canada	1	40	—	—
Chile	1	25	—	—
China	34	130	—	—
Finland	(1)	33	—	—
France	5	297	—	—
Germany, Federal Republic of	2	121	3	$15
Hong Kong	1	61	—	—
Ireland	(1)	53	—	—
Israel	(1)	11	—	—
Italy	1	89	—	—
Japan	1	67	—	—
Korea, Republic of	2	233	—	—
Mexico	3	112	(1)	3
Netherlands	1	128	—	—
Singapore	(1)	16	(1)	20
Spain	2	75	—	—
Sweden	(1)	23	—	—

See footnotes at end of table.

pend purchases when the Government and private inventories reach 42 and 18 days of domestic consumption, respectively. As a result of this year's action, the inventories will stand at 28.2 and 12.1 days, respectively.

Korea, Republic of

Korea Tungsten Mining Co. Ltd. began production of tungsten wire at its Daegu facility in November 1989. Output from this new plant was to provide about one-half of the country's estimated annual consumption of wire, predominantly for use as filament in lamp and lighting applications. The additional wire required to meet internal demand is expected to be acquired from traditional suppliers in Japan and the United States.

Spain

Two Spanish banks, the Banco de Credito Industrial and the Banco Español de Credito, acquired a 50% interest in a restructured joint venture formed in efforts to reopen the La Parilla Tungsten Mine and mill near Merida. Officials of the new company, Grupo Minera La Parilla, stated that they expected the project to be viable even at 1989 tungsten concentrate prices. The mine was closed in 1987 after flooding problems and low market prices caused debts to mount.

Sweden

A report by the Swedish Mining Association disclosed that the Yxsjoberg tungsten mine was closed in mid-1989. Officials of AB Statsgruvor, the operator of the mine, stated that negative market forecasts and low profitability were primary factors influencing their decision. Production of concentrate at the facility averaged an estimated 320 mt per year over the last 5 years.

CURRENT RESEARCH

Advancements in roll mill technology increased the utility of cemented carbides in hot rolling applications.[3] A cast-in-carbide roll design incorporating a ring of cemented carbide, cast in place in ductile iron, has effectively eliminated problems associated with transmitting torque to the carbide rings. As a result, the established use of

TABLE 12—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten compounds—Continued				
Taiwan	1	27	—	—
United Kingdom	34	547	9	29
Venezuela	([1])	2	—	—
Other	1	27	—	—
Total	94	2,299	12	67

[1] Less than 1/2 unit.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes only other tungstates.

Source: Bureau of the Census.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Austria	—	—	47	$346
Australia	235	$1,683	138	1,027
Belgium	35	90	—	—
Bolivia	978	5,685	753	4,515
Burma	43	214	29	182
Canada	134	1,381	—	—
Chile	10	102	—	—
China	4,082	24,097	5,484	29,573
France	24	128	—	—
Germany, Federal Republic of	29	164	—	—
Hong Kong	416	2,328	169	1,144
Japan	57	376	32	172
Mexico	167	945	113	834
Netherlands	129	877	—	—
Peru	370	2,185	666	4,006
Portugal	466	3,423	333	2,580
Singapore	13	74	—	—
Spain	4	38	—	—
Sweden	4	19	2	5
Switzerland	105	732	11	67
Taiwan	21	136	—	—
Thailand	378	2,043	88	476
Turkey	244	920	31	150
United Kingdom	101	625	—	—
Total	8,045	48,265	7,896	45,077

Source: Bureau of the Census.

cemented carbides in cantilever-type rolls can be extended to intermediate rod mills, finishing bar mills, and tube mills.

New uses have been discovered for a modified version of a high-illumination argon arc lamp developed by Vortek Industries Ltd., Vancouver, British Columbia.[4] A 300-kilowatt model, which utilizes tungsten electrodes, and reaches an arc temperature of up to 13,000° C, has been used to anneal silicon wafers for the electronics industry. The process is cleaner and more controlled than traditional heating techniques, resulting in improved wafer quality. The powerful light source also is playing a role in the development of the next generation of aircraft structural materials. It has been employed to test the heat resistance of candidate materials for nose cones and wing leading edges. Another materials area where this lamp is finding increasing application is in the thermal treatment of metals.

A metal-matrix-composite-thermal-spray coating material for wear resistance was developed by Alloy Technology International Inc., Hewitt, NJ.[5] It is especially effective in resisting attack by combinations of heat, corrosion, and wear. The powder, known as ResisTic, was said to have double the wear resistance of tungsten carbide-based coatings.

Titanium diboride is a substitute for tungsten carbide in some applications. A titanium diboride powder, requiring no pressure during sintering, was developed by Union Carbide Corp., Advanced Ceramics Div., Cleveland, OH.[6] As a result, greater design flexibility in the manufacture of products made from it, including cutting tools, bearings and bearing liners, was obtained.

OUTLOOK

Tungsten demand in the United States is keyed to several significant end-use sectors including construction and mining machinery and equipment, metalworking machinery, and lamps and lighting. A statistical projection for each of these end uses was correlated with a specific economic indicator to provide a short-term demand forecast through 1995.

Correlation was excellent between

demand data for construction and mining machinery and equipment and the Federal Reserve Board (FRB) index of construction and allied equipment. Usage, predominantly as cemented carbide tools and equipment in wear-resistant applications, was projected to reach approximately 5,500 mt by 1995. This increase, equivalent to an average of about 540 mt per year above that of 1987 demand, will be associated with generally stronger activity in several industries. These include oil and natural gas drilling, coal and nonfuel minerals mining, highway construction, and commercial and residential construction. The projection is contingent upon stable to moderately higher world oil prices. Should oil prices rise significantly during this time, consumption could go considerably higher as the number of oil rigs is increased.

Correlation was good between demand data for metalworking machinery and the FRB index for this end use. Accordingly, demand is expected to reach about 6,800 mt by 1995. This is equivalent to an average increase of about 340 mt per year over the 1987 level. Machine tool requirements in the automotive and aerospace industries should continue to remain strong. In the automotive industry, in particular, there is expected to be further need for turning, milling, boring, drilling, tapping and grinding tools associated with new transmission and engine machining systems. Consumption of cemented carbide tools to meet future industry requirements will be tempered, however, by continuing 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.

Correlation was poor between lamps and lighting demand data and the FRB index of major electrical equipment and parts. Projected demand for 1995 was about 850 mt. More realistically, the demand for tungsten in lamps and lighting is expected to remain at about 9% to 12% of total U.S. consumption of tungsten. In 1987, demand in lamps and lighting represented 11% of the total demand of 7,951 mt. In general, the demand for lamps and lighting will increase as the population increases. The average annual growth rate in population between 1987 and 1995 is calculated to be approximately 0.8% per year.

Total annual domestic consumption of tungsten by 1995 is projected to be approximately 17,000 mt. This assumes that tungsten demand in the combined construction and mining machinery and equipment and metalworking machinery industries will represent about 70% of total tungsten consumption.

Supplies of tungsten concentrate and intermediate materials for U.S. consumption have been sufficient in spite of minimal production at domestic mines in recent years. It is uncertain, however, whether this situation will exist through 1995. Questions remain as to the ability of the Chinese, the major supplier of these materials, to continue to meet a large portion of the world's demand. Depletion of Chinese stocks or the resumption of political unrest could seriously diminish China's exports.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM TUNGSTATE, BY COUNTRY

Country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
China	267	$2,615	310	$3,517
Germany, Federal Republic of	308	3,029	27	388
Korea, Republic of	60	553	—	—
Taiwan	—	—	30	224
United Kingdom	—	—	64	431
Total	635	6,197	431	4,560

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF FERROTUNGSTEN, BY COUNTRY

Country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Canada	2	$10	—	—
China	468	2,537	359	$1,982
Germany, Federal Republic of	13	83	1	4
Netherlands	13	69	—	—
Switzerland	43	245	—	—
United Kingdom	60	317	—	—
Total	599	3,261	360	1,986

Source: Bureau of the Census.

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 15.86 pounds of tungsten. In most other countries, tungsten is sold in the metric ton unit.

Natural or synthetic scheelite concentrate, in nodular form, is ideal for direct addition to steel melts, since the calcium is removed as slag. Fine material in either synthetic or natural scheelite is not desirable because of high dust losses. Wolframite concentrate is not satisfactory for steelmaking because of the manganese and tin content.

Tungsten ores and concentrates are converted into the following intermediate products: APT, tungstic acid, sodium tungstate, tungsten metal powder, and tungsten carbide powder. Most of the APT is reduced to tungsten metal powder, which then is processed into tungsten carbide powder.

Tungsten alloys and tungsten mill products such as rod, wire, and sheet are produced from hydrogen-reduced tungsten metal powder. The tungsten carbide produced from powder is cemented, usually with cobalt, to form various cutting and wear-resistant tools and parts.

Tungsten chemicals (APT, tungstic acid, and sodium tungstate) are produced as coproducts at some tungsten processing plants and as primary products at others. When not processed further into metal powder, they generally are used in the chemical industry.

Products for Trade and Industry

Tungsten materials can be divided into four major classes, depending upon 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

TABLE 16

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Waste and scrap:				
Australia	8	$94	5	$21
Austria	3	25	5	37
Belgium	2	8	8	35
Canada	21	192	52	594
China	562	3,726	192	1,790
France	(1)	1	—	—
Germany, Federal Republic of	92	675	32	210
Hong Kong	4	54	6	60
Hungary	5	37	5	36
Israel	1	94	114	653
Italy	17	107	—	—
Japan	29	274	178	1,085
Korea, Republic of	—	—	111	648
Mexico	2	23	10	90
Netherlands	261	1,435	248	2,216
Portugal	3	15	—	—
Singapore	42	643	10	102
South Africa, Republic of	44	351	24	143
Sweden	222	1,010	7	62
Switzerland	3	10	—	—
Taiwan	5	24	—	—
United Kingdom	121	656	207	1,152
Other	1	4	15	104
Total	1,448	9,458	1,229	9,038
Unwrought tungsten, except alloys, in lump, grains, and powders:				
Belgium	3	106	3	97
Canada	1	40	8	190
Germany, Federal Republic of	20	581	32	713
Japan	2	82	4	95
Korea, Republic of	2	22	—	—
Luxembourg	—	—	(1)	4
Mexico	1	14	(1)	3
United Kingdom	13	190	37	371
Other	(1)	5	24	174
Total	42	1,040	108	1,647
Unwrought tungsten-ingots, shot, alloys and other:				
Austria	(1)	$45	4	$134
Belgium	1	33	—	—
Canada	1	61	(1)	10
China	(1)	7	5	95
Germany, Federal Republic of	1	14	1	66
Other	4	213	(1)	27
Total[2]	7	373	11	332

See footnotes at end of table.

TABLE 16—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Wrought tungsten-wire, plate, sheet, strip, foil, and other:[3]				
Austria	8	$769	17	$2,166
Belgium	6	647	7	506
China	1	60	(1)	5
France	(1)	5	1	105
Japan	17	3,016	132	13,840
Korea, Republic of	4	72	(1)	8
Netherlands	1	136	3	315
United Kingdom	(1)	19	1	45
Other	1	147	4	902
Total	38	4,871	165	17,892
Tungstic acid:				
China	90	718	68	615
Japan	3	10	—	—
Total[2]	92	729	68	615
Calcium tungstate:				
Germany, Federal Republic of	6	260	4	177
Japan	1	70	—	—
Total[2]	7	329	4	177
Potassium tungstate:				
Germany, Federal Republic of	4	200	—	—
India	(1)	21	—	—
Total	4	221	—	—
Sodium tungstate:				
China	207	$1,896	328	$2,139
Germany, Federal Republic of	—	—	(1)	2
Hong Kong	—	—	178	1,375
Japan	—	—	4	137
Total	207	1,896	510	3,653
Tungsten carbide:				
Austria	(1)	4	1	8
Belgium	11	402	—	—
Canada	6	193	47	1,027
China	28	467	44	783
Germany, Federal Republic of	459	8,515	420	7,602
Japan	1	69	9	36
Korea, Republic of	36	652	38	666
Luxembourg	16	555	29	1,004
United Kingdom	12	263	25	518
Other	8	194	24	431
Total[2]	578	11,315	637	12,075

See footnotes at end of table.

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 earthmoving 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 princi-

TABLE 16—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1988		1989	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten compounds:				
Austria	84	$794	—	—
Canada	7	188	—	—
China	738	6,977	323	$3,283
Germany, Federal Republic of	1	37	(1)	8
Japan	9	261	(1)	1
United Kingdom	5	67	2	22
Total	844	8,324	325	3,314
Mixtures, organic compounds, chief value in tungsten: Other	—	—	(1)	8

[1] Less than 1/2 unit.
[2] Data may not add to totals shown because of independent rounding.
[3] Estimated from reported gross weight.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORT DUTIES ON TUNGSTEN

HTS No.	Item	Rate of duty effective Jan. 1, 1989	
		Most favored nation (MFN)	Non-MFN
2611000000	Tungsten ores and concentrates	$0.37 per kilogram on tungsten content [1]	$1.10 per kilogram on tungsten content.
2825903000	Tungsten oxides	10%	45.5%
2825906010 [2]	Tungstic acid	3.7%	25%
2827394000	Chlorides of tungsten	10%	45.5%
2841800010	Ammonium tungstates	10%	49.5%
2841800020	Calcium tungstate	10%	49.5%
2841800050	Other tungstates	10%	49.5%
2849903000	Tungsten carbide	10.5%	55.5%
2850001000	Other tungsten compounds	10%	45.5%
3823903500	Mixtures of inorganic compounds, chief value tungsten	10%	45.5%
7202800000	Ferrotungsten and ferrosilicon tungsten	5.6%	35%
8101100000	Tungsten powders	10.5%	58%
8101911000	Tungsten waste and scrap	4.2%	50%
8101915000	Unwrought tungsten	6.6%	60%
8101920000	Wrought tungsten—bar, rod, sheet, etc.	6.5%	60%
8101930000	Wrought tungsten—wire	6.5%	60%
8101990000	Wrought tungsten—other	5.5%	45%

[1] Temporarily suspended through Dec. 31, 1990.
[2] HTS No. specific for tungstic acid effective on July 1, 1989. Included under HTS No. 2825906000, other metal oxides and hydroxides, during the period Jan. 1, 1989 to June 30, 1989.

TABLE 18

WORLD TUNGSTEN ANNUAL MINE PRODUCTION CAPACITY, DECEMBER 31, 1989

(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	1,100
Total	2,940
Europe:	
Austria	1,300
Czechoslovakia	50
Portugal	1,400
Spain	400
Sweden	350
U.S.S.R.	9,200
Total	12,700
Africa:	
Rwanda	330
Uganda	10
Zaire	30
Zimbabwe	30
Total	400
Asia:	
Burma	500
China	21,000
India	30
Japan	300
Korea, North	500
Korea, Republic of	2,000
Malaysia	10
Mongolia	2,000
Thailand	750
Turkey	200
Total	27,290
Oceania:	
Australia	3,300
New Zealand	10
Total	3,310
World total	53,640

[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	1985	1986	1987	1988[p]	1989[e]
Argentina	17	20	18	17	20
Australia	1,971	1,600	1,150	1,281	1,250
Austria	1,481	1,387	1,250	1,235	1,245
Bolivia	1,643	1,095	638	900	1,075
Brazil	1,090	875	672	433	450
Burma	945	715	493	307	300
Canada	3,174	r1,959	—	—	—
China[e]	15,000	15,000	21,000	21,000	21,000
Czechoslovakia[e]	50	50	45	50	50
France	735	r987	—	—	—
Guatemala	r18	—	—	—	—
India	28	23	26	r e30	25
Japan	568	579	259	266	300
Korea, North[e]	1,000	1,000	500	500	500
Korea, Republic of	2,579	2,455	2,375	2,029	1,800
Malaysia	13	r4	—	—	—
Mexico	282	294	213	206	225
Mongolia[e]	1,500	1,500	1,500	2,000	2,200
New Zealand	r7	(2)	e5	e5	5
Peru	771	742	259	545	1,100
Portugal	1,766	1,657	1,207	1,382	1,300
Rwanda	167	13	—	—	—
Spain	458	495	81	80	80
Sweden	402	357	334	e320	180
Thailand	586	475	705	651	700
Turkey[e]	100	50	[3]187	[3]142	150
Uganda[e]	4	4	4	4	4
U.S.S.R.[e]	9,200	9,200	9,200	9,200	9,300
United States	996	780	34	W	W
Zaire	18	27	21	20	20
Zimbabwe[e]	10	1	1	1	1
Total	r46,579	r43,344	42,177	42,604	43,280

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."
[1] Table includes data available through Apr. 5, 1990.
[2] Less than 1/2 unit.
[3] Reported figure.

pally 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.

[1] Refers to metric tons of tungsten content throughout chapter.

[2] Equals 1% of a metric ton of WO_3 and contains 7.93 kilograms of tungsten.

[3] 33 Metal Producing. A New Concept in Carbide Hot Rolls. V. 27, No. 12, 1989, pp. 30–35.

[4] Advanced Materials & Processes. A Bright Idea. V. 135, No. 5, 1989, p. 8.

[5] Materials Engineering. Composite Powder For Wear Coating. V. 106, No. 7, 1989, p. 14.

[6] Advanced Materials & Processes. Titanium Diboride Powder Sintered Without Pressure. V. 135, No. 5, 1989, p. 13.

OTHER SOURCES OF INFORMATION

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Tungsten. Reported monthly in Mineral Industry Surveys

Minerals Today. A bimonthly publication.

Other Sources

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Metals Week.

Metal Bulletin (London).

Metalworking News.

UNCTAD Reports. Meeting of Committee on Tungsten.

Media Release. Meeting of Government Representatives of Tungsten Producing and Exporting Countries.

Market Report. ITIA Annual General Meeting.

TABLE 20

TUNGSTEN: WORLD CONCENTRATE CONSUMPTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	28	25	65	30	30
Australia	111	94	[e]200	120	130
Austria[e]	2,000	2,000	2,000	2,100	1,800
Belgium-Luxembourg	341	30	[e]50	[e]50	50
Brazil	1,048	672	867	753	688
Bulgaria[e]	100	100	100	100	100
Canada[2]	12	12	10	10	10
China[2]	7,500	7,500	5,000	5,000	5,000
Czechoslovakia[e]	1,300	1,300	1,300	1,300	1,300
France	808	667	269	34	—
German Democratic Republic[e]	[r]300	[r]300	300	300	300
Germany, Federal Republic of[3]	2,073	1,720	1,863	2,144	2,100
Hungary[e]	400	400	400	500	500
India	250	[r]230	[e]250	[e]250	250
Italy[3]	92	80	86	100	100
Japan	2,616	2,145	2,116	1,980	1,578
Korea, North[e]	1,000	[r]800	500	500	500
Korea, Republic of	2,048	1,987	[r]1,950	1,580	1,600
Mexico	79	42	64	9	5
Netherlands[e]	400	350	300	330	350
Poland[3]	603	1,264	744	424	100
Portugal	158	40	20	—	—
South Africa, Republic of[e]	250	250	250	250	250
Spain	29	159	[e]100	29	—
Sweden	820	855	567	550	550
U.S.S.R.[2]	16,000	16,000	16,000	16,000	16,000
United Kingdom[e]	600	580	550	575	[2]500
United States	6,838	4,804	5,506	7,832	[4]7,725
Total	[r]47,804	[r]44,406	41,427	42,850	41,516

[e] Estimated. [p] Preliminary. [r] Revised.

[1] Source, unless otherwise specified, is Tungsten Statistics, 1989, Annual Bulletin of the UNCTAD Committee on Tungsten.

[2] Estimated by the Bureau of Mines.

[3] Apparent consumption, production plus imports minus exports.

[4] Reported figure.

VANADIUM

By Henry E. Hilliard

Mr. Hilliard, a physical scientist with more than 20 years Bureau of Mines experience, has been the commodity specialist for vanadium since 1986. Domestic survey data were prepared by Lisa Harley, mineral data assistant, and international data tables were prepared by William L. Zajac, Chief, International Data Section.

The year 1988 proved to be a boom year for vanadium producers as tight supply and strong demand by the steel industry and other consumers pushed up the price of vanadium compounds. The U.S. steel industry, which accounted for about 85% of domestic consumption, recorded its highest shipments since 1980's. By the end of 1989, vanadium's fortunes had turned full circle as the market witnessed prices headed for levels lower than at any time since the early 1980s. Price surges in the fourth quarter of 1988 and the first part of 1989 produced the usual results, a significant increase in production and prices followed by a rise in inventories and a consequent slump in prices. Fourth quarter 1988 vanadium pentoxide (V_2O_5) prices of about $3.50 per pound held through the second quarter 1989. Then, demand for ferrovanadium (FeV) by the steel industry and aluminum-vanadium (Al-V) master alloys by the aerospace industry increased sharply. At the same time, operating problems developed in some producer units, causing an apparent shortage and forcing some consumers to buy V_2O_5 and downstream vanadium products from alternate sources at higher prices. Producers of tool and other specialty steels were especially hard hit as the price for V_2O_5 soared to more than $7.00 per pound. As prices continued to rise, consumers began to build inventories in anticipation of even higher prices and tighter supplies expected in the third quarter. Some consumers began to substitute other materials for vanadium. By fourth quarter 1989, it was clear that consumer inventories were excessive and, as producers added new capacity, meeting demand posed no problem. Having built up large stocks, consumers deferred making new purchases while they reduced their inventories. Predictably, prices for V_2O_5 and downstream vanadium products began to fall. First quarter 1990 producer prices for V_2O_5 were expected to fall to about $2.50 per pound. Spot market prices were expected to fall even lower to about $2.30 per pound.

U.S. reported consumption of vanadium was 5,117 tons, a 4% decrease from 1988 consumption.

LEGISLATION AND GOVERNMENT PROGRAMS

On January 1, 1989, the United States and Canada implemented the United States-Canadian Free Trade Agreement (FTA). The objective of the agreement was to eliminate barriers to trade, facilitate conditions of fair competition, liberalize conditions for investment, establish

TABLE 1

SALIENT VANADIUM STATISTICS

(Short tons of contained vanadium unless otherwise specified)

	1985	1986	1987	1988[p]	1989[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]	2,695	2,330	2,508	3,252	2,633
Consumption	4,883	4,308	4,653	5,329	5,117
Exports:					
Ferrovanadium (gross weight)	453	513	436	629	544
Ore and concentrate	3	86	—	—	—
Vanadium pentoxide anhydride (gross weight)	1,527	1,544	1,461	1,220	4,124
Other compounds (gross weight)	322	343	479	978	1,709
Imports (general):					
Ferrovanadium (gross weight)	977	747	422	148	716
Ore, slag, ash and residues	303	2,013	2,264	3,986	3,484
Vanadium pentoxide, anhydride	63	443	357	421	148
World: Production from ore, concentrate, slag[4]	33,299	32,530	31,315	33,660	33,800

[e] Estimated. [p] Preliminary. W Withheld to avoid disclosing company proprietary data.

[1] Recoverarable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recoverd from ferrophosphorus derived from domestic phosphate rock.

[2] Produced directly from all domestic ores and ferrophosphorus slag; includes metavandates.

[3] Includes vanadium recovered from fly ash, residues, and spent catalysts.

[4] Excludes U.S. production.

procedures for the resolution of disputes, and lay the foundation for further bilateral and multilateral cooperation. The new agreement contained rules and safeguards designed to ensure that minerals, metals, and material products that originate or are produced in either country have equal access to both markets.

Before enactment of the FTA, about 70% of the goods that crossed the United States-Canadian border were free of duty. The remaining 30% will have their duty removed in one of three ways: (1) duty elimination as of January 1, 1989, (2) duty elimination in five equal steps by January 1, 1993, and (4) duty elimination in ten equal steps by January 1, 1998. Rates of duty, effective with respect to goods originating in the territory of Canada and entered on or after January 1, 1989 through January 1, 1993 are shown in the following table:

HTS Subheading	January 1, 1989	January 1, 1990	January 1, 1991	January 1, 1992	January 1, 1993
7202.92.00	3.3%	2.5%	1.6%	.8%	Free.
2850.00.20	12.8%	9.6%	6.4%	3.2%	Free.
2841.90.10	8.9%	6.7%	4.4%	2.2%	Free.
2825.30.00	12.8%	9.6%	6.4%	3.2%	Free.
8112.40.60	2.4%	1.8%	1.2%	.6%	Free.
2841.90.10	8.9%	6.7%	4.4%	2.2%	Free.

It should be noted that the FTA had no effect on the tariffs of either country with third countries.

On August 23, 1988, Congress enacted the Omnibus Trade and Competitiveness Act (Public Law 100–418). The stated objective of the act was to enhance the competitiveness of the Nation's industries and to improve the management of U.S. trade strategy. The Act also included provisions modifying U.S. customs laws and tariff schedules. Subtitle B of the Act required that all tariff schedules after January 1, 1989, conform to nomenclature of the internationally established Harmonized Tariff System (HTS), an international system for classifying products for tariff purposes that had already been adopted by most U.S. trading partners. The new law restructured the old U.S. import-export classification system. The new schedule B classification was based on the organizational framework of the Tariff Schedule of the United States Annotated (TSUSA). That means that equivalent import and export items are assigned the same 10-digit classification code.

On July 11, 1989, the U.S. House of Representatives passed House Bill (H.R. 491) calling for a 3-year mining research initiative aimed at reducing the U.S. dependency on the Republic of South Africa and the U.S.S.R. for strategic and critical minerals. During the 3-year period, the Bureau of Mines would be charged with examining new extractive technologies to recover from domestic deposits such strategic minerals as chromium, manganese, platinum group metals, vanadium and several other metals. If the bill were to become law, it would cost the government $5 million the first year, $10 million the second, and $15 million the third year. Most studies would be completed by 1992.

In July 1989 the Senate passed legislation that would establish a Government-owned U.S. enrichment corporation and provide some relief for the ailing domestic uranium-vanadium mining and milling industry. The new corporation would operate as a private company and presumably be more competitive. The Treasury Department would own all of the stock and collect dividends, if any, generated by the $1.5-billion-a-year enterprise. A companion bill (H.R. 2480) was introduced in the House on May 24, 1989. Both bills (Senate bill 83 and H.R. 2480) were referred to several committees where their disposition was uncertain. H.R. 491 also faced an uncertain future because the Administration and the Bureau of Mines have stated that its provisions would duplicate efforts already underway.

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 essential use of vanadium in equipment 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, which was the world's largest producer of vanadium in 1989, accounting for about 60% of the vanadium produced by market economy countries. Between 1983 and 1988, 44% 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 or V_2O_5. The European Community (EC) and Japan were more heavily dependent on South African imports than the United States. In 1988, for example, 60% of the pentoxide consumed by Japan came from the Republic of South Africa. 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.

Stockpile

The National Defense Stockpile (NDS) had a 1989 goal of 7,700 tons of vanadium contained in V_2O_5 and 1,000 tons in FeV. Actual yearend stockpile inventories were only 721 tons of vanadium as V_2O_5. 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, Defense stated that, although 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. In August 1989, the Defense Logistics Agency (DLA) issued its upgrading solicitation of about 1,300 tons of Grade-A

TABLE 2

STOCKPILE STATUS, DECEMBER 31, 1989

(Short tons of contained vanadium)

Material	Goal	Inventory
Vanadium pentoxide	7,700	721
Ferrovanadium	1,000	—

V_2O_5. The solicitation was withdrawn a few weeks later, but was expected to be reissued in the second or third quarter of 1990.

ISSUES

Before 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 power plant 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 plummet from $40.75 per pound in early 1980 to less than $10.00 per pound in 1989. 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 cancelled 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 from petroleum residues. Recovery of vanadium from this source increased during the 1973 Arab oil embargo. Increased demand for petroleum caused refiners to process crude oils with high-sulfur and -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 power plants created a second source of feed materials in the form of fly ash and boiler scale. During this period the author performed chemical analyses on some boiler scales that contained as much as 35 weight percent (wt %) 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 1989, 2,600 tons of vanadium was recovered as oxides from these mostly imported petroliferous materials. 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 with or greater than that of nickel, zinc, and copper. 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, co-ore, 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. U.S. vanadium pentoxide producers are shown in the following table:

Producer	Plant location	Capacity (short tons pentoxide per year)
AMAX Metals Recovery Corp. (a subsidiary of AMAX Inc.)	Braithwaithe, LA	2,000
Gulf Chemical & Metallurgical Corp.	Freeport, TX	1,500
Kerr McGee Chemical Corp.	Soda Springs, ID	2,200
UMETCO Minerals Corp.	Blanding, UT	7,500
U.S. Vanadium Corp. (a subsidiary of Stratcor)	Hot Springs, AR	7,500

In January, Atlas Minerals announced the sale of all its Utah and Colorado uranium and vanadium properties and related mining equipment. The sale finalized an earlier decision by Atlas to withdraw completely from the uranium-vanadium business. The company was also reviewing an engineering study with the Nuclear Regulatory Commission (NRC) that would allow Atlas to finalize the decommissioning and reclamation plan for its Moab, UT, uranium-vanadium operations. The Moab mill had the capacity to produce about 2,200 tons per year of V_2O_5.

In February, Strategic Minerals Corp. (Stratcor), based in Danbury, CT, announced plans to renovate and expand its multimillion dollar ferrovanadium facility at Niagara Falls, NY. The expansion included new furnace operations that allowed Stratcor to increase its output of Nitrovan by about 50%. Nitrovan, a proprietary compound containing vanadium and nitrogen, can be used by steelmakers for strengthening steel in place of standard FeV. The company also announced plans to double its capacity for the production of vanadium tetrachloride to help meet growing demand for vanadium catalysts.

The Niagara Falls plant depended on Stratcor's Hot Springs, AR, mill for supplies of V_2O_5 that it converted to FeV and other vanadium chemicals. The mill, operated by U.S. Vanadium Corp., a subsidiary of Stratcor, produced V_2O_5 from a variety of raw materials, including vanadium-bearing slag and petroleum refinery residues. Delays in obtaining raw materials and

difficulties with reactivating some mothballed equipment kept V_2O_5 supplies from Hot Springs lower than expected. This caused temporary cutbacks on expected shipments of FeV to customers. The problems at Hot Springs were eventually cleared, ensuring an adequate supply of V_2O_5 for the production of FeV and the expanded Nitrovan facilities.

AMAX Metals Recovery Corp. operated a spent catalyst treatment plant in Braithwaite, LA, that recovered vanadium and other metals from petroleum refinery catalyst. In 1989, the plant produced, in addition to more than 1,000 tons V_2O_5, 90 tons of molybdenum trisulfide and 10 tons of cobalt concentrate. The company planned to expand its product base to include extracting chromite from waste acid solutions that were used to etch aluminum and vanadium from fly ash. No timeframe was given for completion of the expansion. The company also planned to recover vanadium from waste Stretford process solutions that were used to scrub hydrogen sulfide from gas streams.

Production of V_2O_5 increased sharply at Umetco Minerals Corp.'s Blanding, UT, mill. Production averaged about 330 tons per month. Total production in 1988 was only about 600 tons. A major portion of the 1989 production represented toll work. The mill, which is jointly owned with Energy Fuels Nuclear Corp., produced V_2O_5 at the rate of about 500 tons per month during the first quarter. The mill was then shut down in the second quarter for routine maintenance and improvements to the vanadium extraction process. Production resumed in September. Output of vanadium increased in part because demand increased and prices rose sharply, but also because the Blanding Mill was the only mill still in operating condition capable of recovering vanadium from uranium-vanadium ores.

CONSUMPTION AND USES

Reported consumption of vanadium was a little more than 5,000 tons of contained vanadium or about 4% less than in 1988. Part of this reduction was attributed to reduced demand by the steel industry, in which production was down by about 2% from that of 1988. Another part could be attributed to substitution of other materials or treatments for vanadium, although an uncertain amount could be assigned to reduced reporting by consumers to Bureau of Mines surveys.

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 in chemical and catalyst preparations. Vanadium is an essential but not totally indispensable alloying metal. Often the addition of micro amounts can provide considerable improvement in performance without further processing or a significant increase in cost over standard grades. When alloyed with steel, vanadium combines with carbon or nitrogen or both, then precipitates, causing an increase in strength and toughness. In addition, vanadium provides such added benefits as better weldability and heat resistance. Various metals, such as columbium, manganese, molybdenum, titanium, and tungsten, are interchangeable with vanadium, but so far there are no substitutes for vanadium in the all-important aerospace titanium alloys that are used in jet engine mountings and wing structures. High-purity vanadium compounds are used as catalysts in the production of sulfuric acid, maleic anhydride, and in pollution control technology where it is necessary to remove hydrogen sulfide gas from flu gases (Stretford Process). In only a few chemical applications can platinum and nickel replace vanadium catalyst.

STOCKS

Reported consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals totaled 1,736 tons contained vanadium at yearend compared with 1,396 at yearend 1988.

FOREIGN TRADE

While overall exports of vanadium products were slightly lower than in 1988, V_2O_5 exports were up sharply in 1989. Canada, Brazil, the Republic of Korea, and Mexico were the leading importers of U.S. materials. Most countries imported V_2O_5 almost exclusively. Austria, Canada, and the Republic of Korea also imported substantial quantities of FeV. Exports of V_2O_5 totaled 2,310 tons, almost double 1988 exports. The average declared value of the pentoxide was $7.62 per pound of contained V. Exports of FeV totaled 544 tons gross weight, down from 909 tons in 1988. The average declared value of the FeV was $18.70 per pound of contained V.

Imports for consumption of vanadium raw materials and down-stream vanadium compounds increased over 1988 imports. FeV imports totaled 716 tons gross weight, up from 147 tons in 1988 and 422 tons in 1987. The imported FeV averaged 81% vanadium with a mean custom value of $12.34 per pound of contained V. Canada was the largest source of FeV with shipments of 163 tons, followed by the Federal Republic of Germany, 128 tons, and Austria, 109 tons. V_2O_5 imports totaled 102 tons of contained V, down from 241 tons in 1988; the average declared value was $9.39 per pound of contained V. Imports of vanadium-bearing slag and residues totaled more than 6,000 tons of contained V. About 44% of these imports were from the Republic South Africa in the form of vanadium bearing iron-slag. Another 28% was vanadium-bearing steel slag from Chile. The remaining 28% 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, providing 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. While the United States imported slag from the Republic of South Africa, it also imported slag, fly ash, petroleum residues, and spent catalyst from many sources. The large importers of vanadium raw materials, for example,

TABLE 3

VANADIUM SUPPLY-DEMAND RELATIONSHIPS AND PRICES

(Short tons vanadium content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[e]
World production from ores, slag, and concentrates											
Recovered basis:											
United States	5,758	5,506	6,368	4,867	2,433	2,620	W	W	W	W	W
World, other	31,791	33,475	33,652	31,800	27,916	32,675	33,2993	2,5303	1,3153	3,6603	3,800
Total	37,549	38,981	40,020	36,667	30,349	35,295	33,299	32,530	31,315	33,660	33,800
Component and distribution of U.S. supply											
Components of U.S. supply:											
Primary production, domestic mines	5,758	5,506	6,368	4,867	2,433	2,620	W	W	W	W	W
Imports, ferrovanadium	517	263	984	670	681	1,171	779	605	342	119	441
Imports, ores, slag, and residues	2,442	1,786	2,435	1,112	58	633	303	2,013	2,264	3,986	3,484
Imports, vanadium pentoxide	907	856	334	119	377	149	11	248	229	421	102
Imports, other	1,519	1,304	1,400	1,090	1,078	2,210	193	201	94	122	397
Shipments of Government stockpile excesses	—	—	—	—	—	−68	−112	—	—	—	—
Industry stocks, January 1	11,374	11,089	11,155	12,502	12,564	12,102	10,486	1,842	2,057	1,396	612
Total U.S. supply	22,517	20,804	22,676	20,360	17,191	18,817	11,657	4,909	4,986	6,044	5,036
Distribution of U.S. supply:											
Industry stocks, December 31	11,089	11,155	12,502	12,564	11,748	10,486	W	W	W	W	W
Exports, ore	101	46	56	57	59	12	3	86	—	—	—
Exports, ferrovanadium	616	562	304	229	542	328	318	415	348	503	434
Exports, vanadium pentoxide	353	406	194	886	1,484	2,079	855	192	134	683	2,310
Exports, other	190	114	36	217	57	183	193	343	479	548	957
Industrial demand	10,168	8,521	9,584	6,406	3,301	5,729	W	W	W	W	W
U.S. demand pattern (SIC)											
Building and heavy construction	1,170	950	1,100	920	490	740	W	W	W	W	W
Chemicals	460	310	220	140	50	130	W	W	W	W	W
Machinery, construction machinery and industrial equipment	1,330	1,210	1,390	790	390	730	W	W	W	W	W
Machinery, metalworking machinery and tools	1,740	960	880	540	450	750	W	W	W	W	W
Mining, quarrying, and lumbering	190	150	160	90	60	110	W	W	W	W	W
Oil and gas industries	800	1,170	1,730	860	100	290	W	W	W	W	W
Transportation	3,550	2,960	3,200	2,260	1,350	2,370	W	W	W	W	W
Other	928	811	904	806	411	609	W	W	W	W	W
Total U.S. primary demand	10,168	8,521	9,584	6,406	3,301	5,729	W	W	W	W	W

See footnotes at end of table.

TABLE 3—Continued

VANADIUM SUPPLY-DEMAND RELATIONSHIPS AND PRICES

(Short tons vanadium content)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989[e]
						Prices					
Average annual, actual (dollars per pound vanadium content)	6.05	6.33	6.28	6.25	6.25	6.25	6.25	6.25	6.2	8.95	7.50
Average annual, based on constant 1989 dollars (dollars per pound)	9.72	9.32	8.43	7.89	7.89	7.89	7.89	7.89	7.89	9.31	7.50

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

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 smaller 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 Eastern Bloc countries.

Capacity

The data in table 7 reflect rated capacity for mills producing vanadium oxides as of December 31, 1989. Included in this data is the 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 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 deposit, consisting of a large magnetite-rich intrusive rock, was analyzed more than 20 years ago and found to contain only about 0.32% V_2O_5. This deposit was ignored for many years because of the low price of vanadium. As the price of vanadium climbed in 1987 and 1988, 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) that extends along a 10 mile strike within PMA's property. The latest sampling was carried out across the SDZ in areas of abundant titanomagnetite surface rock with samples

TABLE 4

PRODUCERS OF VANADIUM ALLOYS OR METAL IN THE UNITED STATES IN 1989

Producer	Plant location	Products[1]
Affiliated Metals and Minerals Inc.	Newcastle, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAl, ZrVAl.
Do.	Wanatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	FeV, VAl, V.
Shieldalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan.[2]
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.
[2] Registered trademark for proprietary products.

TABLE 5

U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM MATERIALS, BY FORM

(Short tons of contained vanadium)

Form	1988		1989	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	4,497	631	4,197	446
Oxide	18	17	21	10
Ammonium metavanadate	W	W	W	W
Other[2]	813	56	898	160
Total[3]	5,329	704	5117	615

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 relatively small quantities of other vanadium alloys and vanadium metal.
[3] Data may not add to totals shown because of independent rounding.

TABLE 6

U.S. CONSUMPTION OF VANADIUM IN 1989, BY END USE

(Short tons of contained vanadium)

End use	Quantity
Steel:	
Carbon	1,216
Stainless and heat-resisting	106
Full alloy	990
High-strength low-alloy	1,350
Tool	463
Unspecified	W
Total	[1] 4,124
Cast irons	20
Superalloys	42
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	W
Welding and alloy hard-facing rods and materials	8
Nonferrous alloys	W
Other alloys [1]	816
Chemicals and ceramics:	
Catalysts	10
Other [2]	W
Miscellaneous and unspecified	96
Grand total [3]	5,117

W Withheld to avoid disclosing company proprietary data, included with "Miscellaneous and unspecified."
[1] Includes magnetic alloys.
[2] Includes pigments.
[3] Data do not add to total shown because of independent rounding of converted units.

collected at two- and six-yard intervals. Indications were 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.[1]

Preliminary metallurgical work suggested that a magnetite concentrate could be produced from grinding and magnetic separation. An $86 million mine development and processing plant was planned to produce about 2,100 tons of V_2O_5 per year.

The deposit ranks as a potentially significant iron ore discovery, but given the long distance from the nearest port, it would be more economic to extract the vanadium and titanium and discard the iron as waste.

Canada

Agra Industries Ltd. of Saskatoon, Saskatchewan, teamed with Renzy Mines

TABLE 7

WORLD VANADIUM PENTOXIDE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989[1]

(Short tons of vanadium content)

Country	Rated capacity [2]
Australia	1,600
Brazil	—
Canada	850
Chile	2,500
China	9,000
South Africa, Republic of	30,000
U.S.S.R.	10,500
United States	12,100
Venezuela	2,700
Other market economy countries	600
Total	69,850

[1] Includes capacity to produce vanadiferous iron slag and vanadium-bearing petrolem residues.
[2] Includes capacity of operating plants, as well as plants on standby basis.

Ltd. and Fairfax Financial Holdings Ltd. of Toronto, Ontario, to construct a vanadium pentoxide facility at Fort McMurry, Alberta. The plant, which cost $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.[2] The Athabasca oil sands, located in northern Alberta, was well known for its wealth of oil, and a number of projects have been launched to extract it. Less known was the fact that a number of other elements, including vanadium, were also found in the oil sands. In fact, the Athabasca oil sands may prove to be the largest reserves of vanadium in North America.

Vanadium appeared 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 steamboiler 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 flyash, Carbovan Inc., obtained an exclusive long-term agreement to purchase the waste flyash produced by Suncor. Carbovan also had access to flyash 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.

Chile

Compañía Minera del Pacífico (CMP), Chile's sole iron ore and pellet producer, examined the possibility of producing and exporting vanadium from its El Romeral Mine where the iron ore has a grade of 0.5% to 0.7% vanadium.[3] A three-stage laboratory, pilot plant, and economic study was completed, and the company began an engineering study to determine the type of equipment required. Based on previous findings, Pacífico decided to use a roast-leach process to produce vanadium as a byproduct from the concentration of 1,500 tons per day of iron ore from El Romeral. The company hoped to earn about $25 million per year from vanadium exports.

China

China's production of vanadium-bearing iron slag was 93,750 tons in 1989.[4] 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.

Vanadium production was down

TABLE 8

U.S. IMPORT DUTIES, JANUARY 1, 1989

Tariff item[1]	HTS Number	Most Favored Nation (MFN)	Non-Most Favored Nation
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 val.	40% ad val.
Vanadium oxides and hydroxides, other	2825.30.0050	16.0% ad val.	40% ad val.
Vanadates	2841.90.1000	11.2% ad val.	40% ad val.
Ferrovanadium	7202.92.0000	4.2% ad val.	25% ad val.
Aluminum-vanadium master alloys	7601.20.9030	Free.	10.5% ad val.
Waste and scrap	8112.40.3000	Free.	Free.

[1] Specific import classes only.

about 4% from 1988 production because of a reduction in the operating level at Panzhihua. Exports were also lower than in previous years, mostly because of increased internal demand.

South Africa, Republic of

The Republic of South Africa, the world's largest producer of vanadium, was projected to increase its capacity by 28% over 1988's capacity and produce about 40% more of the alloying element by 1990. In 1988, production of vanadium marked an alltime high of 63 million pounds of V_2O_5, more than 10% above 1987 production. Production figures for 1989 were not available, but were expected to be about the same, or slightly less, than 1988 production. Sales of vanadium totaled 28,900 tons V_2O_5, of which 653 tons was used internally and 28,300 tons was exported.[5]

Most of the planned increase in capacity was from a new facility, which was to obtain 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.

The company extracted V_2O_5 by the roast-leach process. While other South African producers used a rotary kiln or a conventional furnace to roast the ore, Usco used a shaft furnace. This furnace reportedly had several advantages: (1) the furnace was fired by South African synthetic oil (Sasol) gas instead of coal, which tends to introduce impurities, (2) direct energy costs were claimed to be up to 5% lower, (3) the vanadium yield was at least 90% compared with around 80% for a rotary kiln, and (4) chemical costs were reduced by about 50% because a rotary kiln requires 7 wt % soda ash compared with 4 wt % for a shaft furnace. Usco anticipated the cost of production of V_2O_5 flake would be in the range of $4,500 to $4,700 per ton. Mechanical commissioning of the beneficiation plant at Rhovan's Mine, which provided the magnetite concentrate, was completed and wet commissioning was scheduled to start in March 1990.[6] Brandeis Goldschmidt Ltd., headquartered in London, acted as sole agent for V_2O_5 produced by Usco.

Highveld Steel & Vanadium Corp., the world's largest vanadium producer, was forced to cut production at its Vantra Plant by two-thirds because of low spot market prices. Production of vanadium in iron slag at the Highveld steel plant was not affected by the cutback. The decision to cut production at Vantra was an attempt by Highveld to stabilize prices at a comfortable level and maintain a balance between supply and demand.

The newest South African V_2O_5 producer, Vansa Vanadium Corp., began production in October 1988. Its operations were supplied by the Kennedy's Vale high-grade ore deposit. The plant, located in Eastern Transvaal, had a design capacity of 3,000 tons per year of V_2O_5. 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% capacity. The company expected that full production would be achieved during 1990.

Other established producers in the Republic of South Africa are Vametco in Bophuthatswana, owned by Strategic Minerals Corp. of the United States, and Transvaal Alloys, which produced V_2O_5 and other vanadium chemicals. The Republic of South Africa's domestic consumption of vanadium was believed to be about 1% of its total production.

OUTLOOK

Outlook For 1990

Vanadium shipments in 1990 are expected to decline approximately 3% to about 5,500 tons. The decline is expected to be the result of a weakness in a key vanadium consuming sector, steel used for nonresidential construction, without equal offsetting growth in other important markets. Demand for the transportation sector is expected to be adversely affected by lower sales of domestically produced motor vehicles. The appliance industry is likely to buy less steel because of a decline in housing starts. On the bright side, some pickup in demand for aluminum-vanadium alloys can be anticipated from aerospace industries, which are benefiting from increased demand for air transports. Also, increased demand is anticipated from large capital goods industries that are benefiting from increased capital investment and increased exports. Individually, aerospace and capital goods industries are much smaller consumers of vanadium than the other important markets. Vanadium exports are expected to rise moderately.

The likely drawdown of inventories by vanadium consumers through the first and second quarters of 1990 should also have an adverse effect on domestic demand. Consumers are expected to draw down their inventories because they are no longer concerned about difficulties in obtaining vanadium in a timely manner and at a reasonable price. Prices of most products are likely to stabilize.

Nearly every segment of the chemical industry using vanadium catalysts is growing. Strong demand for chemicals

and polymers, for fuel from petroleum, for products that reduce pollution, and for biological materials, is increasing. With few exceptions, most sulfuric acid produced in the world is made by burning sulfur to produce the oxide and then oxidizing the dioxide to the trioxide using V_2O_5 catalyst on a diatomaceous earth carrier. Growth in demand for this type of catalyst is forecast to be slow. Resurging markets for vanadium catalyst in other sectors of the chemical industry are providing new incentives for research and development in vanadium catalysts and in processes that require their use.

Long-Term Prospects

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.

Fundamental changes over the past 10 years in the industry and in the general economy have all but precluded the possibility of a return to the late 1970's and early 1980's level of vanadium mining activity. There will almost certainly be fewer tons of domestic ore shipped and fewer mine workers by 1995 than there were in 1989. Production of V_2O_5 from fly ash, spent catalyst, and petroleum residues will continue to increase. Given favorable economic conditions, plants using these materials as feed will have higher average sales and be more profitable.

BACKGROUND

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 power plants. 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. An increasing amount of vanadium has been used in the production of high-strength low-alloy (HSLA) steels to provide yield points between 36 and 47 kilograms per square millimeter. The addition of small amounts of vanadium, often less than .1 wt %, 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 wt % aluminum and 4 wt % 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 found in many parts of the world, but 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 clays, petroleum residues, and spent catalysts. At present projected rates of consumption, world reserves of vanadium should last far beyond the year 2000. The world also has extensive subeconomic resources of vanadium contained in oil sands, carbonaceous shale, and bauxite.

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 U.S.S.R. production is consumed internally or by other Eastern Block countries. Other major producers include the United States, and China. 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. 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 1989, including production from petroliferous materials and spent catalysts, was estimated to be 37,400 tons, of which about 2,600 tons was produced in the United States from petroleum residues and spent catalysts.

Definitions, Grades, and Specifications

The term "ferrovanadium," as used by the 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 the following table:

Alloy	Composition, weight percent							
	Vanadium	Carbon	Nitrogen	Aluminum	Silicon	Phosphorus	Sulfur	Manganese
50%–60% ferrovanadium	50.0–60.0	0.2 max.	—	2.0 max.	1.0 max.	0.05 max.	0.05 max.	—
70%–80% ferrovanadium	70.0–80.0	—	—	1.0 max.	2.5 max.	.05 max.	.10 max.	—
80% ferrovanadium	77.0–83.0	.5 max.	—	.5 max.	1.25 max.	.05 max.	.05 max	0.5 max.
Proprietary alloys:								
Carvan (Stratcor)	82.0–86.0	10.5–14.5	—	.1 max.	.10 max.	.05 max.	.10 max.	.05 max.
Ferovan (Shieldalloy)	42.0 min.	.85 max.	—	—	7.0 max.	—	—	4.50 max.
Nitrovan (Stratcor)	78.0–82.0	10.0–12.0	6.0 min.	.1 max.	.1 max.	.05 max.	.01 max.	.05 max.

A standard specification for ferrovanadium has been developed by the American Society for Testing Materials (ASTM).[7]

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 wt % 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 wt % 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. Ti-6Al-4V alloy presently accounts for more than one-half of the titanium-base alloy market.

Products for Trade and Industry

Vanadium is usually traded on the international market in the form of technical grade V_2O_5 and ferrovanadium. Most world exports of vanadium raw material is in the form of vanadium-bearing iron slag from the Republic of South Africa and China, while U.S. and west European converters are the major importers of these materials. U.S. and west European converters are the major exporters of vanadium oxides, which supply the many small consuming countries, and compete for the major markets for imported pentoxide in 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 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 all six continents. As expected, mines and oil fields form the base of the structure (figure 1). Since 1979, an estimated 83% of world production has come from vanadiferous magnetite (Fe_3O_4). The principal sources of the magnetite ore were China, the Republic of South Africa, and the U.S.S.R. World vanadium production for 1985–1989, is shown in table (12). The other 17% of the vanadium was recovered from diverse petroliferous materials.

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 acid-leaching plants with solvent extraction circuits, and salt-roasting operations. Technical grade V_2O_5 and NH_4VO_3 are the principal products at this level.

To have an easily marketable product, it is customary at this point to either convert the oxides into an alloy or upgrade their purity to greater than 98.5 wt %. The two traditional alloy products have been the 80 wt % ferrovanadium and 35 wt % 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 slag plants and frequently blend feed materials to improve recovery.

Of the more than 30 privately owned producers, only 1, the Republic of South Africa's Highveld, operates facilities at all 4 lower levels and can be considered totally integrated. Highveld has plants that process vanadiferous-magnetite ores from the Bushveld Igneous Complex. Two other producers, Shieldalloy Metallurgical Corp. and Stratcor, have extensive operations on the second, third, and fourth tiers. Shieldalloy traditionally uses 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.

Geology-Resources

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.[8] 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.

Technology

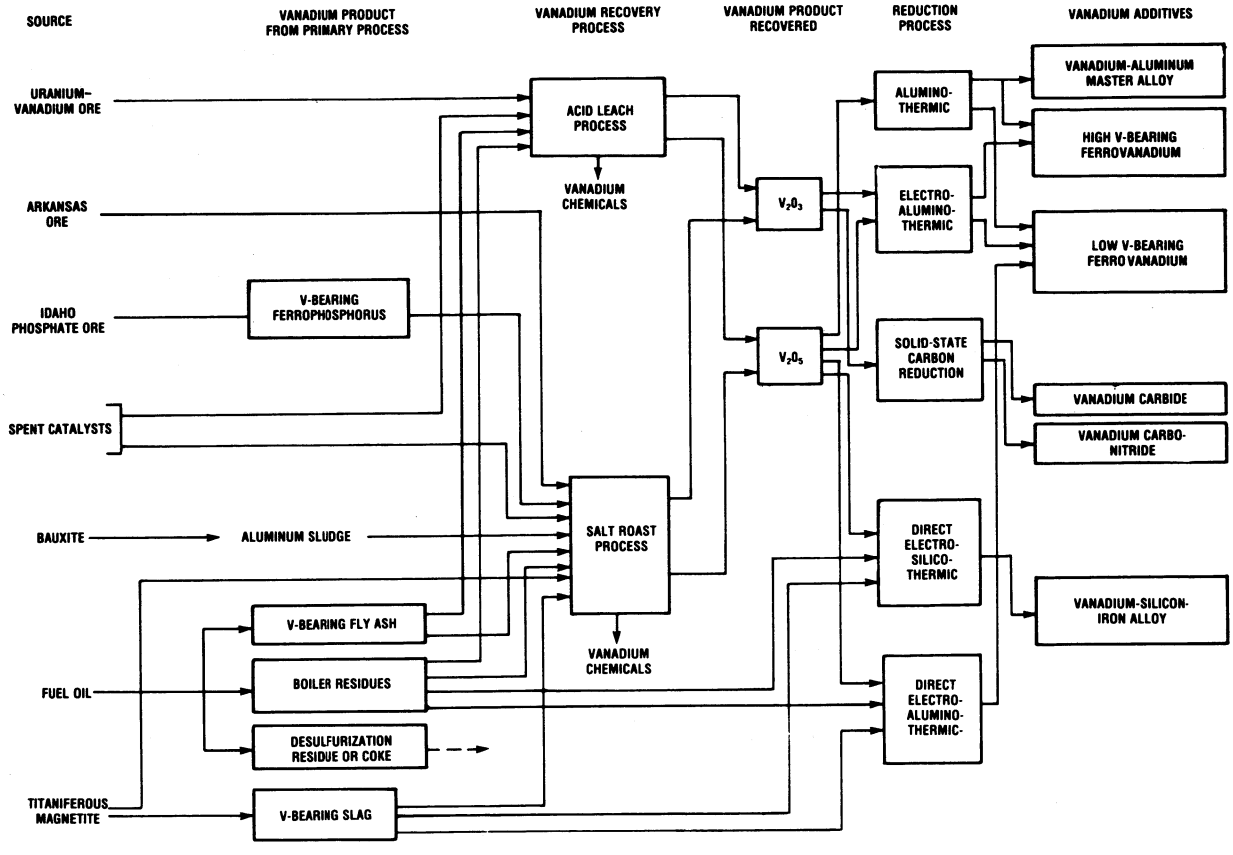
Processing—In the United States, vanadium is recovered as a principal mine product, as a coproduct from carnotite ores, and as a byproduct from ferrophosphorus slag in the production of elemental phosphorus. Increasingly, it is also being recovered from petroleum refinery residues, fly ash, and spent catalysts. In the Republic of South Africa and China, vanadium is recovered as a byproduct of pig iron production from titaniferous magnetite.

The first stage in the processing of vanadium 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 wt % pentoxide and a maximum 8 wt % 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-

FIGURE 1

GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANADIFEROUS RAW MATERIALS



liquid extraction techniques.

In the Republic of South Africa and China, vanadium is concentrated in slag resulting from the production of pig iron from titaniferous 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 which 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 wt % to 24 wt % 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.

Vanadium 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, ferrosilicon, or carbon. 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 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 wt % vanadium can be produced by this method. 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 wt % vanadium, 3.5 wt % silicon, 3.8 wt % manganese, 0.1 wt % carbon, and the remainder iron.

Economic Factors

Prices.—Time-price relationships for vanadium contained in fused vanadium pentoxide (metallurgical grade) in terms of actual prices and in constant 1989 dollars are shown in table 3. Beginning in 1974, published quotes of fused vanadium pentoxide reflect a two-tier price listing of upper and lower producer prices. Actual prices reported in table 3 were based on available information from the producer, or they represent averages of the two-tier quotation as reported in the time period indicated.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1989, are listed in table 8. The tariff listing includes rates for both most-favored-nation (MFN) and non-most-favored-nation status.

[1] Metal Bulletin, No. 7425, Oct. 16, 1989.

[2] Briefing Paper. Vanadium Pentoxide Plant Fort McMurry, Alberta. Carbovan Inc., 2200 Mississauga, Ontario, Canada.

[3] American Metal Market. Pacific to Refine, Sell Vanadium Starting in '91. V. 97, No. 92, May 11, 1989.

[4] Mining Journal (London). Chinese Vanadium Output. V. 313, No. 8047, Nov. 24, 1989, p. 424.

[5] South Africa's Minerals Industry 1988, Republic of South Africa, Department of Mineral and Energy Affairs, Minerals Bureau, p. 129.

[6] The Text Report. V. 21, No. 4892, Apr. 11, 1989, p. 3.

[7] American Society for Testing and Materials. Standard Specifications for Ferrovanadium. A 102-76 in 1980 annual Book of ASTM Standards: Part 2, Ferrous Castings; Ferroalloys. Philadelphia PA, 1980, pp. 88-90.

[8] Renov, A. B., and A. A. Yaroshevsky. Earth's Crust Geochemistry. Sec. in The Encyclopedia of Geochemistry and Environmental Sciences, ed. by R. W. Fairbridge. Van Nostrand Reinhold, 1972, pp. 243-254.

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Metalworking News.
Roskill Reports (London).
The Mining Record.

TABLE 9

U.S. EXPORTS OF VANADIUM IN 1989, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	Ferrovanadium (gross weight)		Vanadium ore and concentrate (vanadium content)		Vanadium compounds (gross weight)			
					Pentoxide (anhydride)[1]		Other[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	—	—	—	—	86	295	—	—
Australia	—	—	—	—	1	5	90	34
Austria	—	—	—	—	87	445	375	1,519
Barbadoes	—	—	—	—	—	—	—	—
Belgium-Luxembourg	—	—	—	—	2,683	11,623	1,791	548
Brazil	—	—	—	—	954	4,038	117	33
Canada	959	4,148	—	—	2	329	140	105
Chile	—	—	—	—	(3)	9	23	39
China	—	—	—	—	—	—	—	—
Colombia	—	—	—	—	—	—	85	43
Egypt	—	—	—	—	—	—	77	23
Finland	—	—	—	—	—	—	—	—
France	10	49	—	—	—	—	5	28
German Democratic Republic	—	—	—	—	734	4,069	—	—
Germany, Federal Republic of	—	—	—	—	931	2,870	20	150
Honduras	—	—	—	—	10	16	—	—
Hong Kong	—	—	—	—	307	1,548	—	—
India	—	—	—	—	—	—	128	245
Israel	—	—	—	—	—	—	—	—
Italy	—	—	—	—	—	—	1	8
Jamaica	—	—	—	—	—	—	2	19
Japan	—	—	—	—	129	350	(3)	9
Korea, Republic of	—	—	—	—	—	—	237	209
Malaysia	7	29	—	—	—	—	—	—
Mexico	10	60	—	—	305	1,425	81	95
Netherlands	—	—	—	—	550	3,069	—	—
Nigeria	—	—	—	—	7	62	—	—
Norway	—	—	—	—	—	—	—	—
Pakistan	—	—	—	—	11	51	—	—
Peru	—	—	—	—	11	8	—	—
Philippines	—	—	—	—	—	—	69	36
Portugal	—	—	—	—	—	—	—	—
Singapore	—	—	—	—	—	—	—	—
Spain	—	—	—	—	—	—	—	—
Sweden	—	—	—	—	482	2,342	150	989
Taiwan	14	60	—	—	1	5	—	—
Thailand	—	—	—	—	—	—	8	82
United Kingdom	2	16	—	—	952	2,635	21	49
Venezuela	88	937	—	—	3	11	—	—
Zimbabwe	—	—	—	—	—	—	—	—
Total[4]	1,087	5,299	—	—	8,248	35,205	3,418	4,262

[1] May include catalysts containing vanadium pentoxide.
[2] Excludes vanadates.
[3] Less than 1/2 unit.
[4] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS OF FERROVANADIUM, BY COUNTRY

(Thousand pounds and thousand dollars)

Country	1988			1989		
	Gross weight	Vanadium content	Value	Gross weight	Vanadium content	Value
General imports:						
Austria	112	92	631	267	218	3,283
Belgium-Luxembourg	86	69	839	149	122	1,625
Brazil	—	—	—	38	27	364
Canada	88	71	730	401	327	5,142
France	—	—	—	2	2	17
Germany, Federal Republic of	10	6	70	415	256	2,631
Japan	—	—	—	154	124	259
Mexico	—	—	—	7	6	10
Total[1]	296	238	2,271	1,433	1,080	13,331
Imports for consumption:						
Austria	112	92	631	267	218	3,283
Belgium-Luxembourg	86	69	839	160	130	1,786
Brazil	—	—	—	38	27	364
Canada	88	71	730	401	327	5,142
France	—	—	—	2	2	17
Germany, Federal Republic of	10	6	70	415	256	2,631
Japan	—	—	—	134	108	259
Mexico	—	—	—	7	6	10
Total[1]	296	238	2,271	1,424	1,073	13,493

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

Source: Bureau of the Census.

TABLE 11

U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1988			1989		
	Gross weight (pounds)	Vanadium content (pounds)	Value	Gross weight pounds)	Vanadium content (pounds)	Value
General imports:						
Canada	—	—	—	1,091	624	$4,076
China	703,936	394,321	$2,230,293	70,548	69,589	564,801
France	700	392	24,265	—	—	—
Germany, Federal Republic of	550	308	2,084	3,823	2,284	47,988
South Africa, Republic of	799,506	447,856	2,724,431	332,997	221,198	2,249,826
United Kingdom	—	—	—	1,034	593	6,586
Total[1]	1,504,692	842,877	4,981,073	409,493	294,288	2,873,277
Imports for consumption:						
Canada	—	—	—	1,091	624	4,076
China	169,836	95,136	502,923	—	—	—
France	700	392	24,265	—	—	—
Germany, Federal Republic of	550	308	2,084	3,823	2,284	47,988
South Africa, Republic of	689,981	386,504	2,419,680	295,587	199,822	1,851,913
United Kingdom	—	—	—	1,034	593	6,586
Total[1]	861,067	482,340	2,948,952	301,535	203,323	1,910,563

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

TABLE 12

VANADIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Short tons of contained vanadium)

Country	1985	1986	1987	1988[p]	1989[e]
Production from ores, concentrates, slag:[2]					
China (in vanadiferous slag product)[e]	5,000	5,000	5,000	5,000	5,000
Finland (in vanadium pentoxide product)	2,350	—	—	—	—
South Africa, Republic of:[3]					
Content of pentoxide and vanadate products[e]	6,537	6,350	4,580	5,600	5,735
Content of vanadiferous slag product[e 4]	8,912	10,580	11,135	12,460	12,465
Total	15,449	16,930	15,715	18,060	18,200
U.S.S.R.[e]	10,500	10,600	10,600	10,600	10,600
United States (recoverable vanadium)	W	W	W	W	W
Total[5]	33,299	32,530	31,315	33,660	33,800
Production from petroleum residues, ash, spent catalysts:[6]					
Japan (in vanadium pentoxide product)[e]	840	[7]929	925	925	925
United States (in vanadium pentoxide and ferrovanadium products)	2,695	2,330	2,508	3,252	[7]2,633
Total	3,535	3,259	3,433	4,177	3,558
Grand total	36,834	35,789	34,748	37,837	37,358

[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 29, 1990.

[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.

TABLE 13

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing[1]				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Vanadium-aluminum alloy	Other[2]
United States:						
AMAX Metals Recovery Corp.	Braithwaite, LA	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	—	—	—	—
Akzo Chemical Co.	Weston, MI	—	—	—	—	E
Canada:						
Masterloy Products Ltd.	Gloucester, Ontario	—	x	—	—	—
Carbovan Inc.	Fort McMurray, Saskatchewan	x	—	—	—	—
Germany, Federal Republic of:						
Gesellschaft fur Electrometallurgie mbH	Nuremburg	—	x	—	x	—
Belgium:						
Sadacem (Langerbruggekaai Plant)	Kent	—	x	—	—	—
Spain:						
Ferroastur SA	Poligono de Maqua, Aviles	—	x	—	—	—
Sweden:						
Metals & Powders Trollhatten AB (Sandvik AB)	Trollhatten	—	x	—	—	—
United Kingdom:						
Murex Ltd.	Rainham, Essex	x	x	x	—	—
London & Scandinavian Metallurgical Co. Ltd.	Rotherham, S. Yorkshire	—	x	—	—	—
Ferroalloys & Metals Ltd.	Glossop, Derbyshire	—	x	—	—	—
South Africa, Republic of:						
Highveld Steel & Vanadium Corp.	Witbank	x	—	x	—	—
Vansa Vanadium SA Ltd.	Steelpoort, Eastern Transvaal	x	—	—	—	—
Vametco Minerals Corp.	Bushveld Complex	x	—	x	—	A
Transvaal Alloys Pty. Ltd.	Roos Senekal, Transvaal	x	—	—	—	—
Union Steel Corp.	Vereeniging	x	—	—	—	—
Japan:						
Awamura Metals Industry Co.	Uji, Kyoto	—	x	—	—	—
Taiyo Mining & Industrial Co.	Ako, —	—	x	—	—	—
Nippon Denko KK	Toyama	—	x	—	—	—
Japan Metals and Chemical Co.	Oguni, Yamagata	—	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	—	—	—

See footnotes at end of table.

TABLE 13—Continued

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing[1]				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Vanadium-aluminum alloy	Other[2]
U.S.S.R.:						
Chusovskoy Met. Savod	Chusovoy	x	x	—	—	—
Novo-Tagilskiy Met. Zavod	Nizhniy-Tagil	x	x	—	—	—
Novo-Tulskiy Met. Zavod	Tula	x	x	—	—	—
Serovskiy Met. Zavod	Serov	x	x	—	—	—

[1] x, Producer; —nonproducer.
[2] A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-zirconium alloy producer; E, Unsupported vanadium catalyst producer.

VERMICULITE

By Michael J. Potter

Mr. Potter, a physical scientist with 23 years of industry and Bureau of Mines experience, has been the acting commodity specialist for vermiculite since 1989. Domestic survey data were prepared by Maureen Nash, mineral data assistant; and the international data table was prepared by Audrey Wilkes, internationl data assistant.

U.S. output of vermiculite concentrate was estimated to be 290,000 short tons, a decrease from that of the previous year. The tonnage of exfoliated vermiculite sold and used was an estimated 215,000 tons, also a decrease from that of 1988. Vermiculite has been facing competition from other cost-effective materials, especially in the building products market. Also, markets have been affected by a decrease in construction activity.

TABLE 1

SALIENT VERMICULITE STATISTICS

(Thousand short tons and thousand dollars unless otherwise specified)

		1985	1986	1987	1988	1989[e]
United States:						
Sold and used by producers:						
Concentrate		314	317	303	304	290
Value		$32,400	$34,400	$33,100	$33,900	$32,600
Average value[1]	dollars per ton	$103.18	$108.52	$109.24	$111.51	$112.41
Exfoliated		258	253	252	249	215
Value		$47,900	$53,200	$54,600	$55,100	$48,800
Average value[1]	dollars per ton	$185.66	$210.28	$216.67	$221.29	$226.98
Exports to Canada		[e]23	[e]25	[e]20	[e]20	20
Imports for consumption		[e]38	[e]35	32	[e]35	40
World: Production[2]		556	580	620	[p]600	604

[e]Estimated. [p]Preliminary.
[1]Based on rounded data.
[2]Excludes production by centrally planned economy countries.

DOMESTIC DATA COVERAGE

Domestic production data for vermiculite are developed by the 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, two responded. The four nonrespondents' data were estimated using previous years' production levels adjusted by trend of the minerals economy. Of the 35 active exfoliating plants to which a survey request was sent, 8 responded. This represented an estimated 10% of the total exfoliated vermiculite sold and used, see table 1. The 27 nonrespondents' data were estimated using previous years' production levels adjusted by the trend of the minerals economy.

PRODUCTION

The leading domestic producer of vermiculite concentrate continued to be W. R. Grace & Co. with operations near Libby, MT, and Enoree, SC. Other producers during the year were Virginia Vermiculite Ltd., Louisa County, VA; Strong-Lite Products Corp.'s Carolina Vermiculite 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 third consecutive year.

Domestic sales of exfoliated vermiculite by 15 producers came from 35 plants in 27 States. Of these plants, 21 in 17 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, California, South Carolina, Florida, New Jersey, Illinois, Texas, and Arkansas.

PRICES AND FOREIGN TRADE

The average value of vermiculite concentrate sold and used by U.S. producers was estimated at $112 per ton, f.o.b. plant, or about the same as in 1988. The average value of exfoliated vermiculite, f.o.b. plant, increased from $221 per ton to an estimated $227 per ton.

Imports of vermiculite concentrate from the Republic of South Africa were estimated to be 40,000 tons, compared with 35,000 tons (revised) in 1988. Exports to Canada were estimated to be 20,000 tons, about 7% of total U.S. sales of vermiculite concentrate.

WORLD REVIEW

Table 4 shows rated annual capacity for vermiculite plants as of December 31, 1989. 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

TABLE 2

EXFOLIATED VERMICULITE SOLD AND USED IN THE UNITED STATES, BY END USE

(Short tons)

End use	1988	1989[e]
Aggregates:		
Concrete	40,100	33,200
Plaster	1,400	1,800
Premixes[1]	71,600	64,300
Total	113,100	99,300
Insulation:		
Loose-fill	22,000	17,900
Block	31,700	21,100
Other[2]	8,200	2,300
Total	61,900	41,300
Agricultural:		
Horticultural	16,700	15,100
Soil conditioning	16,800	15,200
Fertilizer carrier	37,900	36,700
Total	71,400	67,000
Other[3]	2,600	7,800
Grand total	249,000	[4]215,000

[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 total shown because of independent rounding.

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.

TABLE 3

ACTIVE VERMICULITE EXFOLIATING PLANTS IN THE UNITED STATES IN 1989

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.
	Oklahoma	Oklahoma.
	Multnomah	Oregon.
	Lawrence	Pennsylvania.
	Greenville[1]	South Carolina.
	Dallas	Texas.
Intermountain Products Inc.	Salt Lake	Utah.
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, 1989

(Thousand short tons)

Country	Rated capacity[1]
North America:	
Mexico	1
United States	355
Total	356
South America:	
Argentina	25
Brazil	20
Total	45
Africa:	
Egypt	1
Kenya	5
South Africa, Republic of	260
Total	266
Asia:	
India	8
Japan	20
Total	28
World total	695

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

TABLE 5

VERMICULITE: WORLD PRODUCTION, BY COUNTRY[1]

(Short tons)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Argentina	5,387	5,740	20,516	21,275	21,000
Brazil	10,242	15,598	18,546	[re]18,000	18,000
Egypt	538	546	[e]550	260	[3]300
India	1,990	7,365	3,202	4,395	6,000
Japan[e]	19,000	17,000	17,000	17,000	17,000
Kenya	1,670	2,804	4,285	4,086	4,200
Mexico	386	243	177	240	300
South Africa, Republic of	202,902	213,470	252,278	230,578	247,500
United States (sold and used by producers)	314,000	317,000	303,000	304,000	290,000
Total	556,115	579,766	619,554	599,834	604,300

[e]Estimated. [p]Preliminary. [r]Revised.
[1]Excludes production by centrally planned economy countries. Table includes data available through July 18, 1990.
[2]In addition to the countries listed, Tanzania may produce vermiculite, but available information is inadequate ton make reliable estimates of output levels, if any.
[3]Reported figure.

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WOLLASTONITE AND ZEOLITES

By Michael J. Potter and Robert L. Virta

Mr. Potter, a physical scientist with 23 years industry and 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 14 years Bureau of Mines experience, has been the commodity specialist for natural zeolites since 1986. Domestic survey data were prepared by Pam Shorter, mineral data assistant.

WOLLASTONITE

Wollastonite is natural calcium silicate and has a theoretical composition of $CaO \cdot SiO_2$.

The tonnage of wollastonite sold or used by U.S. producers in 1989 increased slightly. Specific data were withheld to avoid disclosing company proprietary data. The two producers were NYCO, a division of Processed Minerals Inc., Essex County, NY, and R. T. Vanderbilt Co. Inc., Lewis County, NY.

NYCO reported the discovery of a wollastonite deposit near Lewis, NY. The new Oak Hill deposit, located near the company's current mine, would reportedly double existing reserves.

In October 1989, Engelhard Corp. announced it had agreed in principle to purchase Processed Minerals Inc. of Syracuse, NY, a wholly-owned subsidiary of Canadian Pacific (U.S.) Inc.[1] However, in late 1989, Englehard announced it was not going to acquire Processed Minerals Inc.

The discovery of a wollastonite deposit in the Gilbert district of southern Nevada was reported by Sikaman Gold Resources Ltd. Grades of material in excess of 50% wollastonite were reported. A detailed mapping and core drilling program was under way. Test work was also being undertaken to determine quality, grade, and market conditions.[2]

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 ceiling and floor tile, and in friction applications such as brake linings.

Prices from Industrial Minerals, December 1989, for wollastonite, exworks, converted to dollars per metric ton, were approximately $260 for acicular, minus 200 mesh, $200 for minus 325 mesh, and $210 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, four samples of wollastonite ore from various locations in the Province of British Columbia in western Canada were evaluated. Wollastonite content varied between 45% and 75%. Processing of the ore samples included wet high-intensity magnetic separation and flotation. For three of the four samples, the Fe_2O_3 content of the wollastonite concentrate was less than 1%; the estimated wollastonite grade was 90%. Wollastonite obtained from the samples is probably suitable for ceramic and filler applications. Final verification of suitability would require detailed product evaluation.[3]

In China, large reserves of wollastonite occur in Jilin Province. At the Dadingshan Mine, rich ore was separated from lower grade material (tailings) by hand sorting. Test work was carried out on samples of tailings, which contained approximately 45% calcite, 32% wollastonite, 17% quartz, and 2% diopside. Using flotation, calcite was removed, followed by separation of wollastonite and quartz. Preliminary estimates indicated that mineral processing would be economical.[4]

Wollastonite was found to have a reinforcing effect on concrete materials. Test results showed that the compression strength of wollastonite-reinforced concrete was increased by approximately 30% and the bending strength by 20%, compared with common concrete. The wollastonite concrete has been successfully used in the construction of methane tanks.[5]

The plastics industry has been proving to be an active market for extender and filler minerals. Demand for both filler and surface-treated grades has been increasing, with the trend being driven by the automotive industry. According to a study by Kline & Co. of Fairfield, NJ, calcium carbonate, mica, silicas, talc, and wollastonite will all show demand growth of over 5% a year in this end use area.[6]

ZEOLITES

Zeolites are hydrated aluminosilicates of the alkaline and alkaline-earth metals. Approximately 40 natural zeolites have been identified over the past 200 years, the most common of which are analcime, chabazite, clinoptilolite, erionite, ferrierite, heulandite, laumontite, mordenite, and phillipsite. Zeolites are commercially valuable because of their unique ion-exchange, molecular sieving, and catalytic properties.

Commercial zeolite deposits in the United States are associated with the alteration of volcanic tuffs in saline, alkaline lake deposits; saline, alkaline soils; and open hydrologic systems. The deposits are located in Arizona, California, Idaho, Oregon, Nevada, New Mexico, and Texas. Their composition was determined primarily by the temperature and pressure of formation and the chemistry of the altering fluids. The major components of these deposits are chabazite, clinoptilolite, mor-

denite, and phillipsite. Erionite, orthoclase feldspar, montmorillonite, opal, quartz, and volcanic glass may be present in some deposits as minor components. 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 air-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.

Six companies mined natural zeolites in the United States in 1989. Four companies mined clinoptilolite from deposits in California, Nevada, Oregon, and Texas; two companies mined chabazite from deposits in Arizona. Total domestic production and sales were 12,117 metric tons (13,357 short tons) in 1989, an increase of 11% from those of 1988.

Natural zeolites were used for aquaculture, aquarium filters, chemical carriers, desiccants, odor control, pet litter, wastewater cleanup, and water purification. 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 and water purification). The major application for natural zeolites in 1989 was in pet litter.

TABLE 1

DOMESTIC ZEOLITE PRODUCERS, 1989

State and company	Type of zeolite
Arizona:	
GSA Resources Inc.	Chabazite
Union Carbide Co.	Do.
California:	
Steelhead Specialty Minerals	Clinoptilolite
Nevada:	
East-West Minerals Inc.	Do.
Oregon:	
Teague Mineral Products Co.	Do.
Texas:	
Zeotech Corp.	Do.

The Bureau of Mines continued research on the use of zeolites to remove dissolved metals and other cations from water. The exchange properties of 21 natural zeolite samples from different locations were determined for Pb^{2+} and NH_4^+ ions. The zeolites tested were chabazite, clinoptilolite, erionite, mordenite, and phillipsite. Exchange capacities ranged from 0.6 to 2.1 milliequivalents for Pb^{2+} ions and 0.9 to 2.8 milliequivalents for NH_4^+ ions. In other tests, competing cations such as Na^+, Ca^{2+}, and NH_4^+ strongly affected heavy metal cation uptake of natural zeolite samples. Wastewater run-off from an abandoned metal mine was passed through columns filled with clinoptilolite to determine the efficiency of heavy metal removal in the presence of competing ions. Twelve percent of the exchange capacity was utilized, and the heavy metal concentration of the treated water exceeded drinking water standards despite several passes through a column. Lime precipitation and aeration of the water reduced heavy metal levels sufficiently to meet drinking water standards.

Research continued on controlling the uptake of cesium by vegetation on Bikini Atoll where levels of surface radioactivity were low enough for habitation but concentrations of cesium in food crops were above acceptable limits. Food crops were grown in cesium-contaminated soils that contained various concentrations of clinoptilolite. The amount of cesium in the food plants were measured after the plants were harvested. The concentration of cesium in plants grown in zeolite-amended soils was significantly lower than in plants grown under control conditions. Further tests were being conducted to determine if the release of exchangeable potassium in the clinoptilolite influenced the results of the tests.[7]

Mordenite, a natural zeolite, was investigated as a combustion catalyst for eliminating residual hydrocarbons and CO in exhaust gases and solvent vapors in factories. Mordenite was chosen because of its large aperture sizes in the crystal structure and its thermal stability. NH_4-mordenite, Ca-mordenite, K-mordenite, and Na-mordenite were prepared through cation exchange. The number of acid and basic reaction sites and the catalytic properties were different for each mordenite type. Each mordenite type also had different abilities for oxidizing organic compounds.[8]

There are many potential agricultural applications of natural zeolites in developing countries. Most developing countries lie in the tropical latitudes where soils are depleted of important plant nutrients. Natural zeolites could serve as low-cost carriers for fertilizers for enriching and retaining the nutrients in the soil or to retain moisture in the soil in arid environments. Another potential application is the reduction of local water pollution that is caused by agricultural runoff from animal pens. Animal wastes are frequently washed from animal holding pens, and the contaminated runoff enters local streams. Zeolites mixed with animal wastes would reduce odors by adsorbing ammonia and would improve the handling characteristics of the manure by adsorbing moisture. The mixture has potential for use as a nitrogen-rich soil supplement. Finally, experiments suggest that zeolites are beneficial as an animal feed supplement, reducing disease and improving yield. More extensive exploration for zeolite deposits in developing countries and more thorough field testing is required in order to demonstrate the practicality of these applications.[9]

[1] Industrial Minerals (London). World of Minerals. No. 266, Nov. 1989, p. 17.

[2] ———. P. 19.

[3] Andrews, P. R.A. Beneficiation of Canadian Wollastonite Ores. Paper from Second World Congress on Non-Metallic Minerals, Beijing, China, Oct. 17-21, 1989, p. 657.

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[5] Xiaoping, B., H. Zhongji, and Z. Zufu. Investigation and Application of Wollastonite Fiber Reinforced Concrete. Paper from Second World Congress on Non-Metallic Minerals, Beijing, China, Oct. 17-21, 1989, p. 7.

[6] Chemical Marketing Reporter. Extender Minerals are Boosted by Paint, Paper Market Changes. V. 236, No. 21, Nov. 20, 1989, p. 14.

[7] Leppert, D. Heavy Metal Sorption with Clinoptilolite Zeolite: Soil and Water Treatment Alternatives. Soc. Min. Eng. AIME preprint 89-110, 1989, 5 pp.

[8] Yuan, X. and X. Zheng. A New Type Carrier for the Combustion Catalyst-Natural Zeolite. Paper from Second World Congress on Non-Metallic Minerals, Beijing, China, Oct. 17-21, 1989, pp. 249-251.

[9] Parham, W. Natural Zeolites: Some Potential Agricultural Applications for Developing Countries. Natural Resources Forum, May 1989, pp. 107-115.

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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 Bureau of Mines for 17 years and the zinc specialist for the past 8 years. Domestic survey data were prepared by Lura M. Nightlinger and Tony E. Morris, mineral data assistants.

Zinc-producing mines in Alaska, Montana, and New Mexico opened in 1989, resulting in increased domestic output for the third straight year. A world-class zinc mine in Alaska, scheduled to open in late 1989, experienced startup problems, and its official opening was rescheduled for early 1990. Refined zinc metal production was the highest since 1981. Improved production was attributable to near-capacity output at U.S. primary smelters and increased zinc recovery from steelmaking dusts. In 1989, U.S. mines produced 4.0% of world mine output, and U.S. smelters produced 5.0% of world refined metal output.

Domestic metal consumption declined modestly in 1989 but was the second highest in the 1980's decade. The consumption decrease was largely attributable to sharply reduced automobile production in the last quarter of the year. Exports of concentrate, scrap, refined metal, and compounds were the best in years, whereas imports generally declined. Nonetheless, net imports of basic zinc products accounted for $1 billion of the Nation's trade imbalance.

World mine production was second highest, whereas world smelter output was a record high. World mine and smelter capacity utilization rates were high throughout the year; however, little new capacity was added to either category in 1989.

World zinc metal consumption exceeded 7 million metric tons for the third straight year and was estimated to have been slightly less than the record-high consumption attained in 1988. High consumption resulted in record zinc prices early in the year; however, prices eased in the latter-half of the year owing to a slight fall in demand and increased stock levels.

LEGISLATION AND GOVERNMENT PROGRAMS

Environmental and trade issues continued to be the major thrusts of governmental and legislative actions in 1989. The Environmental Protection Agency (EPA) applied its revised interpretation of the Bevill Amendment (exclusion) to solid waste from the extraction, beneficiation, and processing of ores and minerals. On September 1, EPA identified 5 wastestreams as having Bevill status and conditionally retained 20 other wastestreams for further consideration.[1] All other mineral processing wastes were permanently removed from the Bevill exclusion and were subject to subtitle C regulation of the Resource Conservation and Recovery Act (RCRA) if they exhibit hazardous characteristics. In late September, EPA proposed to retain only 13 of the 20 conditionally retained wastes for further study; this proposal, which was to be finalized in mid-January 1990, retained slag from primary zinc processing, the only zinc related waste remaining in the Bevill exclusion. Final regulatory determination for Bevill processing wastes was expected in January 1991.

Sites that fall under the Comprehensive Environmental Response, Compensation, and Liability Act are called Superfund sites. A number of the Superfund sites associated with zinc mining and processing attracted considerable attention during 1989. The two most prominent sites were the 21-square-mile area surrounding the Bunker Hill lead-zinc smelter complex in Idaho, and the Tristate lead-zinc mining district of Kansas, Missouri, and Oklahoma. The former owner of Bunker Hill, Gulf Resources and Chemical Corp., agreed to keep at least $150 million in domestic assets to ensure against its potential liability for the cleanup of mainly lead-contaminated soil and residues at the complex and the area around the smelter site. In 1989, cleanup efforts centered on a program to remove and replace up to 2 feet of contaminated soil at private residences, mainly in the nearby mining town of Kellogg.

In the Tristate district, EPA continued its efforts in a few selected areas to reduce heavy-metal contamination of surface and subsurface water caused by lead-zinc mining activity carried out in the area from about 1848 to 1970. Through 1989, about $6 million had been spent on the cleanup of mining sites in the Tar Creek area of Oklahoma. Other areas in the district have been identified as possible Superfund sites. One of these was the Galena, KS, area where an $8 million cleanup program was proposed. Cleanup efforts have or were expected to involve recontouring existing land surfaces and redirecting surface streams around mineral areas, burial of residues of mining operations, blocking of mine shafts that provide surface water access to underground workings, and stabilization of mining-related surfaces by revegetation. Mining companies that operated in the Tar Creek, Galena, and other areas in the district have been named by EPA as the "potentially responsible parties" for the pollution problems and might be liable for some or all of the cleanup costs.

The final draft of the Basel Convention for the control of transboundary movements of hazardous wastes and their disposal was completed. The President was expected to approve the Convention in early 1990 with Senate ratification expected by 1993. The Convention is designed to ensure that exported hazardous wastes will be transported,

TABLE 1

SALIENT ZINC STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Domestic ores, recoverable content	226,545	202,983	216,327	244,314	275,883
Value thousands	$201,607	$170,050	$119,924	$324,249	$499,103
Slab zinc:					
From domestic ores	198,005	191,079	205,275	196,476	166,424
From foreign ores	63,204	62,290	56,070	44,818	96,652
From scrap	72,563	62,912	82,589	88,492	95,133
Total	333,772	316,281	343,934	329,786	358,209
Secondary zinc[1]	256,455	255,752	r327,944	r248,461	251,795
Exports:					
Ores and concentrates (zinc content)	23,264	3,269	16,921	33,590	78,877
Slab zinc	1,011	1,938	1,082	482	5,532
Imports for consumption:					
Ores and concentrates (zinc content)	90,186	75,786	46,464	62,966	40,974
Slab zinc	610,900	665,126	705,985	749,133	711,554
Stocks of slab zinc, Dec. 31:					
Industry	119,892	100,563	96,372	r85,854	90,711
Government stockpile	340,577	340,577	340,577	340,577	340,577
Consumption:					
Slab zinc:					
Reported	770,671	705,963	798,148	r833,473	887,203
Apparent (rounded)[2]	961,000	999,000	1,052,000	1,089,000	1,060,000
All classes (rounded)[3]	1,257,000	1,274,000	r1,383,000	r1,340,000	1,314,000
Price: High Grade, cents per pound (delivered)	40.37	38.00	41.92	60.20	82.06
World:					
Production:					
Mine thousand metric tons	r6,758	r6,936	7,232	p7,015	e7,062
Smelter do.	r6,786	r6,691	7,009	p7,115	e7,187
Price: London, cents per pound	36.23	34.19	36.20	r51.11	76.70

e Estimated. p Preliminary. r Revised.

[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.

treated, and/or disposed of by the importing country in a manner that is consistent with the protection of the environment and human health. This could impact future U.S. exports of zinc scrap, wastes, and residues, especially to developing countries where environmental controls are below accepted standards.

On January 1, the U.S. Bureau of the Census replaced the Tariff Schedule of the United States (TSUS) with the Harmonized Tariff Schedule of the United States (HTS) to surmount increasing difficulties arising from the use of different tariff classification systems in other countries and changing international needs. The new system was international in scope and provided a means for most countries to have a single modern structure for product classification thereby easing duty determination, statistical accounting, and transportation documentation. Many new classification subdivisions were also added to HTS to reflect changes in technology, trade patterns, and user requirements. Because of many, mostly minor, differences between the two U.S. tariff systems, the statistical trade data of 1989 and that of prior years may not be comparable.

Also on January 1, the United States and Canada formed the world's largest free trade area by implementing the United States-Canada Free-Trade Agreement (FTA) Implementation Act of 1988. The FTA eliminates all tariffs on U.S. and Canadian goods by 1998. U.S. duties on imports of zinc metal, alloys, and dutiable zinc chemicals were to be phased out at 10% per year over 10 years.

In April, the Non-Ferrous Metals Producers Committee (NFMPC) submitted a petition to the U.S. Trade Representatives (USTR) seeking identification of the copper, lead, and zinc industries under section 409(b) of the FTA, which has provisions for addressing unfair trade practices. The NFMPC contended that these domestic industries would face in-

creased competition from subsidized imports from Canada. On July 5, the USTR, in consultation with the Secretary of Commerce, concluded that a reasonable likelihood existed that the copper and lead industries could face increased competition from subsidized production in Canada. Data on the zinc industry, however, were insufficient to identify it under the 409(b) provision, but the USTR would seek zinc information within the scope of any study on the lead industry that might be initiated as a result of the USTR decision on lead.

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 1989. 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 on a care and maintenance basis could be reactivated in 3 to 12 months.

The domestic ore reserve base is large 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 was expected to more than double U.S. zinc mine output by 1991, 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 1989, for example, domestic zinc mine production substantially exceeded U.S. smelter feed requirements resulting in net exports of about 39,000 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 come from Canada and Mexico, and, therefore, the risk of supply disruption is low. Other traditional sources of zinc supply depends on sea transport, and the risk of supply disruption is considerably higher.

Substitutes

Substitution for zinc depends on price and availability of substitutes as well as their technical suitability. In an emergency situation, some substitutions may not be possible because the substituting materials themselves are critical or strategic. Virtually all areas of zinc use have been susceptible to some form of reduced zinc consumption either through substitution or technical innovation. Zinc, aluminum, magnesium, and plastics are competitive materials in diecasting where weight, temperature tolerances, and surface finish are important factors. Aluminum and plastic sheet are substitutes for galvanized steel sheet; the use of molded plastics for automobile body parts in particular, has increased at the expense of galvanized steel sheet uses. Although emphasis on corrosion protection has led to increased zinc consumption in the galvanizing sector, former all-zinc coatings are increasingly being replaced by zinc alloy coatings containing less zinc than before, thinner coatings (reduced coating weights), or alloys such as aluminum-based Galvalume. Aluminum alloys, stainless steel, cast iron, and plastics have replaced significant tonnages of brass in building and marine hardware, plumbing goods, and decorative uses.

The competition in chemical and pigment uses of zinc is also substantial. Aluminum and magnesium replace zinc as reducing agents in chemical reactions, and titanium and zirconium compounds are highly competitive in pigment, ceramic, and enamel applications. Zinc compounds formerly were consumed in large amounts in the paint, photocopy, and synthetic fiber industries, but consumption in these industries has been severely impacted by substitution or technological change. Titanium dioxide largely replaced zinc oxide pigments in the paint industry. Zinc-sensitized photocopy paper use declined rapidly following the development of the "plain-paper copier." Somewhat similarly, zinc compounds used in the production of rayon fell as rayon was displaced by other synthetic fibers.

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, 1.293 million tons, was established in April 1980, but no zinc had been purchased through 1989 to meet this goal. At the end of 1989 the zinc stockpile totaled 343,202 tons, including 2,625 tons of zinc contained in brass. The zinc metal stockpile consisted of 183,175 tons of High Grade (HG), 121,752 tons of Prime Western (PW), and 35,650 tons of other grades. New, sharply lower zinc goals were considered by the Department of Defense in 1989 and were expected to be proposed in 1990.

PRODUCTION

Mine Production

Spurred by continuing strong markets and high zinc prices, U.S. zinc mine production increased for the third straight year. Zinc production began at a new mine in Alaska, a reopened group of mines in Montana, and a copper mine in New Mexico. Startups at three other mines that were scheduled to open in 1989 were delayed by technical and/or permitting problems. The strong market outlook for zinc led

to renewed interest in a number of closed domestic zinc mining properties, several of which were being evaluated for reopening in 1990 or 1991.

The 20 leading U.S. zinc-producing mines accounted for more than 97% of production, with the 5 leading mines accounting for 47%. Tennessee, for the 29th time in the past 32 years, was the principal zinc-producing State, followed by Missouri, New York, Colorado, Alaska, Montana, and Idaho. The leading domestic zinc mine producers were ASARCO Incorporated, Jersey Miniere Zinc Co. (JMZ), and Zinc Corporation of America (ZCA).

In Tennessee, zinc was produced at six underground mines by three companies: Asarco, JMZ, and Union Zinc Inc., the parent company of JMZ. Union Zinc bought USX Corp.'s operating east Tennessee zinc mine in June, in part to secure zinc concentrate supply for JMZ's Clarksville, TN, smelter. The mining operation, renamed the Jefferson City Zinc Div. of Union Zinc, had an annual capacity to produce about 22,000 tons of zinc concentrate plus large amounts of agricultural and construction limestone.

Asarco achieved record output at its four mining operations in east Tennessee. According to the company's annual report, Asarco milled 2.72 million tons of ore producing 63,230 tons of zinc in concentrate in 1989, compared with 2.68 million tons of ore milled yielding 67,850 tons of zinc in 1988. Zinc recovery from ore averaged 93.2% in 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 1988.

Zinc was produced by three companies, Asarco, Doe Run Co., and Cominco American Inc., a subsidiary of Cominco Ltd., as a coproduct of lead at nine underground lead mines along the Viburnum Trend in southeastern Missouri. The State's production was up substantially from that of 1988, mainly because of increased output at most mines, especially at Asarco's two mines. According to the Asarco annual report, zinc output in concentrate at the West Fork Mine was 13,060 tons, up 2,200 tons from 1988, and at the Sweetwater Mine production was 4,260 tons, up 2,800 tons. At yearend, ore reserves at the West Fork Mine were 8.3 million tons averaging 1.5% zinc and 5.8% lead with some copper and silver and at the Sweetwater Mine, 21.9 million tons of ore averaging 4.84% lead and 0.58% zinc.

The Doe Run Co., a joint venture of Fluor Corp. and Homestake Mining Co., produced about 28,000 tons of zinc in 49,700 tons of concentrate at four mills that processed 4.35 million tons of ore from six company mines in 1989. Yearend ore reserves at the six Doe Run mines totaled about 60 million tons averaging 5.1 % lead, 0.9% zinc, and 0.3% copper.

Zinc output at the Magmont Mine, a joint venture of Cominco American and Dresser Industries Inc., fell slightly from that of 1988 owing to a small decrease in ore output. According to the Cominco annual report, the Magmont mill processed about 1 million tons of ore grading 1% zinc yielding 7,720 tons of zinc in 13,400 tons of concentrate in 1989. Ore reserves continued to decline and were expected to be exhausted in about 3 years. At yearend, ore reserves totaled 3.3 million tons, a drop of 0.6 million from 1988. Ore reserves averaged 7.5% lead, 1.2% zinc, and 0.3% copper.

At the end of the year, Cominco Alaska Inc., a subsidiary of Cominco Ltd., had completed nearly all phases of mine and mill construction at its Red Dog zinc-lead-silver mine in northwest Alaska. The first ore was fed into the semiautogenous mills in early November, and the first concentrate was delivered to the port site, 52 miles southwest of the mine, on December 6. Technical problems, however, delayed full commissioning of facilities, and regular production operations were rescheduled to start in the first quarter of 1990. Total annual production, planned in 1991, was expected to be 508,000 tons of zinc concentrate, 109,100 tons of lead concentrate, and 45,000 tons of bulk concentrate.

Capital expenditures on the Red Dog project to the end of 1989 totaled $317 million for the mine and mill complex and $170 for the road and port facilities. Ore reserves at Red Dog were 77 million tons grading 17.1% zinc, 5.0% lead, and 2.6 ounces of silver, potentially sufficient for a mine life of 50 years.

The Greens Creek Mining Co., the operating company and a wholly owned subsidiary of RTZ Ltd. through its Kennecott Corp. subsidiary, and minority partners, Hecla Mining Co., Exalas Resources Corp., and CSX Oil and Gas Corp. brought the Greens Creek silver-gold-zinc-lead mine on Admiralty Island, AK, on-stream in February 1989 at a cost of about $79 million. Full production was not achieved during the year because of startup problems. According to the Hecla annual report, Greens Creek Mining milled 240,000 tons of ore in 1989 and produced concentrates containing 18,010 tons zinc, 8,700 tons lead, 5.17 million ounces of silver, and 23,500 ounces of gold. At yearend, ore reserves were 2.65 million tons averaging 8.4% zinc, 3.4% lead, 23.6 ounces of silver per ton, and 0.21 ounce of gold per ton.

In Colorado, zinc production was a coproduct of gold-silver operations at the Leadville Unit (managed by Asarco, but jointly owned with the Resurrection Mining Co.) and at the Sunnyside Mine (a joint venture between Alta Bay Venture and Washington Mining Co.). Asarco produced almost 13,000 tons of zinc in concentrates, down about 500 tons from 1988. Both the tonnage of ore milled, 185,000 tons in 1989, fell as did the zinc recovery factor, which fell to 82.2% from 85.1% one year earlier. At yearend, ore reserves were down about 55,000 tons from 1988 and totaled 709,000 tons averaging 7.77% zinc, 3.22% lead, 0.18% copper, 2 ounces of silver per ton, and 0.07 ounce of gold per ton. At the Sunnyside Mine, 198,000 tons of ore was milled in 1989, resulting in yearend ore reserves totaling 546,000 tons estimated to average 5.4% zinc, 3.8% lead, 0.57% copper, 3.5 ounces of silver per ton, and 0.15 ounce of gold per ton.

In Montana, New Butte Mining Co., Inc. began initial production of zinc-silver-lead-gold ore in July at several of its mining properties at Butte. The ore was custom processed at the Contact Mill in Philipsburg, MT. The company was planning to build its own local mill in 1991. Geologic ore reserves at yearend totaled about 1.0 million tons averaging about 5.9% zinc, 1.7% lead, 10 ounces per ton of silver, and 0.06 ounce per ton of gold.

The Montana Tunnels Mining Co., a subsidiary of Pegasus Gold Inc., mined and milled 3.6 million tons of ore at its Montana Tunnels Mine in 1989; concentrates containing 14,900 tons of zinc, 6,800 tons of lead, 1.2 million ounces of silver, and 62,600 ounces of gold were

produced. The discovery of low-grade zones in the ore body and harder than expected ore adversely affected production in the first half of the year and resulted in development of a new mine plan during the year. Ore reserves were also reduced by 1.5 million tons and at yearend totaled 34 million tons averaging 0.62% zinc, 0.23% lead, 0.023 ounce of gold per ton, and 0.4 ounce of silver per ton. At 1989 production rates, a 9-year mine life was expected.

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 1989, ore milled increased about 27,000 tons to 126,000 tons resulting in an output of 2,950 tons of zinc in concentrates, up about 900 tons from 1988. At yearend, ore reserves were 416,000 tons averaging 2.4% zinc, 14.4% lead, and 17.7 ounces of silver per ton.

In April, Cyprus Minerals Co. began zinc production at its Pinos Altos copper-zinc mine in New Mexico. The mine was opened in 1988 but produced only copper. The inactive Groundhog mill at Deming was leased to process the zinc ore. According to the Cyprus annual report, about 900 tons of zinc in concentrate was produced and sold in 1989. Reserves of zinc ore were about 0.9 million tons at yearend.

Both the Ward Mine in Nevada and the Star-Morning Mine in Idaho had been expected to open in 1989, but their openings were delayed owing to permitting and/or technical problems. Both, however, were expected to open in early 1990. Ore produced at the Ward Mine, wholly owned by Alta Gold Co. since November via the merger of Silver King Mines Inc. and Pacific Silver Corp. into Alta, was stockpiled during the year while awaiting the conversion of the nearby leased Taylor mill from a silver processing plant to a 900-ton-per-day base metal concentrator. 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 1.45 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.

Star Phoenix Mining Co. leased the closed Star-Morning Mine from Hecla and Bunker Hill Ltd. Partners in July. In late 1989, Star Phoenix began mine rehabilitation, including dewatering and upgrading the 1,000-ton-per-day mill at Burke. Plans called for a mid-1990 ore production target of about 13,000 tons per month, yielding about 1,000 tons of zinc concentrate per month. The zinc concentrates were scheduled to be processed at Cominco's zinc smelter at Trail, British Columbia. An estimated 2 million tons of zinc-lead-silver ore reserves were reportedly available in the upper levels. The Star-Morning Mine last operated in 1985.

Two long-closed zinc mines in Washington were being evaluated and could open in late 1990 or in 1991. Equinox Resources Ltd. was completing a feasibility study on the Van Stone Mine near Coville, WA. The mine last produced in 1970. The infrastructure and a 900-ton-per-day mill were reportedly adequate for rapid commissioning. Ore reserves, identified in the late 1970's, totaled about 7 million tons averaging 3.7% zinc and 0.6% lead. Within the reserve was 1.4 million tons of readily minable higher grade ore averaging 6.5% zinc and 1.5% lead.

Resource Finance Co. (RFC) was evaluating the Pend Oreille lead-zinc mine near Metaline Falls, WA, for possible reopening. The Pend Oreille Mine last operated in 1977. RFC estimated ore reserves to be 5.5 million tons averaging 8.8% zinc and 1.9% lead using a 5% zinc cutoff. Reserves were adequate for a 9-year mine life at anticipated production rates.

TABLE 2

MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY MONTH

(Metric tons)

Month	1988	1989
January	16,837	21,994
February	18,327	20,794
March	22,462	24,038
April	21,531	23,315
May	22,187	24,816
June	22,563	24,130
July	19,006	20,605
August	21,710	25,068
September	20,095	22,868
October	20,107	24,864
November	20,058	22,643
December	19,431	20,746
Total	244,314	[1]275,883

[1] Data do not add to total shown because of independent rounding.

Smelter and Refinery Production

Refined metal production was up substantially and was the highest since 1981. Three companies, ZCA, JMZ, and Big River Zinc Co., operated four primary zinc refineries in 1989. Secondary zinc metal was produced at nine secondary

TABLE 3

MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY STATE

(Metric tons)

State	1985	1986	1987	1988	1989
Alaska	—	—	—	—	W
Colorado	W	W	W	W	W
Idaho	W	351	W	W	W
Illinois	W	W	W	W	W
Kentucky	W	—	10	W	—
Missouri	49,340	37,919	34,956	41,322	50,790
Montana	—	—	W	18,935	W
New Jersey	W	W	—	—	—
New Mexico	—	—	—	—	W
New York	W	W	W	W	W
Tennessee	104,471	102,118	115,699	119,954	W
Total	226,545	202,983	216,327	244,314	275,883

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

TABLE 4

LEADING ZINC-PRODUCING MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT

Rank	Mine	County and state	Operator	Source of zinc
1	Elmwood-Gordonsville	Smith, TN	Jersey Miniere Zinc Co.	Zinc ore.
2	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Do.
3	Young	Jefferson, TN	ASARCO Incorporated	Do.
4	Balmat	St. Lawrence, NY	Zinc Corporation of America	Do.
5	Greens Creek	Admiralty Island, AK	Greens Creek Mining Co.	Do.
6	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
7	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Zinc ore.
8	Jefferson City Div.	Jefferson, TN	Union Zinc Co.	Do.
9	New Market	do.	ASARCO Incorporated	Do.
10	Immel	Knox, TN	do.	Do.
11	West Fork	Reynolds, MO	do.	Lead-zinc ore.
12	Leadville Unit	Lake, CO	do.	Zinc ore.
13	Coy	Jefferson, TN	do.	Do.
14	Bunker Hill	Shoshone, ID	Bunker Hill Mining Co. (U.S.) Inc.	Do.
15	Magmont	Iron, MO	Cominco American Incorporated	Lead-zinc ore.
16	Fletcher	Reynolds, MO	The Doe Run Co.	Do.
17	Sunnyside	San Juan, CO	Washington Mining Co.	Do.
18	Sweetwater	Reynolds, MO	ASARCO Incorporated	Do.
19	Viburnum No. 29	Iron, MO	The Doe Run Co.	Do.
20	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
21	Pinos Altos	Grant, NM	Cyprus Sierrita Corp.	Copper ore.
22	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
23	Butte Hill	Silver Bow, MT	New Butte Mining Co. Inc.	Do.
24	Casteel[1]	Iron, MO	The Doe Run Co.	Copper-lead ore.
25	Viburnum No. 28	do.	do.	Do.

[1] Includes Brushy Creek Mill.

plants from scrap materials; however, the largest producer of metal from secondary zinc was ZCA at its primary electrothermic smelter at Monaca, PA. A substantial part of the plant's secondary feed was crude zinc calcine recovered from steelmaking electric arc furnace (EAF) dusts by a sister company, Horsehead Resource Development Co. (HRD), at Palmerton, PA, and Calumet, IL. The largest producers of zinc metal at secondary plants were Huron Valley Steel Corp., Interamerican Zinc Co., and Gulf Metals Corp.

ZCA installed two new furnaces as part of an expansion program at its 103,000-ton-per-year Monaca plant in 1989. Other furnace units and a new sinter plant were expected to be constructed in 1990 and 1991, gradually leading to 45,000 tons of new capacity. Most of this new capacity was expected to be dedicated to the processing of EAF zinc calcine.

Florida Steel Corp. and Nucor-Yamato Steel Co. began production of commercial-grade zinc metal directly from EAF dusts in 1989 at their respective steel plants at Jackson, TN, and Blytheville, AR. Both plants utilized plasma furnace technology developed by Tetronic Research and Development Co. and Bethlehem Steel Corp. Plans called for annual zinc metal production of 1,400 tons and 1,800 tons, respectively.

ZCA temporarily reopened its DePue,

TABLE 5

PRIMARY AND SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES

(Metric tons)

	1985	1986	1987	1988	1989
Primary:					
From domestic ores	198,005	191,079	205,275	196,476	166,424
From foreign ores	63,204	62,290	56,070	44,818	96,652
Total	261,209	253,369	261,345	241,294	263,076
Secondary:					
At primary smelters	39,720	49,852	W	W	W
At secondary smelters	32,843	13,060	W	W	W
Total	72,563	62,912	82,589	88,492	95,133
Grand total (excludes zinc recovered by remelting)	333,772	316,281	343,934	329,786	358,209

W Withheld to avoid disclosing company proprietary data.

IL, zinc dust plant at midyear to produce special grades of zinc dust products not produced at other ZCA facilities. The plant had been scheduled for permanent closure when shut down in January 1988.

Two other companies, Zia Technology of Dallas and Laclede Steel Co., planned to build EAF dust processing facilities at Caldwell, TX, and St. Louis, MO, respectively. Zia was scheduled to have a plant capable of treating 54,000 tons per year of EAF dusts in operation by mid-1990. It planned to use an inclined rotary reduction system to extract a crude zinc product that will then be fed into a top-feed vertical retort for metal reduction, vaporization, and capture in a conventional splash condenser.

Laclede Steel planned an on-site facility to treat about 36,000 tons of EAF dusts per year. The company planned to use an electric-slag-resistance reduction furnace developed by Elkem Technology/AS to produce a crude zinc oxide product suitable for metal recovery.

U.S. Zinc Co., a subsidiary of Gulf Metals, and Meteor Investments formed Plasmet Inc. to produce 7,200 tons of PW zinc metal annually from zinc drosses, wastes, and residues from

TABLE 6

PRODUCTION OF ZINC AND LEAD IN THE UNITED STATES IN 1989, BY STATE AND CLASS OF ORE, FROM OLD TAILINGS, ETC., IN TERMS OF RECOVERABLE METALS

(Metric tons)

State	Zinc ore			Lead ore			Zinc-lead ore		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	W	W	W	—	—	—	—	—	—
Arizona	—	—	—	—	—	—	—	—	—
Colorado	—	—	—	W	W	W	201,322	6,115	4,389
Idaho	W	W	W	—	—	—	W	W	W
Illinois	—	—	—	—	—	—	—	—	—
Missouri	—	—	—	—	—	—	5,707,891	49,941	335,243
Montana	W	W	W	—	—	—	W	W	W
New Mexico	—	—	—	—	—	—	—	—	—
New York	W	W	W	—	—	—	—	—	—
South Dakota	—	—	—	—	—	—	—	—	—
Tennessee	W	W	W	—	—	—	—	—	—
Total	9,106,176	179,850	18,682	W	W	W	6,069,436	58,299	354,381
Percent of total zinc or lead	XX	65	5	XX	W	W	XX	21	86

	Copper-zinc, copper-lead copper-zinc-lead ores			All other sources[1 2]			Total		
	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead	Gross weight (dry basis)	Zinc	Lead
Alaska	—	—	—	—	—	—	W	W	W
Arizona	—	—	—	W	—	W	W	—	W
Colorado	—	—	—	12,791	108	254	W	W	W
Idaho	—	—	—	W	W	W	W	W	W
Illinois	—	—	—	—	W	W	—	W	W
Missouri	[3]1,126,298	[3]849	[3]31,689	—	—	—	6,834,189	50,790	366,931
Montana	—	—	—	2,457,102	—	28	W	W	W
New Mexico	W	W	W	W	—	W	W	W	W
New York	—	—	—	—	—	—	W	W	W
South Dakota	—	—	—	92	—	4	92	—	4
Tennessee	—	—	—	—	—	—	W	W	W
Total	W	W	W	W	W	W	28,415,671	275,883	410,915
Percent of total zinc or lead	XX	W	W	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, gold-silver, 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] Includes Brushy Creek Mill.

galvanizing and die-cast operations. The plant was under construction in Houston, TX, and was expected to be operational by the second quarter of 1990. Plasma-furnace technology, licensed from Tetronic, was to be used.

Zinc Oxide

Domestic American- and French-process zinc oxide was produced entirely from zinc metal and scrap by eight companies in 1989. 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 animal feed and agricultural purposes. The principal zinc oxide producers in 1989 were Asarco, Pasco Zinc Corp., and ZCA.

In 1989, Asarco produced 15,650 tons of zinc oxide at its 27,500-ton-per-year Hillsboro, IL, plant. Modifications and the addition of a new furnace were underway to increase the efficiency and plant capacity in 1990.

North American Oxide, Inc., an affiliate of the Rogers Group Inc., planned to build an 18,000-ton-per-year French-process zinc oxide plant at Clarksville, TN. Startup was expected in mid-1990.

Byproduct Sulfur

Production of sulfur in byproduct sulfuric acid at primary zinc plants was 134,000 tons, down slightly from the 136,000 tons produced in 1988. Acid production at zinc plants in 1989 was valued at $17.4 million.

CONSUMPTION AND USES

Zinc is found in all sectors of the economy, but its role is less obvious to the public because zinc tends to lose its identity in the end products. Zinc-containing products were extensively used 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 steel

TABLE 7

DISTILLED AND ELECTROLYTIC ZINC, PRIMARY AND SECONDARY, PRODUCED IN THE UNITED STATES, BY GRADE

(Metric tons)

Grade	1985	1986	1987	1988	1989
Special High	98,282	78,979	85,010	90,034	113,819
High	98,979	84,737	88,952	74,870	79,145
Continuous Galvanizing	26,139	20,589	38,751	44,890	48,252
Controlled Lead	20,952	18,883	W	W	W
Prime Western	89,420	113,093	131,221	119,992	116,993
Total	333,772	316,281	343,934	329,786	358,209

W Withheld to avoid disclosing company proprietary data, included in "Prime Western."

TABLE 8

ANNUAL 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)	
	1988	1989
Electrolytic:		
Big River Zinc Corp., Sauget, IL[1]	76,000	76,000
Jersey Miniere Zinc Co., Clarksville, TN	95,000	95,000
Zinc Corporation of America, Bartlesville, OK	51,000	51,000
Electrothermic:		
Zinc Corporation of America, Monaca, PA[2]	101,000	103,000
Total available capacity	323,000	325,000
Total operating capacity	323,000	325,000

[1] Sold by AMAX Inc. in August 1988.
[2] Includes secondary capacity.

TABLE 9

SECONDARY ZINC PLANT CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Plant location	Capacity (metric tons)	
		1988	1989
Arco Alloys Corp.	Detroit, MI	55,000	58,000
W.J. Bullock Inc.	Fairfield, AL		
T.L. Diamond & Co. Inc.	Spelter, WV		
Florida Steel Co.	Jackson, TN[1]		
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		
Nucor Yamato Steel Co.	Blytheville, AR[1]		
Pasco Zinc Corp.	Memphis, TN		
Zinc Corporation of America	Palmerton, PA		

[1] Opened in 1989.

TABLE 10

STOCKS AND CONSUMPTION OF NEW AND OLD ZINC SCRAP IN THE UNITED STATES IN 1989, BY TYPE OF SCRAP

(Metric tons, zinc content)

Type of scrap	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
Diecastings	363	5,363	—	5,368	5,368	358
Flue dust	W	5,190	2,759	2,755	5,514	W
Fragmentized diecastings	W	28,352	—	28,217	28,217	W
Galvanizer's dross	4,863	69,172	72,038	—	72,038	1,997
Old zinc[1]	150	2,494	—	2,561	2,561	83
Remelt die-cast slab	563	W	—	16,731	16,731	W
Remelt zinc[2]	22	W	303	—	303	W
Skimmings and ashes[3]	4,288	30,258	30,125	—	30,125	4,421
Steelmaking dust	2,722	39,557	18,690	18,690	37,380	4,899
Other[4]	5,496	24,503	4,910	2,924	7,834	5,527
Total	18,467	204,889	128,825	77,246	206,071	17,285

W Withheld to avoid disclosing company proprietary data; included in "Total."
[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 electrogalvanizing anodes.

TABLE 11

PRODUCTION OF ZINC PRODUCTS FROM ZINC-BASE SCRAP IN THE UNITED STATES

(Metric tons)

Product	1985	1986	1987	1988	1989
Redistilled slab zinc	72,563	62,912	82,589	88,492	95,133
Zinc dust	30,754	26,682	28,620	r24,205	24,908
Electrogalvanizing anodes	—	—	—	—	W
Other metal alloys	982	99	163	317	272
Remelt die-cast slab	3,651	2,564	825	907	3,804
Other zinc metal products	6,695	7,098	6,741	8,016	W
Secondary zinc in chemical products	44,598	44,891	79,361	r55,972	57,572

rRevised. W Withheld to avoid disclosing company proprietary data.

works, tanks, and pipes. Brass was used as shell casings in ammunition and tubes, valves, radiators, and fittings in vehicles, 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 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 1989, about 30,700 tons of Special High Grade (SHG) in rolled zinc was used by the U.S. Mint to produce 12.8 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.

In 1989, domestic consumption of slab zinc for galvanizing and light metal alloying purposes and oxide manufacture increased, whereas other use categories were lower than in 1988. Galvanizing and electrogalvanizing, mainly for sheet and strip, continued to be the principal use of zinc metal consuming an estimated 52%, followed by zinc-based die-cast alloys, 21%; brass alloys, 12%; and other uses,

TABLE 12

ZINC RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1988r	1989
KIND OF SCRAP		
New scrap:		
Zinc-base	105,935	105,203
Copper-base	133,569	124,426
Magnesium-base	122	163
Total	239,626	229,792
Old scrap:		
Zinc-base	74,632	93,919
Copper-base	22,166	22,703
Aluminum-base	349	338
Magnesium-base	180	176
Total	97,327	117,136
Grand total	336,953	346,928
FORM OF RECOVERY		
Metal:		
Slab zinc	88,492	95,133
Zinc dust	24,205	24,908
Other[1]	8,016	15,733
Total	120,713	135,774
In zinc-base alloys	907	3,804
In brass and bronze	159,045	149,506
In other metal alloys	317	272
In chemical products:		
Zinc oxide (lead free)	34,527	37,027
Zinc sulfate	12,962	12,317
Zinc chloride	8,482	7,269
Miscellaneous	—	959
Total	216,240	211,154
Grand total	336,953	346,928

rRevised.
[1] Includes electrogalvanizing anodes and zinc content of slab made from remelt die-cast slab.

15%. SHG accounted for about 52% of the reported slab zinc consumed, followed by PW, 24%; 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%; electrical, 11%; and other, 12%. Zinc metal accounted for about three-fourths of consumption and zinc chemicals about one-fourth in 1989.

According to the American Iron and Steel Institute, shipments of galvanized sheet and strip totaled 9.7 million tons, up 0.4 million tons from 1988. Of the total shipments, electrogalvanized sheet accounted for 20% compared with 21% in 1988. In the first half of the year, the galvanized sheet and strip market was strong, being characterized by near-capacity production, extended delivery schedules, and premium prices. In the second half, domestic prices, delivery times, and production declined in response to falling automobile production and an easing in construction activity. Concurrent with the slowdown in demand were falling zinc prices, especially in the last quarter of the year.

According to the Bureau of the Census, zinc-base alloy die and foundry casting shipments totaled about 200,000 tons, down from 223,000 tons reported in 1988. The decline was attributable to reduced demand by die-cast manufacturers in the second half of the year and partly to the high price of zinc relative to substitute materials. 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 alloys by brass mills, ingot makers, and foundries was down slightly from 1988 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.

The zinc content in typical U.S.-manufactured automobiles was estimated to average about 40 pounds in 1989, about the same as in 1988. Diecastings accounted for about 21 pounds; corrosion protection via galvanizing and coatings, 16 pounds; and other, including rubber, brass, and zinc solder, 3 pounds.

The apparent domestic consumption of zinc oxide was about 176,000 tons, down from 190,000 tons in 1988. Domestic production was up substantially, but so were exports. Imports fell for the first time since 1981. Because the 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 20 only accounts for about two-thirds of the apparent market. Of the reported amounts, the rubber industry continued to be the principal consumer followed by chemicals and paint.

TABLE 13

U.S. CONSUMPTION OF ZINC

(Metric tons)

	1985	1986	1987	1988	1989
Slab zinc, apparent (rounded)	961,000	999,000	1,052,000	1,089,000	1,060,000
Ores and concentrates (zinc content)	39,886	19,236	2,536	2,412	2,107
Secondary (zinc content)[1]	256,455	255,752	r327,944	r248,461	251,795
Total (rounded)	1,257,000	1,274,000	r1,383,000	r1,340,000	1,314,000

r Revised.
[1] Excludes secondary slab and remelt zinc.

TABLE 14

ESTIMATED[1] APPARENT CONSUMPTION OF SLAB ZINC, ACCORDING TO INDUSTRY USE AND PRODUCT

(Metric tons)

Industry and product	1988r	1989
Galvanizing:		
Sheet and strip	395,000	402,000
Other	154,000	150,000
Total	549,000	552,000
Brass and bronze	146,000	130,000
Zinc-base alloys	249,000	220,000
Zinc oxide	65,000	71,000
Other uses[2]	80,000	87,000
Estimated apparent consumption	1,089,000	1,060,000

r Revised.
[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.

STOCKS

Metal stocks held at yearend by domestic producers, consumers, and merchants rose for the first time after 7 straight years of decreases, but were the second lowest in the 1980's. Domestic stock levels tended to rise through mid-year, before declining in line with declining demand. Merchant stocks tended to rise at the end of the year, accounting for the modest rise in domestic stock levels. At any given time in 1989, slightly less than 1 month domestic consumption was available as stocks. Metal stock levels in the market economy countries (MEC), according to the International Lead and Zinc Study Group (ILZSG), were relatively stable in the first half of the year, averaging about 515,000 tons but rose

TABLE 15

U.S. REPORTED CONSUMPTION OF SLAB ZINC, BY INDUSTRY AND PRODUCT

(Metric tons)

Industry and product	1988r	1989
Galvanizing:		
Sheet and strip	303,050	323,684
Other	95,768	120,919
Total	398,818	444,603
Brass and bronze	91,043	95,798
Zinc-base alloy	205,566	189,676
Zinc oxide	61,367	70,417
Other uses[1]	76,679	86,709
Grand total	833,473	887,203

r Revised.
[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.

TABLE 16

U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1989, BY INDUSTRY AND GRADE

(Metric tons)

Industry	Special High Grade	High Grade	Prime Western	Remelt and other grades	Total[1]
Galvanizing	102,374	71,551	201,117	77,925	444,603
Zinc-base alloys	187,338	W	—	W	189,676
Brass and bronze	44,382	38,328	W	W	95,798
Zinc oxide	W	W	W	—	70,417
Other	W	W	W	W	86,709
Total[1]	458,020	120,433	214,410	94,340	887,203

W Withheld to avoid disclosing company proprietary data, included in "Total."
[1] Data may not add to totals shown because of withheld figures.

TABLE 17

U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1989, BY STATE[1]

(Metric tons)

State	Galvanizers	Brass mills[2]	Die-casters[3]	Other[4]	Total
Alabama	W	W	—	—	9,867
California	21,814	481	—	1,273	23,568
Connecticut	W	2,188	W	W	8,262
Florida	5,971	—	—	—	5,971
Illinois	69,124	W	35,216	W	137,589
Indiana	46,756	W	W	W	51,330
Michigan	W	W	39,375	W	66,618
Nebraska	7,724	—	—	W	7,724
New York	3,364	W	71,276	W	100,915
Ohio	80,612	4,853	31,529	W	116,994
Pennsylvania	97,736	W	W	W	169,595
Tennessee	4,052	—	—	56,762	60,814
Texas	12,385	—	—	W	12,385
Undistributed	88,221	88,158	12,245	88,166	97,649
Total	437,759	95,680	189,641	146,201	869,281

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.

to about 592,000 tons at yearend. The stock rise in the second half of 1989 was mainly attributable to increased world metal production, in part because of fewer strikes rather than any substantial fall off in demand.

The London Metal Exchange (LME) planned to terminate its HG contract in March 1990 in favor of the SHG contract that was introduced in September 1988. As a result, LME zinc metal stocks of HG fell from 14,400 tons to 5,800 tons during the year, whereas SHG stocks rose from 26,100 tons to 74,800 tons in the same period.

Inventories of zinc in concentrate at domestic primary smelters totaled 35,500 tons at yearend compared with 49,400 tons at the end of 1988, according to the American Bureau of Metal Statistics Inc. Concentrate stocks were at their lowest level at yearend.

TABLE 18

ROLLED ZINC PRODUCED AND QUANTITY AVAILABLE FOR CONSUMPTION IN THE UNITED STATES

(Metric tons)

	1988	1989
Production[1]	49,771	52,475
Exports	3,814	16,515
Imports for consumption	4,100	3,066
Available for consumption	50,436	37,222

[1] Includes other plate more than 0.375 inch thick and rod and wire.

PRICES

Zinc metal prices rose sharply to record-high levels in the first 3 months of the year, continuing a 17-month price uptrend that began in November 1987. The North American producers' quote for HG was raised to a record-high 95 cents per pound at the end of February. By late March, the tightness in world zinc supply began to ease and prices on the LME trended downward, in turn lowering domestic prices to the

TABLE 19

ZINC CONTENT OF PRODUCTION AND SHIPMENTS OF ZINC PIGMENTS AND COMPOUNDS[1] IN THE UNITED STATES

(Metric tons)

	1988		1989	
	Production	Shipments	Production	Shipments
Zinc oxide	93,527	98,031	103,642	102,515
Zinc sulfate	r15,374	r16,201	14,427	13,671
Zinc chloride[2]	8,482	8,552	7,269	7,076

r Revised.
[1] Excludes leaded zinc oxide and lithopone.
[2] Includes zinc content of zinc ammonium chloride.

TABLE 20

ZINC CONTENT OF ZINC PIGMENTS AND COMPOUNDS[1] PRODUCED BY DOMESTIC MANUFACTURERS, BY SOURCE

(Metric tons)

	1988				1989			
	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 oxide	—	59,000	34,527	93,527	—	66,615	37,027	103,642
Zinc sulfate	W	—	r15,374	r15,374	W	—	14,427	14,427
Zinc chloride[2]	—	—	8,482	8,482	—	—	7,269	7,269

r Revised. W Withheld to avoid disclosing company proprietary data; included with "Secondary material."
[1] Excludes leaded zinc oxide, zinc sulfate, and lithopone.
[2] Includes zinc content of zinc ammonium chloride.

TABLE 21

REPORTED DISTRIBUTION OF ZINC CONTAINED IN ZINC OXIDE SHIPMENTS, BY INDUSTRY[1]

(Metric tons)

Industry	1985	1986	1987	1988	1989
Agriculture	2,060	3,128	3,477	1,988	1,520
Ceramics	5,829	4,010	4,901	3,302	2,780
Chemicals	17,982	18,163	22,789	21,898	22,462
Paints	6,572	8,638	8,007	3,441	4,695
Photocopying	6,659	W	W	W	W
Rubber	57,259	56,246	63,589	55,213	57,781
Other	12,572	6,999	7,814	12,189	13,277
Total	108,933	97,184	110,577	98,031	102,515

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1] In addition, zinc oxide was imported as follows: 1985—39,375; 1986—43,924; 1987—57,276; 1988—73,042; and 1989—59,557; distribution cannot be distinguished by industry.

TABLE 22

DISTRIBUTION OF ZINC CONTAINED IN SULFATE SHIPMENTS

(Metric tons)

Industry	1985	1986	1987	1988r	1989
Agriculture	13,683	18,616	14,934	13,602	10,922
Other	3,532	3,171	3,096	2,599	2,749
Total	17,215	21,787	18,030	16,201	13,671

r Revised.

80-cent-per-pound level by June. Overall, world demand remained strong in the summer months, and U.S. zinc prices stabilized at about the 80 cents level. In September, LME zinc stocks increased, resulting in downward pressure on prices. In the last quarter of the year, domestic zinc prices fell in response to lower LME prices, stock increases, and reduced demand in the domestic economy, in part, owing to sharp cutbacks in automobile production.

Zinc oxide prices, as quoted in the American Metal Market, followed the price trends of zinc metal. Prices ranged from a high of about 95 cents per pound in March to a low of about 72 cents in December, averaging about 90 cents for the year. Imported zinc oxide averaged 75.4 cents per pound compared with 49.4 cents in 1988.

The price quoted in Chemical Marketing Reporter (CMR) for zinc sulfate, monohydrate industrial grade, 36% zinc in bags in carload lots, was $30 per 100 pounds through February and $41 thereafter. Agricultural zinc sulfate in bulk was listed by CMR at $460 per short ton. Technical-grade zinc chloride, 50% solution in tanks, was quoted at $22 per 100 pounds in January and $24 thereafter.

The LME was the principal basis for world zinc pricing in 1989. Not only were most of the world's concentrate sales based on LME prices but also most metal sales. Producers' quotes, including those in North America, tended to become more responsive to LME price changes in 1989. Because of this increased price volatility, some zinc companies were considering dropping producer quotations altogether in favor of basing sales on the LME SHG price.

Most custom zinc smelter companies and producers of zinc concentrates agreed to use the LME SHG cash settlement price as the basis for determining treatment charges in 1989 and in the future. This agreement, plus the fact that LME zinc contracts were U.S.-dollar-based, provided a convenient reference price for both metal and concentrate and made zinc contracts hedgeable at the LME.

Changes in annual U.S. zinc metal prices from 1850 through 1988, and a

TABLE 23

U.S. PRODUCERS OF ZINC OXIDE AND CAPACITY, BY COMPANY

Company	Plant location	Capacity (metric tons) 1988	1989
Asarco Incorporated	Hillsboro, IL		
Big River Zinc Corp.[1]	Sauget, IL		
Eagle Zinc Co.	Hillsboro, IL		
Hitox Corp. of America	Spokane, WA		
Interamerican Zinc Inc.	Adrian, MI	156,000	156,000
Midwest Zinc Corporation	Chicago, IL		
Pasco Zinc Products Corp.[2]	Memphis, TN		
Zinc Corporation of America	Monaca, PA		
Do.	Palmerton, PA		

[1] Big River Zinc Corp. acquired plant from AMAX in Sept. 1988.
[2] Pigment & Chemical Inc. acquired plant from Pacific Smelting in May 1989.

TABLE 24

U.S. PRODUCERS OF ZINC SULFATE AND CHLORIDE PRODUCTS IN 1989

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.	Harrisburg, NC		X
Zaclon Inc.	Cleveland, OH		X
Zinc Corporation of America	Monaca, PA	X	

TABLE 25

STOCKS OF SLAB ZINC IN THE UNITED STATES, DECEMBER 31

(Metric tons)

	1985	1986	1987	1988	1989
Primary producers	29,030	16,722	13,448	e r6,005	e7,200
Secondary producers	3,389	3,203	3,162	695	1,031
Consumers	60,310	54,079	57,410	r64,864	60,297
Merchants	27,163	26,559	22,352	14,290	22,183
Total	119,892	100,563	96,372	r85,854	90,711

e Estimated. r Revised.

brief analysis of the factors that influenced those changes were included in a Bureau of Mines report on nonferrous metal prices.[2] The average annual zinc price over the 1909–88 period, based on 1987 constant dollars, was 57.2 cents per pound.

FOREIGN TRADE

Exports of basic zinc materials in 1989 were the best in years. Waste and scrap exports rose for the eighth consecutive year and set record highs in both content and value. Exports of slab zinc and zinc oxide increased many-fold over 1988 levels and, respectively, were the highest since 1974 and 1947. Exports of zinc in concentrates were the highest since 1985; most were shipped to Canada from western U.S. zinc producers. Interestingly, U.S. exports of zinc in concentrate in 1989 exceeded imports for the first time since the early 1930's.

General imports of zinc in concentrates totaled 388,566 tons, whereas imports for consumption totaled only 40,947 tons. The disparity was due to shipments of concentrates through Skagway, AK, to world markets from Canada's Faro zinc-lead mine in the Yukon Territory. Imports of slab zinc and zinc oxide both fell substantially from those of 1988; however, they were, respectively, the second and third highest levels ever recorded. According to CDA, 397,000 tons of brass mill products were imported and 133,400 tons exported in 1989, compared with 433,600 imported and 115,000 exported in 1988.

WORLD REVIEW

World zinc metal consumption continued its record-setting pace, exceeding 7 million tons for the third straight year. Smelter output was a record high and mine output was the second highest ever recorded.

Zinc metal consumption was about 7.2 million tons, slightly less than that of 1988. The MEC, according to IL-ZSG, consumed 5.23 million tons, down about 40,000 tons from that of 1988. The MEC accounted for about three-fourths of consumption and the

centrally planned economies (CPE) about one-fourth or about 1.9 million tons. The world's leading consuming nations, in order of estimated consumption, were the United States, the U.S.S.R., Japan, the Federal Republic of Germany, China, and France. The United States, Japan, and Western Europe accounted for slightly more than one-half of world consumption and about 70% of the MEC consumption. According to ILZSG, the principal uses of zinc metal in 1988 in the major Western countries were: galvanizing, 45.1%; brass and bronze, 20.4%; zinc-based alloys, 15.0%; chemicals, 8.1%; zinc semimanufacturers, 7.0%; and others, 4.4%.[3] In 1989, galvanizing was estimated to have increased to 46%, whereas other uses were about the same as in 1988 except brass and bronze, which declined to slightly less than 20%.

World zinc mine production was 7.06 million tons, marginally higher than in 1988, but about 160,000 tons less than the record high of 1987. In tonnage terms, Australia, Peru, and the United States recorded significantly higher production in 1989, whereas, Canada, Japan, and Sweden produced significantly less than in 1988.

On a geographic basis, North and South America accounted for about 38% of world mine output; Europe, including, Greenland and the U.S.S.R., 30%; and Australia, 11%. Canada was the leading world zinc mine producer despite a second consecutive sharp decrease in output. Canada, together with the U.S.S.R., Australia, and Peru, accounted for 48% of world zinc production.

World exports of zinc in concentrates totaled about 2 million tons, of which more than 90% were from the MEC. Australia, Canada, and Peru accounted for about 75% of the total exported. Japan was by far the leading importer of zinc concentrates, followed by the Federal Republic of Germany, France, Belgium, and the Netherlands. According to ILZSG, the MEC imported 106,000 tons from CPE countries and exported 111,000 tons to CPE countries in 1989.

World refined metal production was up about 70,000 tons to 7.2 million tons in 1989. According to ILZSG, MEC production was 5.23 million tons, virtually the same as in 1988. Most countries produced at last year's level; however, China, the Republic of Korea, and the United States recorded notable increases, whereas Belgium and Canada produced less. Canada, China, Japan, and the U.S.S.R., the four largest zinc metal producers, accounted for about 38% of world refined zinc metal production.

The world supply-demand position was extremely tight in the first few months of 1989, continuing the tight supply-demand situation that persisted throughout 1988. Prices rose to alltime high levels in the first quarter before easing in the second quarter. After August, stock levels rose, easing prices further. According to ILZSG, net exports of metal from the MEC to the CPE countries were 11,000 tons in 1989. The U.S.S.R. was the largest importer of the CPE countries, importing 47,000 tons of the 117,000 imported by that group.

Further corporate concentration of the world's zinc industry took place in 1989 continuing the trend of the past few years. The Société Générale de Belgique, located in Belgium, merged its majority-owned zinc companies into an 87.5%-owned subsidiary, called Acer-Union Miniere SA. The new company was estimated to control about 10% of world zinc smelter output. Acer-Union Miniere's zinc subsidiaries included Metallurgie Hoboken-Overpelt S.A.; Soc. des Mines & Fonderies de Zinc de Ra Vielle Montagne S.A., the world's largest custom zinc producer; and Union Zinc and JMZ in the United States.

TABLE 26

AVERAGE MONTHLY U.S., LME,[1] AND EUROPEAN PRODUCER PRICES FOR EQUIVALENT ZINC

(Metallic zinc, cents per pound)

Month	1988			1989		
	United States[2]	LME cash[r]	European producer[r]	United States[2]	LME cash	European producer
January	44.44	39.81	39.65	79.27	78.57	79.30
February	45.44	39.72	40.37	87.70	87.54	88.62
March	47.90	44.50	42.38	93.71	88.89	87.67
April	51.50	48.46	45.29	88.52	75.04	75.35
May[3]	56.04	53.33	49.03	84.64	78.24	76.25
June	62.55	61.87	55.05	80.59	75.65	73.30
July	65.64	56.08	56.13	79.67	75.63	73.69
August	66.46	59.35	54.43	81.32	82.04	78.74
September	68.26	60.30	60.91	81.08	75.56	74.90
October	69.75	68.85	63.11	79.95	69.25	73.77
November	71.25	70.63	65.83	75.92	65.65	64.89
December	73.44	72.24	68.04	72.33	68.28	64.98
Average	60.20	51.11	53.37	82.02	77.64	75.95

[r] Revised.
[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.

TABLE 27

U.S. EXPORTS OF ZINC AND ZINC ALLOYS, BY COUNTRY

Country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought zinc and zinc alloys:						
Belgium-Luxembourg[1]	6	$21	23	$81	—	—
Canada	1,059	2,608	1,574	4,175	2,023	$5,275
Chile	—	—	5	8	—	—
Germany, Federal Republic of	120	34	60	48	4,787	7,187
Hong Kong	1	5	67	99	210	411
India	—	—	100	84	19	20
Israel	—	—	18	57	6	36
Jamaica	77	99	62	68	207	451
Japan	27	77	10	28	8	14
Korea, Republic of	4,257	8,603	2,281	3,364	10	36
Mexico	44	134	45	115	86	162
Netherlands	2	5	15	54	9	32
Panama	42	54	4	5	18	49
Salvador	1	2	1	2	1	3
Singapore	14	21	63	107		—
Spain	—	—	1	10	1	7
Switzerland	3	7	—	—		—
Taiwan	1,113	775	1,186	875	454	455
United Kingdom	7	16	602	1,194	(2)	3
Venezuela	50	305	1	5		—
Other[3]	84	171	112	275	116	292
Total	6,907	12,937	6,230	10,654	7,955	14,433
Wrought zinc and zinc alloys:						
Argentina	1	2	—	—	—	—
Australia	—	—	2	16	34	86
Bahamas	39	33	67	151	4	7
Brazil	—	—	—	—	44	81
Canada	1,087	1,744	1,076	2,130	1,932	2,293
Chile	53	94	6	28	17	62
Colombia	7	25	14	47	19	61
Costa Rica	1	2	4	14	9	52
Dominican Republic	23	50	9	21	131	307
Ecuador	2	7	14	34	10	38
El Salvador	23	36	—	—	—	—
France	—	—	307	101	96	66
Germany, Federal Republic of	863	542	2,091	1,121	1,218	466
Guyana	6	11	6	10	2	5
Hong Kong	7	12	181	239	192	138
India	2	7	77	53	3	23
Jamaica	—	—	124	186	1,691	1,820
Japan	59	126	83	225	50	223
Korea, Republic of	4	7	108	77	28	77
Leeward and Windward Islands	18	19	—	—	—	—
Mexico	521	775	712	1,170	488	1,312

See footnotes at end of table.

TABLE 27—Continued

U.S. EXPORTS OF ZINC AND ZINC ALLOYS, BY COUNTRY

Country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought zinc and zinc alloys—Continued						
Netherlands Antilles	46	55	41	39	3	10
Pakistan	—	—	(2)	3	—	—
Panama	22	44	12	23	20	37
Philippines	42	116	26	74	14	62
Saudi Arabia	1	5	380	370	12	33
Singapore	—	—	101	591	6	46
South Africa, Republic of	3	5	4	18	8	104
Spain	1	3	3	11	(2)	2
Sudan	—	—	153	231	127	241
Taiwan	2	3	72	77	12,548	9,697
Trinidad and Tobago	10	10	—	—	—	—
United Kingdom	11	46	6	35	199	333
Venezuela	29	45	39	114	5	27
Other[4]	120	224	112	278	258	739
Total	3,003	4,048	5,830	7,487	19,168	18,448

[1] For 1987, Belgium and Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.
[2] Less than 1/2 unit.
[3] Includes Argentina, Colombia, Dominican Republic, Ecuador, France, Greece, Indonesia, Italy, Nigeria, Pakistan, Portugal, Republic of South Africa, Saudi Arabia, Sweden, Syria, Thailand, the United Arab Emirates, and Uruguay.
[4] Includes Angola, Antigua, Aruba, Belgium, Bermuda, British Virgin Islands, Cayman Islands, Denmark, Dominica, French Guiana, Guatemala, Honduras, Iceland, Israel, Italy, Microns, the Netherlands, New Zealand, Peru, Salvador, St. Lucia, St. Christopher-Nevis, Suriname, Sweden, Switzerland, Turkey, the United Arab Emirates, and Uruguay.

Source: Bureau of the Census.

TABLE 28

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)
1987	265	$531	16,921	$8,304	1,082	$2,114	5,825	$10,823
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

Year	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)
1987	1,732	$2,337	1,271	$1,711	88,277	$46,182	1,927	$3,300
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

Source: Bureau of the Census.

TABLE 29

U.S. EXPORTS OF ZINC ORES AND CONCENTRATES, BY COUNTRY

(Zinc content)

	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	—	—	3,500	$1,942
Belgium	—	—	10,752	21,016
Brazil	—	—	5,126	3,291
Canada	33,260	$19,510	42,770	26,843
India	42	24	—	—
Israel	—	—	5	11
Japan	249	143	13,126	6,891
Korea, Republic of	—	—	1,386	1,663
Mexico	—	—	478	759
Philippines	1	3	(1)	2
Sweden	29	16	—	—
Taiwan	9	3	547	580
Trinidad	—	—	13	7
United Kingdom	—	—	1,174	1,219
Total	33,590	19,699	78,877	64,224

[1] Less than 1/2 unit.

Source: Bureau of the Census.

Curragh Resources Inc., operator of the Faro zinc-lead mine in Canada, bought a 20% interest in Europe's largest zinc producer, Asturiana de Zinc S.A. Curragh, one of the world's largest exporters of zinc concentrate, expected to gain further diversification of its concentrate markets, and Asturiana expected to gain zinc supply to feed its ongoing 80,000-ton smelter expansion in Spain as well as help replace future zinc concentrate deficiencies owing to the possible closure of its partially-owned Rubiales Mine in 1991.

In September, Noranda Ltd. and Trelleborg AB jointly completed their acquisition of Falconbridge Ltd. that included the Kidd Creek zinc-copper operations in Ontario. Through this acquisition, Noranda's direct share of world zinc mine and smelter capacity rose to about 3.5% and 4.7%, respectively. In 1989, Trelleborg, through its Boliden subsidiary, also acquired zinc mining interests in Portugal and in Maine, where the company planned to develop the Bald Mountain copper-zinc-silver-gold deposit.

Capacity

World mine capacity was about 8 million tons, up about 200,000 net tons from 1988. Seven new zinc-producing mines opened, four closed, and six mines expanded capacity in 1989. The Red Dog Mine in Alaska, which was expected to add 325,000 tons to world zinc capacity, was not included in the 1989 total owing to startup problems that delayed full commissioning into 1990. The Hellyer Mine in Australia, rated at 92,000 tons capacity and San Vicente Mine in Peru, 33,000 tons new capacity, respectively, were the largest zinc producers to open and to expand in 1989. The Prieska Mine in the Republic of South Africa, 24,000 tons capacity, was the largest zinc producer to close.

World smelter capacity gained about 0.1 million tons to 8.0 million tons in 1989, mainly as a result of minor capacity additions in a number of countries. Greenfield smelters under construction in India and Iran and expansions underway in Belgium, Brazil, the Federal Republic of Germany, Mexico, Spain, and the United States were expected to add about 400,000 tons of new smelter capacity in the next few years.

The data in table 36 are rated annual production capacity for zinc mines and primary zinc refineries 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 mine or plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Refinery capacity is based on engineering capacity provided by the companies or as estimated by the Bureau of Mines. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

CURRENT RESEARCH

The Bureau of Mines continued to conduct zinc-related research in many diverse areas. The lead, silver, tin, and zinc resources of the Sheep Creek prospect in north-central Alaska were evaluated by field investigations and mineralogical, characterization, and concentration tests.[4] The effect of common sulfide minerals, including sphalerite, on the corrosion rates of various types of ferrous alloy grinding media was studied.[5] The extraction of gallium and germanium from hydrometallurgical zinc process residues were studied.[6] Extraction rates of more than 90% were attained. Soil-extraction methods on agricultural lands contaminated by acid mining waste were studied to provide a means for predicting potential phytotoxicity of zinc, copper, and arsenic.[7] One of the extraction procedures provided good correlations with metal levels in plant tissues and was anticipated to be a useful measure of toxicity for plants. A hydrothermal sulfidation and chloride leaching procedure was investigated to detoxify and recover lead and silver from plumbojarosite, a hazardous residue product generated during pressure-oxidative leaching of zinc concentrates in commercial operations.[8] The procedure tested was a potentially effective method for detoxification of such residues and, in addition, resulted in high-lead and high-silver recovery.

A comprehensive coverage of zinc-related investigations and an extensive review of current world literature on zinc extraction, alloys, uses, products, and research was available in quarterly issues of Zincscan, published by the

TABLE 30

U.S. GENERAL IMPORTS OF ZINC, BY COUNTRY

Country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
ORES AND CONCENTRATES (zinc content)						
Australia	476	$63	458	$61	600	$78
Bolivia	—	—	50	6	28	6
Canada	399,755	61,634	365,175	73,816	366,244	72,346
Chile	12	2	—	—	15	10
China	223	30	—	—	—	—
Germany, Federal Republic of	5,103	3,044	—	—	—	—
Honduras	6,469	869	1,172	614	—	—
Mexico	5,494	1,648	7,218	3,164	16,408	9,114
Peru	7,978	3,001	31,633	11,748	5,301	3,036
Total	425,510	70,291	405,706	89,409	388,596	84,590
BLOCKS, PIGS, OR SLABS[1]						
Algeria	505	389	2,300	2,152	—	—
Argentina	—	—	—	—	3,013	4,490
Australia	51,435	42,451	25,000	26,701	42,766	69,473
Austria	—	—	300	243	—	—
Belgium-Luxembourg[2]	9,769	8,371	11,635	13,993	2,562	4,221
Brazil	—	—	3,997	5,318	8,899	15,158
Canada	360,729	301,773	424,390	474,621	435,254	730,463
China	4,199	3,474	93	105	317	524
Finland	18,336	15,702	14,779	17,591	24,321	41,386
France	10,539	8,575	9,308	9,818	8,110	13,789
Germany, Federal Republic of	15,272	13,065	7,321	7,806	3,512	5,884
Hong Kong	1,289	1,020	—	—	150	252
Italy	16,388	12,752	7,981	8,155	—	—
Japan	11,943	9,892	1,492	1,298	([3])	2
Korea, Republic of	3,868	4,184	18,122	20,702	2,352	3,776
Mexico	53,344	42,368	60,947	70,494	70,817	115,330
Monaco	—	—	—	—	136	231
Netherlands	28,281	23,451	11,097	12,332	4,685	7,532
New Zealand	500	423	—	—	—	—
Norway	17,507	15,440	31,695	30,150	28,801	47,325
Peru	22,383	17,235	11,943	12,213	34,409	54,772
Poland	250	232	4,177	4,909	—	—
South Africa, Republic of	—	—	—	—	201	331
Spain	55,427	42,256	65,231	76,679	26,277	44,747
Sweden	—	—	—	—	8	137
Taiwan	—	—	200	202	220	426
United Kingdom	3,570	2,875	4,311	5,206	1,239	2,114
Yugoslavia	2,035	1,550	792	1,010	—	—
Zaire	17,338	12,870	21,086	22,830	13,155	20,720
Zambia	1,078	873	1,000	1,304	749	1,159
Zimbabwe	—	—	1,663	1,421	—	—
Total	705,985	581,221	740,860	827,253	711,953	[4]1,184,244

[1] In addition, in 1989, 3,250 tons of zinc anodes were imported from Canada, China, the Federal Republic of Germany, Finland, France, Hong Kong, India, Italy, Japan, Mexico, the Netherlands, Norway, the Republic of Korea, Spain, Switzerland, Taiwan, Thailand, and the United Kingdom.

[2] For 1987, Belgium-Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.

[3] Less than 1/2 unit.

[4] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 31

U.S. IMPORTS FOR CONSUMPTION OF ZINC, BY COUNTRY

Country	1987		1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
ORES AND CONCENTRATES (zinc content)						
Canada	28,960	$7,130	25,463	$10,934	20,161	$11,150
Honduras	6,469	869	1,172	614	—	—
Mexico	5,422	1,639	5,967	2,618	16,408	9,114
Peru	5,613	2,684	30,364	11,580	4,405	2,783
Total[1]	46,464	12,322	62,966	25,746	40,974	23,047
BLOCKS, PIGS, OR SLABS[1]						
Algeria	505	389	2,300	2,152	—	—
Argentina	—	—	—	—	3,013	4,491
Australia	51,435	42,451	25,000	26,701	42,766	69,473
Austria	—	—	300	243	—	—
Belgium-Luxembourg[2]	9,769	8,371	16,739	17,037	2,562	4,221
Brazil	—	—	3,997	5,318	8,899	15,158
Canada	360,729	301,773	427,558	477,855	435,254	730,463
China	4,199	3,474	93	105	317	524
Finland	18,336	15,702	14,780	17,591	24,321	41,386
France	10,539	8,575	9,308	9,818	8,110	13,789
Germany, Federal Republic of	15,272	13,065	7,321	7,806	3,512	5,884
Hong Kong	1,289	1,020	—	—	150	252
Italy	16,388	12,752	7,982	8,155	—	—
Japan	11,943	9,892	1,492	1,298	([3])	2
Korea, Republic of	3,868	4,184	18,122	20,702	2,352	3,776
Mexico	53,344	42,368	60,947	70,494	70,817	115,330
Monaco	—	—	—	—	136	231
Netherlands	28,281	23,451	11,097	12,332	4,685	7,532
New Zealand	500	423	—	—	—	—
Norway	17,507	15,440	31,695	30,150	28,801	47,325
Peru	22,383	17,235	11,943	12,213	34,010	54,051
Poland	250	232	4,176	4,909	—	—
South Africa, Republic of	—	—	—	—	201	331
Spain	55,427	42,256	65,231	76,679	26,277	44,747
Sweden	—	—	—	—	8	137
Taiwan	—	—	200	202	220	426
United Kingdom	3,570	2,875	4,311	5,206	1,239	2,114
Yugoslavia	2,035	1,550	792	1,010	—	—
Zaire	17,338	12,870	21,086	22,830	13,155	20,720
Zambia	1,078	873	1,000	1,304	749	1,159
Zimbabwe	—	—	1,663	1,421	—	—
Total	705,985	581,221	749,133	833,531	711,554	[4]1,183,523

[1] In addition, in 1989, 3,250 tons of zinc anodes were imported from Canada, China, the Federal Republic of Germany, Finland, France, Hong Kong, Italy, Japan, Mexico, the Netherlands, Norway, the Republic of Korea, Spain, Sweden, Switzerland, Taiwan, Thailand and the United Kingdom.
[2] For 1987, Belgium-Luxembourg combined, data not available to separate; 1988 and 1989 data for Belgium only.
[3] Less than 1/2 unit.
[4] Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 32

U.S. IMPORTS FOR CONSUMPTION OF ZINC

Year	Ores and concentrates (zinc content)		Blocks, pigs, slabs[1]		Sheets, plates, strips, other forms	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1987	46,464	$12,322	705,985	$581,221	960	$1,384
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

	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)	
1987	4,025	$1,928	6,727	$3,461	7,001	$7,940	$608,256
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

[1] Unwrought alloys of zinc were imported as follows, in metric tons: 1987—60 ($53,687); 1988—50 ($76,864) and 1989—632 ($952,159).
[2] In addition, the value of manufactures of zinc imported was as follows: 1987—$1,569,545; 1988—$1,415,747; and 1989—$2,080,347.

Source: Bureau of the Census.

Zinc Development Association, London, United Kingdom.

OUTLOOK

U.S. demand for zinc was forecast to rise slowly, increasing from about 1.06 million tons in 1989 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.

Despite having an adequate zinc resource base, imports were expected to continue to account for more than one-half of U.S. zinc demand 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 threats posed by Superfund. Ironically, the United States is poised to become 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% of present levels in the next decade and constitute 40% of total U.S. zinc metal and compound consumption by the year 2000. Increased secondary recovery was expected to be driven by public policies related to waste 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 7.2 million tons consumed in 1989. No new major-consuming 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 usage in the next decade. No long-term problems with supply were foreseen, although environmental concerns could affect zinc mine and refinery production, especially in developed countries. World zinc resources and reserves were adequate to supply the higher demand through the year 2000, and the industry, historically, has always responded to shortages with increased production.

TABLE 33

U.S. IMPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Zinc oxide	73,042	$79,465	59,557	$93,448
Zinc sulfide	2,487	3,622	1,840	3,178
Lithopone	2,386	1,628	3,365	2,155
Zinc chloride	1,306	1,181	2,578	2,301
Zinc sulfate	3,445	1,784	3,387	1,856
Zinc cyanide	160	307	(1)	(1)
Zinc hydrosulfite	213	391	(1)	(1)
Zinc compounds, n.s.p.f.	5,188	9,076	1,098	2,151

[1] Data not available because of change in tariff codes.

Source: Bureau of the Census.

BACKGROUND

Zinc is the fourth most widely used metal after iron, aluminum, and copper, yet through most of its history, zinc was not known as a distinct metal. Zinc

TABLE 34

TARIFF CODES FOR IMPORTS AND EXPORTS OF ZINC

Material	Exports	
	1988	1989
	TSUSA[1]	HTS[2]
Slab zinc	626.0200	7901.11.0000
		7901.12.0000
		7901.20.0000
Ore and concentrate (zinc content)	601.6100	2608.00.0030
		2608.00.0045
Zinc waste and scrap (zinc content)	603.0030	2620.11.0000
	626.1000	2620.19.0000
		7902.00.0000
Zinc powders and flakes (zinc content)	626.4100	7903.10.0000
		7903.90.0000
Zinc oxide (gross weight)	472.5500	2817.00.0000
Zinc chloride	422.7200	2827.36.0000
Zinc sulfate	422.7600	2833.26.0000
Zinc compounds, other	422.7700	2830.20.0000
		2841.20.0000
		3206.42.0000

Material	Imports	
	1988	1989
	TSUSA[1]	HTS[2]
Slab zinc	626.0200	7901.11.0000
	626.0400	7901.12.5000
Ore and concentrate (zinc content)	602.2012	2603.00.0030
	602.2022	2607.00.0030
	602.2032	2608.00.0030
	602.2042	2608.00.0045
		2616.10.0030
		2616.90.0030
Zinc waste and scrap (zinc content)	626.1000	7902.00.0000
		2620.11.0000
Zinc powders and flakes (zinc content)	626.4000	7903.10.0000
	626.4200	7903.90.3000
		7903.90.6000
Zinc oxide (gross weight)	473.7600	2817.00.0000
	473.7800	3206.49.3000
Dross, ashes, and fume (zinc content)	603.3000	2620.19.3000
	603.3030	2620.19.6030
	603.5020	
Zinc sheets	626.1500	7905.00.0000
	626.1700	
	626.1800	
	626.2000	
	626.2200	
	626.2400	
	644.2000	

[1] Tariff Schedules of the United States Annotated.
[2] Harmonized Tariff Schedule of the United States.

Source: Bureau of the Census.

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. In the 6th century, A.D., the Chinese are known to have produced articles of zinc metal and are generally credited with being the first to develop the technology to make zinc metal. Recent archeological studies, however, suggest that smelter technology in India may have preceded that in China.[9] 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 were apparently unfamiliar with zinc metal until the 16th century, even though they had used earthy forms of zinc compounds for many years to make brass.

The derivation of the name zinc is obscure but "zinken" and "zinck" were used by alchemists in central Europe in the early 1500's in reference to a "semimetal," the source of which is unknown, but was likely zinc metal formed by accident in smelting zinc-rich lead and copper ores. Paracelus, a German-Swiss professor of medicine who died in 1541, is credited with being the first European to list zinc as a distinct metal and to describe some of its properties. During the 17th and 18th centuries, zinc metal was imported from Asia by Portuguese and Dutch traders and was sold under various names, but eventually became known as spelter, the commercial form of slab zinc. Spelter, as a term for slab zinc, is still used, but in many countries, including the United States, the term is used little today.

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 began in Europe, mainly as a result of improved distillation methods utilizing horizontal muffles of large capacity known as the Silesian method. Zinc distillation by the Belgian method or by numerous

TABLE 35

U.S. IMPORT DUTIES FOR ZINC MATERIALS, JANUARY 1, 1989

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¢ kg on lead content	1.3¢ kg on lead content	3.7¢ kg on zinc content
Unwrought metal	7901.11.1250	1.5% ad val.	1.2% ad val.	5.0% ad val.
Alloys, casting-grade	7901.12.1000	19.0% ad val.	15.2% ad val.	45.0% ad val.
Alloys	7901.20.0000	19.0% ad val.	15.2% ad val.	45.0% ad val.
Waste and scrap	7902.00.0000	2.1% ad val.[1]	Free	11.0% ad val.
Hard zinc spelter	2620.11.0000	1.5% ad val.	1.2% ad val.	5.0% ad val.
Zinc oxide, dry	2817.00.0000	Free	Free	5.5% ad val.

[1] Duty temporarily suspended.

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, D.C. 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 1860 when smelters were built in Illinois and Pennsylvania 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, and Missouri because of closeness to Tristate and Wisconsin 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

TABLE 36

ZINC: WORLD MINE AND PRIMARY SMELTER CAPACITY, BY COUNTRY

(Thousand metric tons)

Country	Mine	Smelter
Algeria	15	40
Argentina	35	33
Australia	865	345
Austria	20	25
Belgium	—	325
Bolivia	75	—
Brazil	130	161
Bulgaria	70	90
Burma	5	—
Canada	1,430	735
Chile	35	—
China	550	375
Congo	3	—
Czechoslovakia	7	—
Ecuador	1	—
Finland	64	170
France	40	315
German Democratic Republic	—	18
Germany, Federal Republic of	75	350
Greece	30	—
Greenland	75	—
Honduras	50	—
Hungary	1	—
India	75	99
Indonesia	1	—
Iran	70	—
Ireland	200	—
Italy	85	253

TABLE 36—Continued

ZINC: WORLD MINE AND PRIMARY SMELTER CAPACITY, BY COUNTRY

(Thousand metric tons)

Country	Mine	Smelter
Japan	170	893
Korea, North	230	260
Korea, Republic of	25	235
Mexico	320	217
Morocco	25	—
Namibia	40	—
Netherlands	—	200
Norway	25	140
Peru	655	171
Philippines	2	—
Poland	205	175
Portugal	—	11
Romania	45	60
Saudi Arabia	3	—
South Africa, Republic of	90	105
Spain	300	304
Sweden	190	—
Thailand	85	70
Tunisia	10	—
Turkey	50	30
U.S.S.R.	870	1,050
United Kingdom	7	105
United States	390	325
Vietnam	10	10
Yugoslavia	100	170
Zaire	80	72
Zambia	45	55
Total	7,979	7,992

Sources: Bureau of Mines and International Lead and Zinc Study Group.

second major world production center. By 1901 the United States had become the leading world zinc 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 significant 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 production declined because numerous smelters closed for environmental and technical reasons, resulting in the reduction of U.S. zinc smelter capacity to one-third its former level. Occurring concurrent with the decline of the domestic zinc industry and in the prior decade, many countries began or expanded their zinc mine and smelter production. Whereas only 9 countries were known to be producers of zinc metal in 1900, 37 produced metal in 1989. Zinc mining was similarly limited to a few countries in 1900, but 54 countries produced zinc in 1989.

Uses before zinc metalmaking by the Chinese in the sixth century 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 of ancient Egypt contain appreciable amounts of zinc carbonate and/or zinc oxide.

Zinc was a little used and obscure metal in most of the world until production began on a small scale in England in 1740. Since then, world consumption of zinc has increased from less than 100 tons per year to more than 7 million. Zinc metal consumption grew slowly, initially being used mainly to make brass, pigments, and rolled products, and later to produce galvanized steel and die-cast products. From 1740, 173 years (1913) lapsed before world zinc metal consumption reached 1 million tons and 203 years (1943) before it reached 2 million tons. After World War II, annual world consumption increased rapidly, reaching 7 million tons in the mid-1980's.

Definition, Grades, and Specifications

Zinc is a bluish-white metal with a melting point of 419.6 °C and boiling point of 907 °C. The melting point permits low-temperature casting, and the boiling point is an important factor in purifying the metal by distillation methods and in producing metal dust and zinc oxide in very fine particles, a feature desirable for many uses. The properties of being chemically active and alloying readily with other metals are utilized industrially in preparing a large number of zinc containing compounds and alloys. The relatively high position of zinc in the electromotive series largely accounts for the extensive use of the metal to protect iron and steel products against corrosion.

Zinc produced from ores is termed "primary" zinc. When zinc is produced from scrap or residues, it is termed "secondary," "redistilled," or "remelt" zinc, depending on the recovery process. Primary zinc metal is categorized as electrolytic or distilled zinc according to the reduction process used. Commercial zinc metal cast in various shapes and sizes is termed slab zinc in the United States; the older term spelter is now rarely used in this country.

The American Society for Testing and Materials (ASTM) has approved specification in the past for as many as six commercial grades of slab zinc at one time, but currently lists only three—PW, HG, and SHG. The compositions of these grades are as follows:

Grade[1]	Analysis (percent)			
	Lead, maximum	Iron, maximum	Cadmium, maximum	Zinc minimum (by difference)
Special High Grade[2]	0.003	0.003	0.003	99.990
High Grade	.03	.02	.02	99.90
Prime Western[3]	1.4	.05	.20	98.0

[1] When specified for use in the manufacture of rolled zinc or brass, aluminum shall not exceed 0.005%.
[2] Tin in Special High Grade shall not exceed 0.001%.
[3] Aluminum in Prime Western shall not exceed 0.05%.

Historically, PW zinc was the first specification and was established for hot-dip galvanizing. HG, and later SHG, were established when metal of high purity was required for diecasting purposes.

Two other grades of nonspecified slab zinc, Continuous Galvanizing Grade (CGG) and Controlled Lead Grade (CLG), have gained acceptance for galvanizing purposes. CGG and CLG are prepared to customer specifications. CGG contains up to 0.35% lead and some aluminum, whereas, CLG contains less than 0.18% lead and no aluminum. Former specified grades, known as Immediate, Brass Special, and Selected, were largely used in alloying with copper to form brass.

Galvanizing is the process of coating iron with zinc to form a protective coating. This is generally accomplished by immersion of clean steel or iron in a bath of molten zinc (hot-dip galvanizing) or by electrodeposition of zinc from solution onto steel or iron (electrogalvanizing). Other forms of galvanizing are accomplished by tumbling a heated mixture of zinc dust and small steel parts, such as nails or bolts (sherardizing), by spraying atomized molten zinc metal through a gun onto clean steel (metallizing), and by painting with zinc dust paint.

The zinc used in hot-dip galvanizing, historically, was PW, HG, or specially prepared alloys composed of more than 98% zinc, and for electrogalvanizing, the zinc metal quality was SHG or HG. In recent years, a number of alloy coatings have been developed that have superior characteristics over those mentioned above. The two principal new hot-dip coatings are Galfan and Galvalume. Galfan, 95% zinc and 5% aluminum-mischmetal alloy, has gained widespread acceptance as a coating for sheet, tube, and wire; whereas, Galvalume, a 55% aluminum and 45% zinc plus some silicon alloy, is highly competitive with typical galvanizing and Galfan mainly in steel sheet uses. In electrogalvanizing, alloy coatings such as iron-zinc, manganese-zinc, and nickel-zinc are gaining an increased share in the automotive sheet market compared with pure zinc coatings.

In recent years, the usage of 1-sided, 1½-sided, and 2-sided galvanized and

TABLE 37

ZINC: WORLD RESERVES AND RESERVE BASE 1989, BY CONTINENT AND COUNTRY

(Million metric tons)

Continent and country	Reserves	Reserve base
North America:		
Canada	21	56
Mexico	6	8
United States	20	50
Other	(1)	(1)
Total	47	114
South America:		
Brazil	2	3
Peru	7	12
Other	1	1
Total	10	16
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	6
Sweden	1	3
U.S.S.R.	10	15
Yugoslavia	2	3
Other	2	4
Total	36	54
Africa:		
South Africa, Republic of	3	14
Zaire	5	7
Other	1	2
Total	9	23
Asia:		
China	5	9
India	5	7
Iran	2	6
Japan	4	6
Korea, North	4	6
Thailand	1	1
Turkey	1	2
Other	1	2
Total	23	39
Oceania: Australia	19	49
Grand total	144	295

[1] Less than 1 million metric tons.

electrogalvanized sheet and strip, especially in the automobile industry, has increased to provide corrosion protection. One sided has a normal zinc surface on one side; the other side is uncoated or stripped of its coating to provide a smooth paintable surface. The 1½ sided has a galvanized surface on one side and a thinner paintable iron-zinc alloy coating on the other side. Galvannealed steels have also made inroads in automobile manufacturing and are used for both exposed and unexposed parts. Galvannealed steel differs from regular hot-dipped products in that an additional annealing treatment is employed to more fully alloy the zinc with iron in the substrate, thereby improving the weldability, formability, and paintability of the product.

The typical hot-dip galvanizing strip is coated on both sides with anywhere from 0.1 to 2.0 ounces of zinc per square foot. Designations such as G-90 and G-60 for galvanized strip indicate coating weight; G-90, for example, indicates a coating weight of 0.9 ounce of zinc per square foot.

For electrogalvanizing, coating weights range from 20 to 120 grams per square meter. A designation such as 70/50 electrogalvanized sheet indicates both sides are coated but with different coating weights, 70 grams per square meter on one side and 50 grams per square meter on the other.

Zinc diecasting alloys, commonly known commercially as Zamak alloys or as die-cast alloys No. 2, 3, 5, or 7 are any of several zinc-base alloys in which aluminum and copper are the principal alloying elements. The most widely used of these alloys, No. 3, contains from 3.5% to 4.3% aluminum, up to 1.25% copper, and from 0.03% to 0.08% magnesium. The aluminum imparts wear resistance, high strength, and corrosion resistance properties to the alloy; copper improves tensile strength, hardness, and other physical properties; and the magnesium counteracts subsurface corrosion caused by certain impurities.

Three zinc-based aluminum alloys, generically identified by their approximate aluminum contents, 8%, 12%, and 27%, are used for general-purpose industrial foundry castings. These alloys are specifically intended for gravity-casting methods, where they provide substantial energy savings in casting over conventional foundry alloys, such as aluminum, bronze, and iron.

Brasses are copper-base alloys in which the zinc content ranges from 5% to 40%. Some bronzes, whose principal alloying materials are copper and tin, contain up to 4.5% zinc.

Zinc dust is made by zinc distillation from slab zinc or secondary zinc metals; the particle size is controlled by the rate of distillation and condensation. The principal standard grades of zinc dust have metallic contents of 95% to 97% with the remainder in oxide form. Materials of lower metallic contents are not suitable for pigment use but are suitable for some chemical uses. Dust with an average particle size of 7 to 9 micrometers can be classified as a standard grade, while an average particle size of 4.5 to 7 micrometers would be classified superfine dust, and dust of 2.5 to 4.5 micrometers would be ultrafine. The term "blue powder" generally refers to the zinc dust distillation product of pyrometallurical retort smelting processes. Blue powder was the earliest form of zinc dust and owes its name to its bluish-gray appearance caused by surface oxidation on dust particles.

Zinc powder is generally produced by atomizing a stream of molten zinc metal by a high-pressure blast of air or other gases. The resultant particles, which are considerably coarser than distilled zinc dust, are sized before use. Leafed or flaked zinc powder is composed of flattened particles generally made by milling spherical zinc powder with stearic acid added to prevent agglomeration.

Zinc vapor burns in air to form the white powder, zinc oxide. Zinc oxide is produced commercially by both the indirect or French-process from zinc metal or metallic residues and by the direct or American-process from zinc ores or oxidic secondary materials. The following table present zinc oxide specifications:

	American process	French process
Zinc oxide, minimum	99.0	99.0
Sulfur, maximum	.2	.1
Moisture and other voiatiles, maximum	.5	.5
Total impurities, maximum	2.0	1.0
Material retained on 325-mesh (44-micro meter) sieve, maximum	1.0	1.0

Source: ASTM Standards, pt. 28, pp. 28-29 (Specification 079-44), reapproved 1974.

Lithopone is a white pigment composed of a mixture of barium sulfate and zinc sulfide. Formerly an important paint pigment, its use has declined in recent decades.

Products for Trade and Industry

Commercial zinc is traded or sold to industry mainly in the grades produced at primary smelters or as zinc-based alloys specified by diecasters and galvanizers. The size and shapes of metals sold are varied, but generally are in the form of slabs, blocks, or waffle ingots. Slabs typically weigh 25 kilograms, whereas blocks range up to 2 tons. Each slab or block is identified as to grade and producer by a registered brand cast into the metal. Zinc metal is also commercially available in the form of plate, rolled sheet and strip, wire, dust, powder, and flake.

Brass is generally marketed as ingot that is used in foundries for castings and in brass mills for production of rolled, extruded, and forged products. Zinc oxide is the most widely marketed zinc chemical. It is purchased according to ASTM specification, particle size and shape, and customer requirements. For example, acicular and plate-type forms of zinc oxide are favored as paint pigments, whereas, nodular forms are preferred in rubber compounding. Special treatment may be required for photoconductive and pharmaceutical uses.

Other zinc chemicals, such as zinc sulfate and zinc chloride, are marketed in high-purity and technical grades in solid and liquid form. Solids are sold in bags, drums, and carload lots, whereas, liquids are sold in drums and tanker car volumes.

Industry Structure

The U.S. zinc mining and smelter sector underwent profound changes in the past two decades. Most changes involved closures and industry contraction and restructuring. A number of old-line companies, long identified with the domestic zinc industry, disappeared from the zinc scene. Among them were Anaconda, American Zinc, AMAX, New Jersey Zinc, St. Joe, and Eagle Pitcher. Many mines and most smelters, including all those using horizontal-retort technology, closed during this period. Mine capacity declined by one-half and smelter capacity by two-thirds. Of 14 primary smelters

TABLE 38

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Algeria	13.5	14.0	[e]13.0	[e]12.0	12.0
Argentina	35.7	39.5	35.6	36.8	[2]43.2
Australia	759.1	712.0	778.4	[e]765.7	[2]803.0
Austria	21.7	16.3	15.7	17.1	16.5
Bolivia	37.1	33.5	39.3	57.0	[2]74.8
Brazil	123.8	123.9	133.4	155.5	157.1
Bulgaria[e]	68.0	70.0	70.0	70.0	70.0
Burma	4.4	4.6	2.6	2.7	2.0
Canada	1,172.2	1,290.8	1,481.5	1,351.7	[2]1,214.9
Chile	22.3	10.5	19.6	19.2	18.4
China	[e]300.0	396.0	458.0	527.0	550.0
Colombia	2.0	[e]6.0	[e]—	0.1	0.2
Congo (Brazzaville)[e]	[2]2.3	2.3	2.3	2.3	2.3
Czechoslovakia[e]	[r]7.9	[r]7.3	[r]7.5	[r]7.6	7.5
Ecuador[e]	[r]0.1	[r]0.1	[r]0.1	[r]0.1	0.1
Finland	60.6	60.4	55.1	63.9	58.4
France	40.6	39.5	31.3	31.1	27.0
Germany, Federal Republic of	117.6	103.7	98.9	75.6	73.5
Greece	21.5	22.5	21.0	22.6	22.6
Greenland	70.3	62.1	69.2	77.5	[2]71.5
Honduras	44.0	25.4	15.4	23.5	37.2
Hungary[e]	2.2	[2]—	—	—	—
India	45.3	49.2	53.4	57.9	[2]66.4
Indonesia	0.5	0.5	—	—	—
Iran[e]	[r]25.0	[r]29.0	[r]36.0	[r]25.0	25.0
Ireland	191.6	181.7	177.0	173.2	168.8
Italy	45.4	26.3	33.1	37.2	38.0
Japan	253.0	222.1	165.7	147.2	[2]131.8
Korea, North[e]	180.0	225.0	220.0	225.0	225.0
Korea, Republic of	45.7	37.3	23.5	21.8	[2]23.2
Mexico	[r]275.4	[r]271.4	271.5	262.2	[2]284.1
Morocco	15.3	17.2	10.3	10.9	[2]17.3
Namibia	30.3	35.4	39.7	36.7	37.0
Nigeria[e]	[r]0.1	—	—	—	—
Norway	27.8	27.5	22.2	17.8	[2]15.0
Peru	523.4	597.6	612.5	485.4	[2]597.4
Philippines	1.9	1.6	1.1	1.4	1.4
Poland	188.0	185.0	184.0	[e]184.0	184.0
Romania[e]	43.0	43.0	41.0	41.0	[2]54.5
Saudi Arabia	—	—	—	0.7	2.0
South Africa, Republic of	96.9	101.9	112.7	89.6	[2]77.3
Spain	234.7	[r]227.0	273.0	278.0	265.0
Sweden	216.4	[r]219.3	218.6	186.9	163.5
Thailand	77.5	97.2	88.7	78.0	[2]62.8
Tunisia	5.6	4.5	5.9	9.4	9.0
Turkey[3]	37.4	41.1	42.2	[r e]44.0	43.0
U.S.S.R.[e]	810.0	810.0	810.0	810.0	810.0

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	1985	1986	1987	1988[p]	1989[e]
United Kingdom	5.3	5.6	6.5	5.5	[2]5.8
United States	251.9	220.8	232.9	256.4	[2]288.3
Vietnam[e]	5.0	5.0	5.0	[r]5.5	5.5
Yugoslavia[4]	89.3	[r]99.1	87.4	91.2	90.0
Zaire	77.5	81.3	74.7	[r e]80.0	75.0
Zambia[4]	32.0	33.0	35.4	33.9	33.5
Total[3]	[r]6,758.3	[r]6,935.8	7,231.9	7,014.8	7,061.8

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through June 29, 1990.
[2] Reported figure.
[3] Data may not add to totals shown because of independent rounding.
[4] Content in ore hoisted.

operating in 1969, 11 were permanently closed and 3 were extensively modified after extended shutdowns. Only one new "greenfields" zinc smelter has been brought on-stream in the intervening period. In 1989 only four U.S. primary zinc smelters with a capacity of 325,000 tons were in operation compared with 14 smelters with a capacity of about 1 million tons in 1969. Also during this period, all domestic slag-fuming zinc plants at lead smelters and the remaining ore-based American-process zinc oxide plants were closed permanently. In the 1980's decade, both mine and smelter output were the lowest since the 1900–09 decade. In the latter half of the 1980's, the domestic zinc industry began to improve, mainly in the area of mine output, but structurally it was much different than it had been in the 1970's.

In two decades, the United States fell from a position of world leader and near self-sufficiency in zinc metal production to a Nation two-thirds dependent on imports. Concurrent with the smelter production decline, U.S. mine output fell from second highest in the world to sixth place. Foreign ownership of the surviving industry also had increased to major proportions. In the 1970's, virtually all domestic zinc mining and smelting were controlled by U.S.-owned companies, but by the end of 1980's about 60% of the domestic mine production capacity, including Red Dog, and 30% of the primary smelting capacity was controlled by U.S. subsidiaries of foreign companies.

Since the early 1900's, world zinc mine and smelter production has risen from 1 million tons to more than 7 million tons. Many countries mine and refine zinc; however, a relatively small number of private and state-owned companies control the bulk of world zinc production. State-owned zinc operations mainly in the CPE countries but also in countries such as Greece, India, Iran, Italy, Peru, Zaire, and Zambia accounted for an estimated 40% of world mine and smelter capacity. Much of the world's privately held mine and/or smelter capacity is related to 16 companies either through direct ownership, subsidiaries, holding companies, or equity sharing. These companies often own interest in each other either directly or via subsidiaries. As a consequence, ownership links and production control in the zinc industry are less than clear. The major privately held companies in the world zinc industry include MIM Holding Co. and Pasminco Ltd. (Australia); Acer-Union Miniere (Belgium); Cominco and Noranda Ltd. (Canada); Outokumpu Oy (Finland); Metaleurope S.A. (France); Metallgesellschaft AG (Federal Republic of Germany); Mitsui Mining and Smelting (Japan); Grupo Industrial Minera Mexico, S.A. de C.V. (Mexico); Asturiana (Spain); Anglo American Corp. (Republic of South Africa); Trellborg (Sweden); RTZ Corp. (United Kingdom); and Asarco and ZCA (United States).

Geology-Resources

Zinc is the twenty-third most abundant element in the Earth's crust and is a trace constituent in most rocks. Many minerals contain zinc as a major component; however, only a few are economically important. Sphalerite (ZnS) is, by far, the most important ore mineral and is the source for most of the world's zinc production. Zinc sulfide oxidizes readily to the common oxide zinc minerals smithsonite ($ZnCO_3$) and hemimorphite ($H_2Zn_2SiO_5$). Ores containing these oxide minerals were mined extensively before the development of froth-flotation processes, but currently only a few deposits are exploited. At the world famous Franklin Furnace and Sterling Hill deposits in New Jersey, a unique assemblage of zinc minerals—willemite, $ZnSiO_4$; franklinite, (Zn, Fe, Mn)$(FeMn)_2O_4$; and zincite, ZnO—were mined for more than 120 years before ore depletion in 1986.

Sphalerite is commonly associated with cadmium, copper, lead, and silver minerals and to a lesser degree with tin minerals and gold. Sphalerite nearly always contains iron and commonly small amounts of elements such as cadmium, gallium, germanium, indium, mercury, and thallium, which substitute for zinc atoms in the mineral crystal structure.

Exploitable zinc deposits, together with associated elements, are found in many diverse geological environments. These can be divided into seven broad categories based on differences in their geological occurrences: (1) volcanic-hosted submarine exhalative massive sulfide deposits, (2) sediment-hosted submarine exhalative deposits, (3) strata-bound carbonate-hosted deposits, (4) strata-bound sandstone-hosted deposits, (5) vein deposits, (6) diatremes, and (7) metamorphic deposits. Oxidized zinc deposits are sometimes formed at the surface or near surface by supergene enrichment or laterization processes acting on primary zinc deposits.

Most major zinc deposits occur as massive, often strata-bound, sulfide ore bodies or as fillings in breccia or replacement strata-bound deposits in carbonate rocks, commonly known as "Mississippi Valley Type." Examples of massive ore deposits are the Broken Hill and Mount Isa Mines in Australia, the Sullivan and Kidd Creek Mines in Canada, lead-zinc mines in the Bath-

urst district in Canada, the Ducktown district in Tennessee, and the Red Dog Mine in Alaska. Mississippi Valley Type deposits are common worldwide; the major deposits of this type in the United States are in the East and Central Tennessee districts in Tennessee, the Viburnum Trend in Missouri, and the Tristate district in Kansas, Missouri, and Oklahoma.

Technology

Exploration and Development.—Most of the important zinc-producing mines of the United States except those in Tennessee, St. Lawrence County, NY, Sussex County, NJ, and the Picher portion of the Tristate district, began as lead or lead-silver mines discovered as outcrops. In recent years, outcrops with base metal mineralization or surface indications of base metal mineralization have led to the discovery of a number of large zinc deposits. Such discoveries include the Polaris Mine in Canada, the Rubiales Mine in Spain, the Black Angel Mine in Greenland, and the Red Dog Mine in Alaska.

Prospecting techniques using geophysics and geochemistry have been used increasingly in mineral exploration. Airborne magnetic surveys were instrumental in the discovery of large reserves of base metals, including zinc in Canada and Missouri. The massive sulfide deposit at Crandon, WI, was discovered by drilling in an anomalous area identified by geophysical methods. Geochemistry has been widely used in Tennessee, Virginia, and elsewhere to determine favorable areas of drilling on the basis of anomalous quantities of zinc in the soil or vegetation. In middle Tennessee, much of the exploration was by surface mapping, by study of stratigraphy from oil-well drilling, and from random widespaced diamond drilling. After initial discovery, exploration is continued by further drilling, shaft sinking, crosscutting, and drifting.

Mining.—The principal methods employed in zinc mining are room and pillar, shrinkage stoping, and cut and fill. Several different methods may be used within one mine. Except for a few open pit mines in Australia, Brazil, and Canada, and more recently at the Montana Tunnels and Red Dog Mines in the United States, open pit methods

TABLE 39

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Algeria, primary	35.7	29.0	19.0	[r e]38.0	31.0
Argentina:					
Primary	30.4	29.1	31.9	[e]29.0	29.0
Secondary	2.5	3.0	2.6	[e]2.4	2.5
Total	32.9	32.1	34.5	[e]31.4	31.5
Australia:					
Primary[2]	288.7	303.1	307.6	302.5	[3]294.0
Secondary[e]	4.5	4.5	4.5	4.5	4.5
Total[e]	293.2	307.6	312.1	307.0	298.5
Austria, primary and secondary	25.0	24.0	24.3	23.9	26.0
Belgium, primary and secondary	290.5	288.8	308.6	323.8	299.6
Brazil:					
Primary	116.1	130.6	138.7	139.7	[3]165.5
Secondary	4.6	5.9	9.4	7.0	[3]6.7
Total	120.7	136.5	148.1	146.7	[3]172.2
Bulgaria, primary and secondary[e]	90.0	90.0	[3]92.0	90.0	[3]86.8
Canada, primary	692.4	571.0	609.9	703.2	[3]669.7
China, primary and secondary[e]	275.0	[3]336.0	383.0	340.0	425.0
Czechoslovakia, secondary	[r e]1.0	[r e]1.1	1.1	1.4	1.4
Finland, primary	160.4	155.4	150.5	156.1	162.5
France, primary and secondary	247.2	257.4	249.3	274.1	266.0
German Democratic Republic, primary and secondary[e]	17.0	17.0	18.0	[r]21.0	19.0
Germany, Federal Republic of:					
Primary	339.9	344.3	348.2	309.9	[3]297.5
Secondary	27.9	26.6	29.3	42.5	[3]45.3
Total	367.8	370.9	377.5	352.4	[3]342.8
Hungary, secondary[e]	.6	.6	.6	.6	.6
India:					
Primary	70.9	72.0	68.9	68.9	[3]75.3
Secondary[e]	.2	.2	.2	.2	.2
Total[e]	71.1	72.2	69.1	69.1	75.5
Italy, primary and secondary	215.6	229.4	247.0	242.1	246.0
Japan:					
Primary	629.5	626.5	591.5	601.1	[3]590.5
Secondary	110.1	81.5	74.1	77.1	[3]73.3
Total	739.6	708.0	665.6	678.2	[3]663.8
Korea, North, primary[e]	180.0	180.0	210.0	210.0	210.0
Korea, Republic of, primary	111.7	127.4	186.1	223.0	[3]240.2
Mexico, primary	[r]171.4	[r]173.5	184.8	192.5	[3]193.3
Netherlands, primary and secondary	201.7	196.2	207.1	211.0	[3]203.0
Norway, primary	92.7	90.4	116.5	121.2	[3]120.4
Peru, primary	162.7	155.8	144.2	123.1	137.8
Poland, primary and secondary	180.0	179.0	177.0	174.0	177.0
Portugal, primary	5.9	5.7	5.8	6.0	5.0
Romania, primary and secondary[e]	40.0	39.0	39.0	42.0	42.0
South Africa, Republic of, primary	93.7	81.0	96.1	84.4	[3]85.0
Spain, primary	213.3	202.0	224.0	256.0	257.0
Thailand, primary	62.1	58.9	66.9	68.6	[3]68.4
Turkey, primary	22.2	15.4	18.0	22.7	24.0

See footnotes at end of table.

TABLE 39—Continued

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
U.S.S.R.:[e]					
Primary	890.0	880.0	890.0	848.0	862.0
Secondary	100.0	105.0	110.0	115.0	115.0
Total	990.0	985.0	1,000.0	963.0	977.0
United Kingdom, primary and secondary	74.3	85.9	81.4	76.0	[3]79.8
United States:					
Primary	261.2	253.4	261.3	241.3	[3]263.1
Secondary	72.6	62.9	82.6	88.5	[3]95.1
Total	333.8	316.3	343.9	329.8	[3]358.2
Vietnam, primary[e]	4.2	4.2	4.2	4.2	4.2
Yugoslavia, primary and secondary	83.4	82.0	118.1	127.5	[3]119.4
Zaire, primary	64.0	63.9	54.9	61.1	[3]54.0
Zambia, primary	22.8	22.5	21.0	20.2	12.9
Grand total[4]	[r]6,785.6	[r]6,691.1	7,009.2	7,115.3	7,186.5
Of which:					
Primary	[r]4,717.7	[r]4,570.9	4,745.8	4,826.5	4,848.1
Secondary	[r]323.0	[r]291.3	314.4	339.2	344.6
Undifferentiated	[r]1,743.9	[r]1,828.9	1,949.0	1,949.6	1,993.8

[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 June 29, 1990.

[2] Excludes zinc dust.

[3] Reported figure.

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

have not been used extensively in zinc mining.

Room and pillar mining involves the extraction of ore from a flat or gently dipped ore body by excavation of rooms supported by unmined pillars of ore or waste rock. Zinc and lead-zinc stratiform bodies are the types of deposits most often mined by some variation of this method. Examples are to be found in the zinc mines of Tennessee, the Missouri lead belt, and the Balmat-Edwards zinc district in New York.

In shrinkage stoping, ore is mined in successive flat or inclined cuts or slices progressing upward from a haulage level. After each slice, enough broken ore is drawn off through chutes or drawpoints to provide working space between the top of the pile and the new back or roof of the stope. The remaining broken ore serves as the floor on which the miners prepare to cut a new slice. Shrinkage stoping is generally employed in mining vein deposits, but is sometimes used in conjunction with room-and-pillar mining at zinc mines in east Tennessee.

Cut-and-fill mining is best suited to steeply dipping veins such as found in the silver-lead-zinc mines in the western United States. In the cut-and-fill method, the ore is broken and removed from the stope; waste in the form of rock, sand, and tailings is backfilled into the stope to within working distance of the back; and the mining cycle is repeated. A modification of this method is used at the Lucky Friday Mine in Idaho where the process is reversed. In this case, the mined area is completely sandfilled, followed by mining immediately under the backfilled stope. The method was developed to improve safety by reducing rock bursting problems.

The cycle of operations in mining consists of drilling, blasting, and removing broken rock. Drilling usually is done with compressed-air percussion drills mounted on self-propelled jumbos with either crawler-treads or rubber tires. Following blasting, broken ore is loaded with a variety of diesel or electric, high-capacity, specialized shovels or loaders, and haulage is done with trucks or load-haul-dump units. Track haulage is by electric, diesel, or compressed-air locomotives, but the trend is toward trackless haulage using rubber-tired, high-speed, maneuverable machines that service stopes at great distances from the entry and convey the broken ore rapidly to the hoisting skip with a minimum of handling.

Beneficiation.—Most zinc ores are treated in a mill to separate the desirable mineral constituents in the ore from unwanted impurities or gangue. This process involves the crushing and grinding of the ore to release the individual mineral constituents from each other, followed by flotation procedures to selectively concentrate the valuable minerals in fractions separate from the gangue components. For noncomplex, carbonate-hosted ores such as those in Tennessee, heavy media separation pretreatment before zinc flotation has been designed into some mills to reduce the amount of nonmineralized, low specific gravity gangue going to the grinding and flotation circuit.

A general scheme for the flotation of a mixed sulfide ore is (1) flotation of the lead-copper minerals and depression of the zinc and iron minerals, (2) separation also by flotation of the lead-copper concentrate into separate lead and copper concentrates, (3) activation and flotation of the sphalerite from the iron and gangue minerals, and (4) flotation of the pyrite if a recovery is desired.

Column cells, large cylinders typically 35 feet or more in height, are increasingly being installed at lead-zinc operations for flotation purposes. Substantial cost reductions, increased recovery, and higher grade concentrates are generally attained using column cells compared with standard flotation equipment.

Many zinc and zinc-lead mills are highly automated and require few operating personnel. Many have instrumentation, sensors, and on-stream X-ray analyzers to provide central control of most mill functions ranging from head feed rates and flotation reagent control to tailings disposal.

High-grade concentrates, 60% zinc or better, are produced from straight-zinc ores. Zinc concentrates from zinc-lead ores contain about 50% to 59%

zinc, and concentrates from more complex mixed ores range from 35% to 55% zinc. The concentrate is shipped to smelters for refining to zinc or zinc oxide, recovery of byproduct metals, and production of sulfuric acid.

The zinc content in lead concentrates or in mixed bulk lead-zinc concentrates is sometimes recovered as a zinc oxide fume from processing lead slags, produced at lead smelters using sinter-blast furnaces. The zinc fume, after deleading and densifying, is sent to a zinc plant for refining. Zinc fume has been an important smelter feed source in the United States but because of high costs, all domestic slag fuming plants have closed; the last operating plant closed in 1985. Two recently commercialized lead smelting methods, known as the QSL (Oueneau-Schuhmann-Lurgi) and Kivcet CS processes, similarly yield a zinc oxide or metal product from zinc-rich lead feed owing to zinc fuming in the reduction section of the furnaces.

Smelting.—Reduction of the concentrates to zinc is accomplished by electrolytic deposition from a sulfate solution or by distillation in retorts or furnaces. For either method, the zinc concentrate is roasted to eliminate most of the sulfur and produce impure zinc oxide known as roasted concentrate or calcine. At a few refineries, pressure leaching of the concentrates is employed instead of roasting. The zinc pressure leach process, developed by Sherritt Gordon Ltd., produces leachable zinc sulfate directly, as well as elemental sulfur, thereby supplanting the roast and acid plant processes. In Thailand, an electrolytic zinc refinery produces zinc from run-of-mine zinc silicate-carbonate ore that averages about 26% zinc. Zinc is leached directly from the ore by hot sulfuric acid followed by electrowinning. The typical roasting step is again not required.

At electrolytic zinc plants, which comprise about four-fifths of world primary metal capacity, the calcine is leached with dilute sulfuric acid to form a zinc sulfate solution. The solution is then purified and piped to electrolytic cells, where the zinc is electrodeposited on aluminum cathodes. The cathodes are lifted from the tanks at intervals and stripped of the zinc, which is remelted and cast into slabs. The quality of this zinc is either SHG or HG. The electrolysis of the solution regenerates sulfuric acid, which is used in succeeding cycles of leaching. During the roasting of concentrates, iron reacts with zinc to form insoluble zinc ferrite, which on leaching remains in the leach residue and results in decreased zinc recovery. Several processes, known by the iron residue product produced—jarosite, goethite, and hematite—are used in smelters to treat leach residues to extract this zinc and increase recovery. Lead and silver, which are commonly found in zinc concentrates, are also insoluble in the roast-leach process and are concentrated in the leach residue. Residues with sufficiently high lead and silver contents are usually shipped to a lead smelter, where the lead and silver are recovered in lead bullion.

There are three basic types of distillation retort plants: (1) batch horizontal retorts, (2) continuous vertical retorts externally heated by fuel, and (3) continuous vertical retorts heated electrothemally. Only a few horizontal and vertical retort plants remain in the world. One of the four primary smelters in the United States is an electrothermic plant, a type of vertical retort. Calcine or sinter together with coal or coke as a reducing agent yield zinc vapor and carbon monoxide which pass into a condensation zone or splash-type condenser where the zinc is collected as liquid metal ready for casting into slab form. Zinc produced by distillation is normally the lower commercial grade, but it may be upgraded by redistilling to reduce impurities. In refining, the impurities such as lead and cadmium are separated by distillation in vertical fractionating columns. The zinc product can be 99.995% pure.

A blast furnace process for producing both lead and zinc, known as the Imperial Smelting Process (ISP), follows the normal blast furnace practice of burning coke in intimate association with calcine sinter, and as in the retort process, the zinc is released as a vapor and condensed. Twelve plants of this type have come on-stream in the past two decades and account for about 12% of world zinc capacity. An important advantage of the process is the ability to treat a wide range of zinc-lead materials and recover both metals, as well as any gold or silver present, with no extra coke consumption and little extra labor. The zinc metal produced by ISP smelting is typically PW grade.

Recycling.—Recovery of zinc from old scrap, mainly in the form of diecastings, steelmaking electric arc furnace (EAF) dusts, and brass and bronze, currently represents about 7% of the total U.S. demand. New scrap, which typically is two to three times the quantity of old scrap, is mainly zinc-base and copper-base alloys from manufacturing operations and drosses and skimmings from galvanizing operations. The large use of zinc in galvanizing, paints, and rubber has limited recovery of zinc from old scrap, but in the past few years, increasing amounts have been recovered from these sources, especially from galvanized steel scrap where zinc is recovered in steelmaking EAF dust. The zinc in calcine recovered from the intermediate processing of EAF dust is typically produced as metal at pyrometallurgical plants such as ZCA's Monaca plant or an ISP plant. Plasma-furnace technology is also increasingly being used to recover zinc by the direct processing of EAF dusts. Electrolytic recovery is generally not cost effective because of the high expense of solution purification required by the process. At several plants, crude zinc oxides are recovered from processing used automobile tires.

Recovery of zinc diecastings from scrapped automobiles is highly efficient and is a major source of old scrap. However, this source is not expected to grow significantly because the weight of zinc diecastings in automobiles has declined from the mid–1970's as a result of downsizing and weight-reduction programs. Zinc in zinc-base alloys is generally recovered by distillation as zinc oxide, dust, or slab zinc, whereas the zinc in copper-base alloys is generally recovered by remelting and recasting directly back into brass or bronze ingot. Scrap is the source material for most of the domestic output of zinc dust and chemicals and about one-half of the zinc oxide production.

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ZIRCONIUM AND HAFNIUM

By James B. Hedrick and David A. Templeton

Messrs. Hedrick and Templeton are physical scientists with the Branch of Nonferrous Metals. They have shared coverage of zirconium and hafnium for about 2 years. Domestic survey data were prepared by Ms. Imogene P. Bynum, Nonferrous Metals Data Section.

Zirconium and hafnium occur together in nature at a ratio of about 50 parts zirconium to 1 part hafnium. Hafnium must be separated from zirconium that is to be used for certain nuclear applications but the two elements are used in combined form for most other applications.

Domestic production of zircon and zirconium oxide (zirconia) increased over that of the previous year. Two companies produced zircon as a coproduct of processing titanium minerals from three mines in Florida. Two companies in New Jersey recovered zircon from tailings previously accumulated as a byproduct during processing for ilmenite. The world production of zircon increased to a record-high level in 1989, but the supply continued to remain slightly below the level of demand. Zircon's strong demand in 1989 continued to result in historically high price levels.

Major uses for zirconium were in foundry sands, refractories, ceramics, abrasives, chemicals, and metallurgical applications. Hafnium was used in metallurgical applications, refractories, and ceramic cutting tools.

Advanced technology applications of zirconium included stabilized and partially stabilized zirconia used in extrusion dies, industrial cutting blades, ceramic engine parts, thermal barrier coatings for jet engines and other high-temperature environments, and radar transparent covers for radar equipment (radomes). Zirconium fluoride and hafnium fluoride glasses were used in fiber optics.

LEGISLATION AND GOVERNMENT PROGRAMS

Teledyne Wah Chang Albany (TWCA) requested Federal and State permission to dispose of low-level radioactive sludge generated by the pre-1980 refining of zirconium from zircon sand. The plans submitted for approval were prepared for TWCA by CH_2M-Hill, based in Corvallis, OR. The estimated 85,000 to 100,000 cubic yards of material, currently held in evaporation ponds, contains traces of uranium and thorium, and the decay products radium and radon. Previous findings concluded that the concentrations of these elements were insufficient to classify the waste as radioactive or hazardous. However, a Nuclear Regulatory Commission law disallowing the waste from being stored on a flood plain (Willamette River, 500-year) and public pressure prompted the company to seek disposal elsewhere. The plans included transport, via truck or rail, to a solid waste landfill, consolidation with Portland cement to prevent leaching, and disposal of the aggregate in a sealed structure. The Environmental Protection Agency (EPA) Record of Decision for Operable Unit #1 (Sludge Ponds) was signed at yearend, affirming the company plans. The EPA expected the estimated $10 million cleanup to commence in mid-1990.[1]

STRATEGIC CONSIDERATIONS

The National Defense Stockpile stocks of zirconium ore, totaling 14,507 metric tons, were classified as excess to goal. Zircon was produced in the United States, and there were no stockpile objectives for zirconium and hafnium materials.

Zircon was used in important defense related applications. Investment casting molds of zircon and zirconia were used to cast superalloy components of jet engines. Zirconia was used to form the crucibles in which superalloys were melted and in several other strategic applications, such as thermal barrier coatings on jet engine combustors and turbine vanes, as a white pigment for camouflage coatings in snow environments, and in sonar equipment for submarines.[2]

Zirconium was a minor constituent of many superalloys, and hafnium was a major component of an engine alloy used in the F-15 and F-16 military fighter planes. Both metals were required for use in U.S. Navy submarine nuclear reactors because of their dependability and performance in this application. At yearend 1989, the U.S. Department of Energy inventories were approximately 15 tons of zirconium sponge, 899 tons of zirconium ingot and shapes, 24 tons of zirconium scrap, 1 ton of zirconium crystal bar, 5 tons of hafnium oxide, 28 tons of hafnium ingot and shapes, and 3 tons of hafnium crystal bar.

PRODUCTION

Zircon was produced primarily as a coproduct or byproduct of processing heavy mineral sands for titanium minerals. Associated Minerals (USA) Inc., a subsidiary of the Australian firm Renison Goldfields Consolidated Ltd., produced zircon from heavy minerals mined and processed at Green Cove Springs, FL. E.I. du Pont de Nemours & Co. Inc. operated two mines near Starke and Lawtey in northeastern Florida that produced zircon and other heavy minerals. Heritage Minerals Inc. and Nord Ilmenite Corp. produced zircon from tailings that were previously generated during processing for ilmenite at Lakehurst and Jackson, NJ, respectively.

Molycorp Inc., a wholly-owned subsidiary of Unocal Corp., and the Mescalero Apache Tribe announced a joint

venture agreement to develop a deposit on the tribe's reservation in New Mexico. The deposit, identified by Molycorp in 1985, contains the mineral eudialyte, a zirconium- and yttrium-bearing silicate mineral. Reported reserves were 2.4 million metric tons grading 1.2% zirconium oxide and 0.18% yttrium oxide. Initial metallurgical tests by Molycorp indicated that the ore could be processed with conventional heap-leach technology, a low-cost process presently used by many gold and copper operations. Although Molycorp was engaged in the production and processing of yttrium and other rare earths for the past 20 years, zirconium would be a new addition to its product line. A schedule for development was not set.[3]

Piedmont Mining Company, Inc. was reportedly investigating occurrences of titanium minerals and zircon in North Carolina.

TAM Ceramics Inc., a subsidiary of the United Kingdom-based Cookson Group, began construction of a new facility at Niagara, NY, to produce zirconia using a recently developed chemical precipitation process. The new process, developed by Cookson Research, reportedly yields ultra-high purity zirconia using selective precipitation on an industrial scale. Completion of the new plant was scheduled for late 1990.[4]

CONSUMPTION AND USES

Apparent consumption of zircon in 1988 and 1989 was calculated by adjusting domestic production for net trade and changes in stocks. Prior to 1988, production data were withheld to avoid revealing proprietary data and consumption was estimated, based on a survey of the industry. The zircon consumption pattern, shown in the following table, was estimated based on survey data and were adjusted to equal total apparent consumption as rounded for 1988 and 1989. These data were not consistent with end use data published by the Bureau of Mines in prior years.

End use	1988[r]	1989
Zircon refractories[1]	29,000	23,000
AZS refractories[2]	15,000	12,000
Zirconia and AZ abrasives[3]	W	W
Alloys[4]	W	W
Foundry applications	50,000	41,000
Other[5]	60,000	50,000
Total	177,000	145,000

[r] Revised. 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-based refractories.
[3] Alumina-zirconia-based abrasives.
[4] Excludes alloys above 90% zirconium.
[5] Includes chemicals, zirconium metal, welding rods, sandblasting, and other miscellaneous uses.

TABLE 1
SALIENT U.S. ZIRCONIUM STATISTICS
(Metric tons)

	1985	1986	1987	1988	1989
Zircon:					
Production:					
Concentrates	W	W	W	117,606	118,388
Milled zircon	42,744	46,970	42,394	64,393	54,994
Exports	15,291	15,852	20,054	[r]21,794	48,176
Imports for consumption	39,723	68,764	67,917	76,331	73,196
Consumption, apparent[1 2]	117,934	143,335	132,800	[r]176,991	144,813
Stocks, Dec.31: Dealers and consumers[3]	26,570	28,074	39,218	[r]34,370	32,965
Zirconium oxide:					
Production[e 4]	8,322	7,148	5,226	4,438	10,179
Exports	951	1,648	1,206	1,809	NA
Imports for consumption	1,332	464	1,274	1,089	NA
Consumption, apparent	6,804	6,078	3,800	[r]3,548	NA
Stocks, Dec. 31: Producers[e 4]	1,383	2,002	1,213	[r]1,383	1,767

[e] Estimated. [r] Revised. NA Not available. W Withheld to avoid disclosing company proprietary data.
[1] Includes insignificant amounts of baddeleyite.
[2] Please refer to the text under "Consumption and Uses" for a discussion of the apparent consumption of zircon.
[3] Excludes foundries.
[4] Excludes oxide produced by zirconium metal producers.

TABLE 2
YEAREND STOCKS OF ZIRCONIUM AND HAFNIUM MATERIALS IN THE UNITED STATES
(Metric tons)

Item	1988[r]	1989
Zircon concentrate held by dealers and consumers excluding foundries	31,522	26,966
Milled zircon held by dealers and consumers excluding foundries	2,848	5,999
Zirconium:[1]		
Oxide	1,383	1,767
Sponge, ingot, scrap, alloys	2,206	2,452
Refractories	6,202	5,383
Hafnium: Sponge and crystal bar[e]	27	27

[e] Estimated. [r] Revised.
[1] Excludes material held by zirconium sponge metal producers.

WORLD REVIEW

World capacity to produce zirconium minerals, shown in table 7, lagged demand by approximately 5%. Because of the strong and persistent demand for zirconium in both natural and processed forms, several deposits were in either the exploration, pilot plant, or development stage. The additional supplies provided by anticipated new and expanded operations should substantially ease the worldwide shortage of zircon.

Australia

The Nissho Iwai Corp. of Japan purchased RZ Mines (Newcastle) Ltd. and Cable Sands Pty. Ltd. for A$240 million from Pioneer International Ltd. Nissho had been importing rutile and zircon produced by RZ Mines for 20 years prior to the purchase. The company anticipated growth in demand for zircon resulting from Japan's increase in steel production and from the expanding European markets for fine ceramics. Combined, the two mining companies produced 50,000 to 60,000 tons of zircon per year, about 5% of world production.[5]

Cable Sands continued development of the Jangardup deposit in the southwest of Western Australia. The heavy

TABLE 3

PUBLISHED PRICES OF AUSTRALIAN ZIRCON

(U.S. dollars per metric ton)

Date of publication	Standard grade	Intermediate grade	Premium grade
December 1988	265-316	299-342	367-641
December 1989	395-474	395-474	474-790

Source: Industrial Minerals (London). No. 225, Dec. 1988, p. 83; and No. 267, Dec. 1989, p. 75.

TABLE 4

PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1988	1989
Zircon:		
Domestic, standard-grade, f.o.b. Starke, FL, bulk, per short ton[1]	$242.00	$320.00
Domestic, 75% minimum quantity zircon and aluminum silicates, Starke, FL, bulk, per short ton[1]	161.00	204.00
Imported sand, containing 65% ZrO_2, f.o.b., bulk, per metric ton[2]	237.00- 259.00	435.00- 452.00
Domestic, granular, bags, bulk rail, from works, per short ton[3]	300.00- 350.00	300.00- 600.00
Domestic, milled, 200- and 325-mesh, rail, from works, bags, per short ton[3]	350.00- 450.00	350.00- 800.00
Baddeleyite, imported concentrate:[4]		
96% to 98% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	.51	.85- 1.05
99%+ ZrO_2, minus 325-mesh, c.i.f. Atlantic ports, per pound	.91	1.16- 1.30
Zirconium oxide:[3]		
Powder, commercial grade, drums, 2,000-pound minimum, per pound	5.80- 5.85	2.00- 7.00
Electronic, same basis, per pound	8.50	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, 30° F, same basis, per pound	3.00	3.00
Zirconium oxychloride: Crystal, cartons, 5-ton lots, from works, per pound[3]	.91- 1.04	.91- 1.04
Zirconium acetate solution:[3]		
25% ZrO_2, drums, carlots, 15-ton minimum, from works, per pound	.97	.97
22% ZrO_2, same basis, per pound	.78	.78
Zirconium hydride: Electronic-grade, powder, drums, 100-pound lots, from works, per pound[3]	.31- .75	.31- .75
Zirconium:[5]		
Powder, per pound	70.00- 150.00	70.00- 150.00
Sponge, per pound	12.00- 18.00	12.00- 18.00
Sheets, strip, bars, per pound	16.00- 45.00	16.00- 45.00
Hafnium: Sponge, per pound[5]	75.00- 135.00	75.00- 135.00

[1] E. I. du Pont de Nemours & Co. Inc. price lists. Oct. 1, 1988 and 1989 respectively.
[2] Industrial Minerals (London). No. 255, Dec. 1988, p. 83; and No. 267, Dec. 1989, p. 75.
[3] Chemical Marketing Reporter. V. 234, No. 26, Dec. 26, 1988 p. 26; and v. 236, No. 26, Dec. 29, 1989, p. 40.
[4] American Vermiculite Corp., Atlanta, GA. Baddeleyite price lists; and Ronson Metals Corp. price lists (effective Jan. 1, 1990).
[5] American Metal Market. V. 96, No. 253, Dec. 30, 1988, p. 6; and v. 97, No. 252, Dec. 30, 1989, p. 6.

mineral mine was expected to begin operation in 1990 or 1991, with an estimated capacity of 10,000 tons per year of zircon concentrate.

Production from Australmin Holdings Ltd. mine at Newrybar, New South Wales, was postponed because of an appeal by environmentalists to the Land and Environment Court. The appeal was not upheld and the company expected production to begin early in 1990. Processing of the 30,000 tons of concentrate expected to be produced annually will reportedly yield 10,000 tons of zircon and 12,000 tons of rutile.[6]

Associated Minerals Consolidated (AMC) Mineral Sands Ltd. began development of the Eneabba West deposit. The deposit, due to come onstream in 1990 or 1991, reportedly contains 230 million tons of sand with a heavy mineral grade of 3.1%. Projected annual production of zircon from Eneabba West was expected to reach 70,000 tons.

Two companies investigated heavy mineral deposits in the Scott River area of Western Australia. BHP-Utah Minerals International indicated that the Beenup deposit would be capable of dredging upwards of 500,000 tons of heavy mineral-bearing sand per year. The environmental impact on agricultural activity nearby was studied. A joint venture comprised of Golden Plateau NL, Kingsgate Consolidated Ltd., and Wynarde Pty. Ltd. found encouraging concentrations of ilmenite (39% to 64%), rutile (3% to 8%), and zircon (0.5% to 2%) on leases held in the vicinity. The overburden on the concentrated zones and slimes generated during the treatment phases were expected to present difficulties.[7]

North Broken Hill Peko Ltd. was evaluating the feasibility of the King Island, Naracoopa, mineral sand project. Total reserves were estimated to contain 25 million tons grading 5.2% heavy minerals. King Island is situated midway between Victoria and Tasmania near the Bass Strait.[8]

The Cooljarloo mineral sand deposit near Catabay, Western Australia, was expected to begin production near the end of the year. With reserves containing over 18 million tons of heavy minerals grading 12% zircon, the estimated 80% recovery rate should bring about one and three-quarter million tons of

zircon to market during the life of the mine. Zircon production expected in 1990 and 1991 was 31,000 and 67,000 tons, respectively. The Oklahoma City-based Kerr-McGee Chemical Corp. had a 50% interest in the venture through its Australian subsidiary KMCC Western Australia Pty. Ltd. The Australian firm Minproc Holdings Ltd. had equal equity in the project through its subsidiary Minproc Chemicals Pty. Ltd.

Mineral Deposits Ltd. planned to have a new mine near Bundaberg, Queensland, in operation by 1991. Initial output of zircon from this heavy mineral deposit, on the coast north of Rocky Point at Agnes Water, was projected to be 30,000 tons per year.[9]

The offshore portion of the Eastern Australian Rutile Province, encompassing the nearshore from Sydney north to the Queensland border, was found to contain over 2 million tons of zircon and rutile in noneconomic deposits as surveyed in the mid-1960's. New exploration for heavy minerals in the Province began in June on the nearshore of the continental shelf off the coast of New South Wales. The new marine geophysical survey includes sidescan sonar mapping and seismic reflection and magnetometer profiling; all data were to be digitized for high-resolution processing.[10]

Bangladesh

The Government was reported to have begun a mineral sands project which was previously discontinued. A survey of 240 square kilometers (km^2) of beach sands indicated heavy mineral resources totaling 420,000 tons. Minerals identified included titanium minerals, monazite, and zircon.[11]

Denmark

Morstral Minerals conducted exploratory drilling on an extensive (100 km^2) beach sand deposit exhibiting anomalous concentrations of zircon and other heavy minerals. The sands are located on the Thy Coast of the Jutland Peninsula in the vicinity of the Hanstholm Harbor.[12]

Guyana

An estimated 450 river-based diamond and gold dredges were reportedly processing heavy mineral-containing resources. Zircon and titanium minerals comprised the largest portion of the heavy minerals.[13]

Madagascar

QIT-Fer et Titane Inc. (QIT) indicated that problems mounting against the development of a mineral sand deposit, on the southeast coast in the Mandena region near Toalagnaro (formerly Fort Dauphin), would delay production until 1995. The ilmenite project, with reserves of 145 million tons, was a joint venture between QIT-Madagascar Mineral (49%) and the National Military Office for Strategic Industries (OMNIS), 51%. OMNIS reportedly initiated pilot plant construction, further exploration, and related industrial activity at the outset of the year. Annual zircon production of 24,000 tons was expected when fully operational.[14]

Mozambique

Kenmare Resources PLC of Ireland began the preconstruction and finance sourcing stage of its Congolone project after receiving approval from the Ministry of Mineral Resources to mine the deposit. Proven reserves of 167 million tons grading 3.25% heavy minerals were estimated to contain 373,000 tons of premium zircon. Beginning in early 1992, 37,000 tons per year of zircon were expected to be produced. Kenmare held a 71.25% equity in project, the Mozambican Government held 25%, and the geologic survey of Yugoslavia, Geoloski Zavod, which first explored the deposit, held 3.75%.[15]

New Zealand

In December, Fletcher Titanium Products Ltd. brought on stream a pilot mine located on the west coast of South Island. Combined production of 400 tons per year of monazite, rutile, and zircon was expected.[16] The possibility of more zircon production from South Island was to be decided upon the completion of a A$4 million feasibility study funded by Nissho Iwai Corp. of Japan, to be completed by May 1990. The study concerned a proposed titanium slag and pig iron plant at a 17-million-ton ilmenite deposit at Westport. Zircon, monazite, and gold would be byproducts of the operation.[17]

Republic of South Africa

Rhombus Mining (Pty.) Ltd. planned to develop a deposit to produce 27,000 tons of zircon per year. Drilling and seismic data on the heavy mineral sand deposit in the Transkei at Wavecrest, near the southeast coast, indicated reserves of 200 million tons grading 5% heavy minerals. Approval of the mining lease by the Department of Commerce, Industry, and Tourism was uncertain at yearend.[18]

The Anglo American Corp. of South Africa Ltd. studied the feasibility of developing heavy mineral sand deposits in Namaqualand. The deposits were on lands owned by De Beers Consolidated Mines near the west Cape coast, 30 miles north of the Olifants River. A wet concentration pilot plant was operated during the year. If a decision is made to proceed with the project, production was planned to commence in 1992, with expected annual zircon output of 100,000 tons per year. Rutile and monazite production were expected to be 25,000 and 1,000 tons per year, respectively.[19]

Severin Mining and Development Co. (Pty.) Ltd. conducted pilot plant tests in Australia on samples taken from a deposit it was exploring, 30 miles south of Richards Bay at Mitunzini. The deposit was reported to have a 10% heavy mineral grade resembling the Richards Bay Minerals deposit and a tentative mine life of 20 years. A decision was expected in early 1990, following completion and analysis of pilot plant tests.[20]

Richards Bay Minerals delayed exploration and development work on its project at Lake St. Lucia in the Natal Province because of environmental concerns. Although the company had reclamation practices which, according to the parent company QIT, "meet the highest standards for such operations anywhere in the world," environmentalists asked the International Union for Conservation of Nature to officially protect the area.[21]

Richards Bay Minerals received approval for the construction of a second dry mill which would double its zircon production to 300,000 tons per year by 1991–1992. The increase in raw feed material for the plant arises from the addition of two dredges in the past few years for a total of four. The company also planned to upgrade more of the standard grade zircon produced to an improved prime grade having a lower iron content than the prime grade previously produced.[22]

Sierra Leone

Australian mining companies, Intercontinental Gold & Minerals NL and MC Mining NL, expected to begin production of a heavy mineral deposit at Rotifunk in late 1990. Exploration of the deposit in the mid-1970's delineated reserves measuring 146 million tons grading 0.06% zircon (87,000 tons). The joint venture estimated production of 6,000 tons of zircon per year for 13 years. Rutile and ilmenite were to be the primary coproducts.[23]

Sierra Rutile Ltd. expected to begin zircon production of 15,000 tons per year in late 1990. Production is expected from stockpiled, zircon-rich tailings, and from a rutile deposit at Pejebu. Parent company Nord Resources Corp. recovered zircon from heavy mineral-rich tailings in New Jersey, in the United States. Following completion of the New Jersey project, operated by subsidiary Nord Ilmenite Corp., the company tentatively planned to dismantle and ship the separation plants to Sierra Leone to support these operations.[24]

United Kingdom

Butte Mining PLC, a precious and base metals producer, purchased Gramcol Zircon Ltd. for $6.6 million (£4 million).[25] Gramcol produced milled zircon for use as opacifiers in the ceramic industry. The company was reported to have a mill capacity of 1,500 tons per year.[26]

In a move to increase zirconium chemical production by one-third, Magnesium Elektron Inc. allocated $49 million (£30 million) for new plant construction and expansion of existing facilities at its manufacturing complex in Manchester. The company provided a full line of zirconium chemicals processed from raw zircon sand. Expansions were also planned for the company's facility in Flemington, NJ, in the United States.[27]

British Petroleum exited the mining business upon its sale of subsidiary BP Minerals Development Ltd. to the Rio Tinto Zinc Corp. PLC for $3.9 billion (£2.4 billion).[28] Rio Tinto Minerals Development Ltd. acquired total ownership of QIT-Fer et Titane Inc., which held 50% interest in a zircon producer, Richards Bay Minerals, in the Republic of South Africa. QIT tentatively planned to develop an ilmenite deposit in Madagascar.

TABLE 5

U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY[1]

Class and country	1988		1989	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Ore and concentrates:				
Argentina	840	$451	650	$679
Australia	171	155	261	1,893
Belgium	468	450	1,945	1,394
Brazil	—	—	538	943
Canada	386	157	2,979	1,456
Chile	—	—	90	200
Colombia	1,244	852	1,950	2,562
Costa Rica	—	—	140	93
Dominican Republic	—	—	201	176
Ecuador	276	269	779	757
Egypt	—	—	519	308
France	505	232	781	514
Germany, Federal Republic of	8,938	5,741	9,414	6,291
Guatemala	58	37	—	—
Guinea	88	29	—	—
Hungary	—	—	306	389
India	5	5	12	6
Indonesia	—	—	99	40
Ireland	18	3	38	9
Italy	14	6	5,874	1,623
Japan	776	141	3,388	1,748
Korea, Republic of	302	228	531	367
Mexico	6,346	2,662	8,327	4,760
Netherlands	109	103	1,041	759
Pakistan	—	—	53	102
Peru	—	—	18	45
Portugal	—	—	78	61
Spain	—	—	1,773	1,878
Taiwan	—	—	2,187	1,563
Thailand	88	65	18	34
U.S.S.R	—	—	1,234	610
United Kingdom	125	33	2,147	809
Uruguay	—	—	18	41
Venezuela	875	584	515	576
New Zealand	—	—	31	63
Other	162	137	241	410
Total	21,794	[2]12,339	48,176	33,159
Unwrought zirconium and waste and scrap:				
Belgium	36	321	36	394
Canada	9	89	14	316
France	7	64	—	—
Germany, Federal Republic of	3	50	6	54
Japan	61	2,704	83	3,050
Netherlands	14	48	—	—
Sweden	11	250	30	680
Switzerland	2	14	3	41
Taiwan	—	—	2	63
Thailand	—	—	7	179

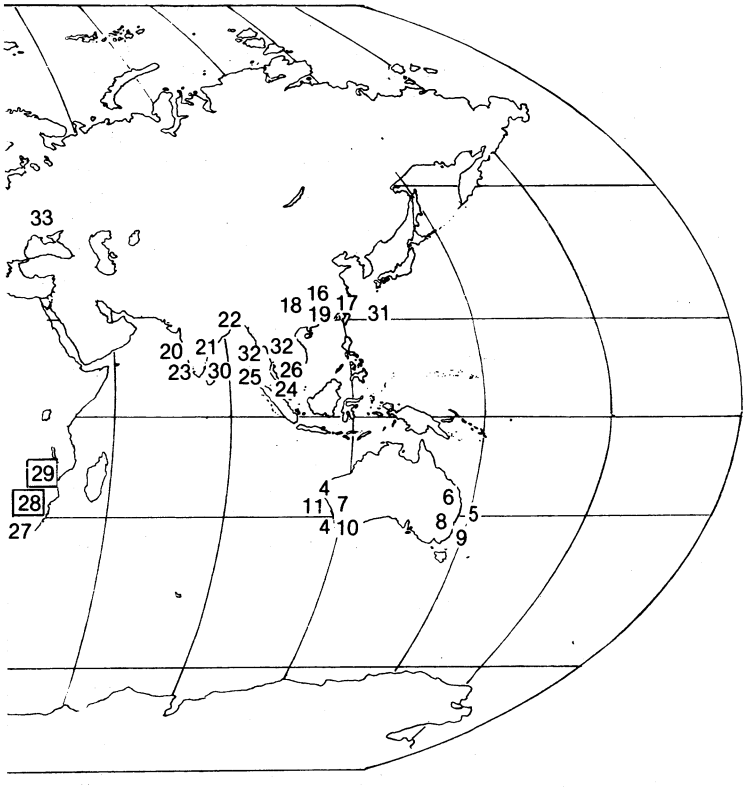
See footnotes at end of table.

PRINCIPAL WORLD ZIR



COMPANY	LOCATION
UNITED STATES	
1. E.I. du Pont de Nemours & Co. Inc.	Starke and Lawtey, Florida
2. Associated Minerals (USA) Inc.	Green Cove Springs, Florida
3. Heritage Minerals Inc.	Lakehurst, New Jersey
AUSTRALIA	
4. Associated Minerals Consolidated Ltd.	Capel and Eneabba, Western Australia
5. Consolidated Rutile Ltd.	Amity, Bayside, Gordon, Dunwich, and Pinkenba, Queensland
6. Currumbin Minerals Pty. Ltd.	Kirra, Kingscliff, Gympie, Gold Coast, Rainbow Beach, Cudgen, and Currumbin, Queensland
7. Cable Sands (WA) Pty. Ltd.	North Capel, Waroona, and Bunbury, Western Australia
8. Mineral Deposits Ltd.	Stockton, Durness, Hawks Nest, New South Wales
9. RZ Mines (Newcastle) Pty. Ltd.	Tomago and Nabiac, New South Wales
10. Westralian Sands Ltd.	North Capel, Yoganup, Yoganup North, and North Capel, Western Australia
11. TiO2 Corp. (Kerr-McGee Corp. and Minproc Holdings)	Cooljarloo, Western Australia (planned 1991)
BRAZIL	
12. Nuclebras de Monazita e Associados Ltda. (NUCLEMON)	Aracruz/Guarapari; Espirito Santo; Sao Joao da Barra, Rio de Janeiro; Usina de Santo Amaro, Sao Paulo
13. MINEGRAL	Aguas da Prata, Sao Paulo; Caldas and Pocos de Caldas, Minas Gerais
14. Rutilo e Ilmenita do Brasil Ltda.	Mataraca, Paraiba
15. Grupo Paranapanema	Presidente Figueiredo, Amazonas
CHINA	
16. State-owned	Yangjiang (Nanshanhai), Xitou, Dianbai, Zhanjiang, and Haikang, Guangdong Province
17. State-owned	Nangang, Guangdong Province

MINERALS PRODUCERS



LEGEND

Zirconium Minerals

Zircon	1-12, 14-27, 30-33
Baddeleyite	28 29
Caldasite	13

COMPANY	LOCATION
CHINA (cont'd)	
18. State-owned	Qinzhou and Beihai, Guangxi Province
19. State-owned	Sai-Lao, Wuzhaung, and Xinglong, Hainan Island
INDIA	
20. Indian Rare Earths Ltd.	Chavara, Alwaye, Kerala
21. Indian Rare Earths Ltd.	Manavalakuruchi, Tamil Nadu
22. Indian Rare Earths Ltd.	Chatrapur, Orissa
23. Kerala Minerals & Metals Ltd.	Chavara, Kerala
MALAYSIA	
24. Malaysian Mining Corp. Berhad	Various locations in Perak and Selangor States
25. Beh Minerals Sendirian Berhad	Lahat, Perak
26. Others	Various locations
SOUTH AFRICA	
27. Richards Bay Minerals	Richards Bay, Natal
28. Palabora Mining Co.	Palabora, Transvaal
29. Phosphate Development Corp. (Foskor)	Palabora, Transvaal
SRI LANKA	
30. Ceylon Mineral Sands Corp.	Pulmoddai
TAIWAN	
31. Pacific Ocean Rare Earth Industry	Yuanlin and Chiai Counties
THAILAND	
32. Various companies	Prachuap Khiri Khan, Chumphon, Phuket, and Takua Pa
U.S.S.R.	
33. State-owned	Verkhnedneprovskiy complex Dnepropetrovsk Oblast

TABLE 5—Continued

U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY[1]

Class and country	1988		1989	
	Metric tons	Value (thousands)	Metric tons	Value (thousands)
Unwrought zirconium and waste and scrap—Continued				
United Kingdom	20	100	43	1,011
Other	2	71	18	209
Total	165	[2]3,712	242	5,997

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, export categories for 1989 are not necessarily comparable to those of previous years.
[2] Data do not add to total because of independent rounding.

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF ZIRCONIUM AND HAFNIUM IN 1989, BY CLASS AND COUNTRY[1]

Class and country	Metric tons	Value (thousands)
Zirconium ore and concentrates:[2]		
Australia	51,445	$21,149
Belgium	18	13
Canada	111	24
Germany, Federal Republic of	51	43
Malaysia	250	263
South Africa, Republic of	20,832	11,840
United Kingdom	416	569
Other	73	59
Total[3]	73,196	33,958
Zirconium, unwrought and waste and scrap:		
Canada	10	12
France	10	53
Germany, Federal Republic of	35	352
Japan	57	446
United Kingdom	39	387
U.S.S.R.	91	740
Other	26	120
Total	268	2,110
Hafnium, unwrought and waste and scrap:		
France	4	806
Germany, Federal Republic of	(4)	151
Switzerland	(4)	19
Total	4	976

[1] Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 are not necessarily comparable to those of previous years.
[2] Excluding Australia, Malaysia, and the Republic of South Africa, countries are believed to be point of shipment rather than point of origin.
[3] Data may not add to totals shown because of independent rounding.
[4] Less than 1/2 unit.

Source: Bureau of the Census.

CURRENT RESEARCH

The increased use of zinc-coated and electrogalvanized steels by the automobile industry created a need for more durable electrodes such as resistance spot welding (RSW) electrodes on assembly line welding robots. When spot welding zinc-coated steel, the coating melts and brass tends to form on the copper-based electrode surface, thus affecting integrity and service life. Similar affects occur when spot welding galvanized steels because of the higher current and longer welding times required to weld these metals. Tests conducted on various compositions of RSW electrodes by an Outokumpu Copper subsidiary, the Nippert Company, and the Edison Welding Institute found that copper-zirconium electrodes showed "superior performance" in the conventional electrode life test.[29]

The National Aeronautics and Space Administration contracted Basic Industry Research Laboratory of Northwestern University, Evansville, IL, to evaluate wear characteristics on coating materials for eventual use on the main-engine bearings of the space shuttle. Among the many materials to be tested

TABLE 7

WORLD ANNUAL ZIRCONIUM MINERAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Thousand metric tons)

Country	Rated capacity[1]
Australia	550
Brazil[2]	22
China[e]	35
India	16
Malaysia	12
South Africa, Republic of[3]	190
Sri Lanka	6
Thailand	2
United States	130
U.S.S.R.[e]	30
Total (rounded)	1,000

[e] Estimated.
[1] Capacity for the zirconium minerals, zircon, baddeleyite, and caldasite.
[2] Includes 500 tons of capacity for caldasite.
[3] Includes 20,000 tons of capacity for baddeleyite.

TABLE 8

ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia	501,440	451,824	456,590	480,049	546,000
Brazil[2]	21,039	15,116	18,140	[r e]19,000	19,000
China[e]	15,000	15,000	15,000	15,000	15,000
India[e]	[3]14,800	16,000	[r]10,000	[r]15,000	16,000
Malaysia	11,652	12,633	17,828	25,671	19,700
South Africa, Republic of[e 4]	[3]160,533	140,000	140,000	150,000	160,000
Sri Lanka[e]	[3]4,061	4,000	4,000	4,000	4,000
Thailand	1,292	1,705	1,532	5,098	5,000
U.S.S.R.[e]	85,000	85,000	[r]90,000	[r]90,000	90,000
United States	W	W	W	117,606	[3]118,388
Total	814,817	741,278	753,081	921,424	993,088

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1]Includes data available through May 9, 1990.

[2]Includes production of zircon and caldasite.

[3]Reported figure.

[4]Includes production of zircon and baddeleyite.

are zirconium- and hafnium-nitride hard film coatings and nitride alloys of titanium and zirconium. The coatings were to be developed via a high-rate reactive sputtering process and deposited in vacuo within a reactor vessel.[30]

A new mill developed by Metprotech, based in the Republic of South Africa, for increasing the recovery of gold from refractory ores was reported to reduce the milling time required to mill zircon. The mill, which has a throughput range of 2 to 4.5 tons per hour, incorporates a horizontal central arm which stirs both feed material and grinding balls within a cylindrical drum.[31]

The Bureau of Mines sponsored research which identified a zirconium-nickel compound that may possibly substitute for the platinum-group metals catalysts currently used in automobile emission control systems.[32]

A new zirconia-alumina ceramic was developed by Diamonite Products of W. R. Grace & Co. The flexural strength was reported to be twice that of 87% alumina, accompanied by a five-fold increase in wear resistance. These qualities combined with its resistance to chemical attack made it an ideal candidate for industrial applications including mineral handling and processing. The ceramic was said to be capable of fabrication by many different processes.[33]

Sumitomo Metal Industries, Ltd. of Japan produced zirconium-manganese alloys for hydrogen storage. The high-frequency melted, coarse alloy powders absorb and desorb hydrogen between 200° C and 300° C and perform effectively after many cycles. The new alloy was reported to work faster and cost less than lanthanum-nickel alloys.[34]

A new zirconia-based thermal barrier coating was developed by Woking, United Kingdom-based Metco Ltd. which reportedly outperformed standard yttria-stabilized zirconia thermal coatings. Incorporating 24% to 26% cerium, 2% to 3% yttria, and the balance zirconia, the coating was claimed to have more resistance to cyclic thermal fatigue, less susceptibility to hot corrosion and erosion, lower thermal conductivity, and more predictable performance. Standard stabilized zirconia coatings (i.e., calcia-, magnesia-, and yttria-stabilized) have proven to be efficient thermal barriers in clean fuel environments; however, fuel contaminated with chlorine, sodium, sulphur, and/or vanadium adversely affect the performance of the coating. The company used its own plasma spray process to apply hollow, spherical particles to form the coating. This development was related to work initiated by U.S. parent company Perkin-Elmer Corp.[35]

OUTLOOK

Exploration and development of heavy mineral deposits in recent years was expected to lead to development of several new zircon mines by the early 1990's. The increase in production from planned, new, and expanded operations was expected to ease the supply shortages experienced in the late 1980's. An increase in world production of about 100,000 tons, or 10% of current world production, was expected by 1991. The near-term affect on zircon prices will likely be downward; however, it also was possible that increased availability of processed materials could create new demand pressures and prices could remain high.

New uses for zirconia grew dramatically in recent years. Substantial increases in consumption of this material in end products, ranging from scissor and knife blades to wear-resistant bearings and oxygen sensors, are expected in the next few years. Growth of wear-resistant ceramics and composites for the coming decade have been estimated at 18% to 23%.[36] Certain niches of the tungsten cutting tool market have already been penetrated by ceramics and ceramic-metal composites, some of which contain zirconia. Stabilized zir-

conia thermal barrier coatings are becoming the mainstay of commercial and military turbine engine components. The added costs of manufacture are negligible considering the added performance and extended service life.

A multimillion dollar expansion being implemented by one of the largest zirconium chemical producers foreshadowed growth in this area.

The supply side outlook for zircon is rather encouraging. The demand for other heavy minerals, such as ilmenite and rutile to make titanium dioxide (white pigment) and metal, is very strong and expected to remain so. Also, there is no slack in demand foreseen regarding the rare earths and hence the source mineral monazite. As these minerals are the marketable products of most heavy mineral mining operations, there appears to be adequate incentive for mining companies to fully exploit existing deposits and to continue with exploration and development efforts.

The world reserve base for zircon was conservatively estimated to be about 75 million metric tons. At the current rate of production this is ample supply for nearly 75 years.

BACKGROUND

Definition, Grades, and Specifications

Zirconium and hafnium are chemically similar elements with atomic numbers 40 and 72, respectively. Both elements are classified in the periodic table as members of Group 4b, and have only one oxidation state, +4, and have similar ionic radii. Owing to these similar properties, zirconium and hafnium are usually found together in nature.

Zircon purity is commonly measured by the combined zirconium dioxide (zirconia) and hafnium dioxide (hafnia) content. Hafnium occurs in zircon in a typical ratio of 1 part hafnium to 50 parts zirconium. Commercially available zircon typically grades 64.5% to 66% combined zirconia-hafnia. Zircon grades are similar on a worldwide basis, but no standard requirement exists. Standard grade zircon has a typical analysis of 65% minimum zirconium dioxide-hafnium dioxide, 0.25% maximum titanium dioxide, and 0.12% maximum iron oxide. Intermediate grade zircon has a typical analysis of 65.5% zirconium dioxide-hafnium dioxide, 0.03% maximum titanium dioxide, and 0.1% maximum iron oxide. Premium grade zircon has a typical analysis of 66% minimum zirconium dioxide-hafnium dioxide, 0.1% maximum titanium dioxide, and 0.05% maximum iron oxide.

Zirconium metal for the chemical process industry is available in three American Society for Testing and Materials (ASTM)-approved grades: R60702 for unalloyed zirconium, R60704 for the tin-iron alloy, and R60705 for the niobium alloy. Zirconium alloys for the nuclear industry, the compositions of which are specified, are designated as Zircaloy-2, Zircaloy-4, or Zr-2.5 Cb.

Hafnium metal as produced by the Kroll process is called hafnium sponge or "Kroll-process" sponge or metal. After refining by the iodide process, the metal is called crystal bar.

Industry Structure

Zirconium ore minerals are sold by mine producers directly to processors, consumers, and commodity brokers. Primary ore concentrate of zircon and baddeleyite may be used in certain industrial uses with little or no processing, but most applications require additional processing. Processors grind the concentrates to specification for certain applications or convert zircon and baddeleyite to refined products such as zirconium metal, hafnium metal, alloys, high-purity zirconia, and other compounds. Extensive processing is required to produce ultrapurity powders and nuclear-grade metals. Processors producing oxide and metal are often partially integrated, and market fabricated and semi-fabricated products directly to manufacturers. The worldwide distribution of the mining industry is illustrated in figure 1.

Geology-Resources

Zircon is a common accessory mineral in igneous rocks. It is frequently found associated with silicic rocks, including granite, granodiorite, syenite, monzonite, and nepheline syenite. Zircon is also found in pegmatites, crystalline limestone, and the metamorphic rocks gneiss and schist. One occurrence of zircon is reported from a meteorite. From an economic viewpoint, sedimentary placer deposits are the most significant.

Placer deposits begin forming when chemical and mechanical weathering liberates minerals from the source rock. This is followed by transport of the minerals to the sea by water, wind, and gravity. Upon reaching the sea, deposits of economic value form primarily by hydraulic sorting. Heavy minerals, including zircon, are concentrated by marine currents and wave action. Mechanical sorting by the sea and wind further sorts the grains to produce well-sorted beach deposits.

With distance from the source, zircon undergoes varying degrees of rounding, but because of its hardness typically retains an elongate shape with rounded edges and high relief. If sufficient source material exists, an economic heavy mineral deposit forms. Zircon and other heavy minerals are primarily recovered as sand ranging in size from very fine to coarse.

Technology

Economic concentrations of zircon are found in association with other heavy minerals such as ilmenite, rutile, and monazite. Heavy mineral sand deposits are usually mined by floating cutterhead- or bucketwheel-dredges that handle up to 2,800 metric tons of sand per hour. Sand recovered by these techniques is sent to a wet mill and treated by wet-gravity methods, using spirals, cones, sluices, or jigs, to produce a mixed heavy mineral concentrate containing zircon. The mixed concentrate typically contains other economic minerals such as the titanium minerals (ilmenite, rutile, and leucoxene) and oftentimes smaller amounts of the rare-earth mineral monazite. In southeast Asia, heavy mineral sand deposits containing zircon are mined primarily for the tin minerals cassiterite and stannite.

The mixed heavy mineral concentrate is scrubbed, dried, and screened, and the individual heavy minerals are separated by electrostatic, electromagnetic, magnetic, and gravity processes. Zircon, in contrast to ilmenite, rutile, and many other heavy minerals, is nonconductive and can be separated along with monazite, by electrostatic methods. Monazite, which is slightly magnetic and may be slightly higher in specific gravity, can be separated from zircon by electromagnets or by additional gravity methods.

To obtain premium grade zircon, the zircon concentrate from the electrostatic-

electromagnetic circuit is again subjected to gravity concentration to reduce the content of aluminum- and titanium-bearing minerals. Certain zircon products are leached in an acidic solution to remove iron oxide and other grain coatings.

Zircon used in foundry and certain refractory applications is graded, sized, and, in many cases, ground or milled to produce zircon flour. Foundry applications generally use zircon sand and flour mixtures, which may be treated with resin coatings and binders.

Zirconia is produced directly from zircon by either plasma fusion or electric arc techniques. The plasma method for zirconia production employs heating a finely divided zircon above its dissociation temperature to form small zirconia crystallites and glassy amorphous silica. The hot zirconia and silica particles are rapidly quenched, and the silica removed by leaching with sodium hydroxide, leaving insoluble zirconia crystallites.

In electric arc production, zircon is heated to temperatures of approximately 2,500° C producing dissociation. The silicon component is vaporized and recovered as fumed silica leaving a residual zirconia melt that is rapidly air quenched to form spherules. A more complex electric arc method melts a mixture of limestone and zircon to form calcium zirconate and tricalcium silicate clinker. Cooling of the mixture disintegrates the mixture into a very fine powder composed of tricalcium silicate and lime and a coarser fraction of calcium zirconate crystals. The calcium zirconate is separated from the other constituents by either air classification or flotation. The acid-soluble calcium zirconate crystals are treated with acids or other reagents forming zirconia or zirconium salts.

Other compounds of zirconium, such as the hydrous or carbonated oxide, acetate, sulfate, fluoride, chloride, and organic complexes are usually prepared from zirconia or its salts by chemical reactions.

The deBoer-van Arkel iodide process, first described in 1925, is essentially a refining process and was commercially adopted in 1945 as the first practical method for producing ductile zirconium metal. Zirconium metal is reacted with iodine vapor at 200° C to form zirconium tetraiodide, leaving most impurities except hafnium in a solid state. The gaseous halide diffuses to a heated filament where, at 1,300° C, the reaction is reversed, depositing very high-purity elemental zirconium on the filament and regenerating iodine vapor for reuse. The process yields high-purity metal but is expensive to operate.

Industrial scale plants for producing zirconium metal are based on the Kroll process in which zirconium tetrachloride is reduced with molten magnesium in an inert atmosphere. The resulting mixture of zirconium metal sponge and magnesium chloride is vacuum-distilled to remove the magnesium chloride. The zirconium is crushed, sized, and compacted to form a consumable electrode. The electrode is arc-melted in an inert atmosphere to give a first-melt ingot. The first-melt ingot is then used as a consumable electrode to produce a metallurgically homogeneous second-melt ingot, which is machined to give a clean surface and readied for fabrication.

Zirconium tetrachloride is produced by chlorinating zircon sand in a fluidized bed containing carbon at a temperature of about 1,150° C.

BYPRODUCTS AND COPRODUCTS

Zircon is mined from deposits with a heavy mineral grade between 2% and 20%. The associated economic heavy minerals are ilmenite, leucoxene, rutile, monazite, and the tin minerals cassiterite and stannite. Its classification as a byproduct or a coproduct depends on the fraction of zircon in relation to the other minerals. If zircon and the titanium minerals are expected to account for the majority of the revenue, it is considered a coproduct. If minerals other than zircon provide the carrying costs of the operation, then zircon is considered a byproduct. Small quantities of baddeleyite are recovered as a byproduct of copper, phosphate, and vermiculite mining in the Republic of South Africa.

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