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MINERALS YEARBOOK

U.S.
DEPARTMENT
OF THE
INTERIOR

BUREAU
OF
MINES

1993

UNITED STATES DEPARTMENT OF THE INTERIOR • Bruce Babbitt, Secretary

BUREAU OF MINES

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

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Foreword

This edition of the Minerals Yearbook discusses the performance of the worldwide minerals and materials industry during 1993 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 survey methods with a statistical summary of nonfuel minerals, and a chapter on trends in mining and quarrying in the metals and industrial mineral industries are also included.

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

Volume III, International Review, contains the latest available mineral data on more than 175 foreign countries and discusses the importance of minerals to the economies of these nations. The reports also incorporate location maps, industry structure tables, and an outlook section.

The annual international review is presented as five area reports and one world overview: Mineral Industries of Africa, Mineral Industries of Asia and the Pacific, Mineral Industries of Latin America and Canada, Mineral Industries of Europe and Central Eurasia, Mineral Industries of the Middle East, and Minerals in the World Economy. Due to budget constraints detailed mineral trade statistics by country will no longer be included in this publication. However, in the future abbreviated trade data for the major mineral trading countries will be made available by electronic or other means. For information on trade statistics call the Chief, Section of International Data at (202) 501-9700.

The U.S. Bureau of Mines continually strives to improve the value of its publications to users. Constructive comments and suggestions by readers of the Yearbook are welcomed.

Acknowledgments

Volume I, Metals and Minerals, of the Minerals Yearbook presents data on more than 60 minerals and materials commodities that were obtained as a result of the information gathering activities of the U.S. Bureau of Mines.

The collection, compilation, and analysis of domestic minerals industry data were performed by the staffs of the Division of Mineral Commodities and the Division of Statistics and Information Services. Statistical data were compiled from information supplied by mineral producers and consumers in response to canvasses, and their responses are gratefully appreciated. Information obtained from individual firms by means of the U.S. Bureau of Mines canvasses has been grouped to provide statistical aggregates. Data on individual firms are presented only if available from published or other nonproprietary sources or when permission of the respondent has been granted. The chapter "Survey Methods and Statistical Summary of Nonfuel Minerals" discusses in greater detail procedures for canvassing the minerals industry and the processing and evaluation of these data. Other information appearing in this volume was obtained from the trade and technical press, industry contacts, and additional sources; this cooperation is gratefully acknowledged.

Statistics on world production were compiled in the Division of Statistics and Information Services and Division of International Minerals from numerous sources, including reports from the U.S. Department of State. U.S. foreign trade data were obtained from reports of the U.S. Department of Commerce, Bureau of the Census. The U.S. Bureau of Mines also was assisted by numerous cooperating State agencies.

Ronald F. Balazik
Chief, Division of Mineral Commodities

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SURVEY METHODS AND STATISTICAL SUMMARY OF NONFUEL MINERALS

By Jacqueline A. McClaskey and Stephen D. Smith

Ms. McClaskey, an operations research analyst with 8 years of Government experience, has been with the U.S. Bureau of Mines Branch of Statistics and Methods Development since 1990.

Mr. Smith, industry data analyst in the Section of Industry Data Analysis and Coordination, was assisted in the preparation of the Statistical Summary by Imogene P. Bynum, Chief, Section of Metals Data; Maria Arguelles and Christopher Lindsay, co-chiefs, Section of Industrial Minerals Data; Ivette E. Torres, Chief, Section of International Data; and Raymond L. Cantrell, physical scientist, Branch of Industrial Minerals.

SURVEY METHODS

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

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

Data Collection Surveys

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

Specific questions about the production, consumption, shipments, etc., of mineral commodities are structured in the survey forms to provide meaningful aggregated data. Thus, the entire mineral economic cycle from production through consumption is covered by 149 monthly, quarterly, semiannual, and annual surveys.

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

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

Survey Processing

The USBM surveys approximately 25,000 establishments. Each year the USBM mails about 43,500 forms that gather information for 149 different surveys. Each completed survey form returned to the USBM undergoes extensive scrutiny to ensure the highest possible accuracy of the mineral data. The statistical staff monitors all surveys to ensure that errors are not created by reporting in physical units different from the units requested on the form. Relationships between related measures, such as produced crude ore and marketable crude ore, are analyzed for consistency. Engineering relationships, such as recovery factors from ores and concentrates, are also employed. The totals for each form are verified, and currently reported data are checked against prior reports to detect possible errors or omissions.

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

The USBM is modernizing and automating all of its survey processing and data dissemination functions. Automated commodity data system functions include computerized preparation of statistical tables; the use of desktop publishing to integrate text and tables; and the implementation of a microcomputer bulletin board, known as MINES-DATA, for electronic dissemination of minerals data. Also, information on minerals and mineral-related publications is now available through an easy-to-use automated facsimile (fax) response system known as MINES FaxBack.

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

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

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

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

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

International Data

International data are collected by country specialists in the USBM Division of International Minerals with assistance from the Section of International Data. The data are gathered from various sources, including published reports of foreign Government mineral and statistical agencies, international organizations, the U.S. Department of State, the United Nations, the Organization of Petroleum Exporting Countries, and personal contact by specialists traveling abroad. Each February an annual "Minerals Questionnaire" is sent through the Department of State to more than 70 U.S. Embassies asking them to provide estimates of mineral production for the host country for the preceding year. Missing data are estimated by USBM country specialists based on historical trends and specialists' knowledge of current production capabilities in each country.

Publications

The USBM disseminates current and historical minerals information through a broad range of printed publications.

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

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

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

Volume III of the Minerals Yearbook contains the latest available mineral data for the year of review on more than 180 foreign countries and discusses the importance of minerals to the economies of these nations. Volume III is presented as five area reports and one world overview: Mineral Industries of Africa, Mineral Industries of Asia and the Pacific, Mineral Industries of Latin America and Canada, Mineral Industries of Europe and Central Eurasia, Mineral Industries of the Middle East, and Minerals in the World Economy.

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

Mineral Commodity Summaries, an up-to-date summary of about 80 nonfuel mineral commodities, is the earliest Government publication to furnish estimates covering the previous year's nonfuel mineral industry data. It contains information on the domestic industry structure, Government programs, tariffs, 5-year salient statistics, and a summary of international mining news.

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

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

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

Order free copies of the Mineral Industry Surveys or the Metal Industry Indicators from Publication Distribution, U.S. Bureau of Mines, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236, (412) 892-4338.

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

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

Electronic Data Dissemination

In addition to the USBM's printed publications, current Mineral Industry Surveys for all commodities and 85 annual reports from the Minerals Yearbook are now available through the USBM's MINES-DATA computer bulletin board. Using this system, the public may obtain information up to 4 weeks before published copies of the reports would arrive in the mail. The MINES-DATA system may be accessed by calling (202) 501-0373 using a modem set to 1200 or 2400 baud, 8 data bits, no parity, and 1 stop bit. Further information on how to use the MINES-DATA system may be obtained from the system operator by calling (202) 501-0406.

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

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

To access the MINES FaxBack System, use a touch-tone handset attached to a fax machine or connect a touch-tone telephone to the fax machine's telephone jack and dial (202) 219-3644. Listen to the menu options and select an option using the touch-tone telephone. After completing a selection, press the start button on the fax machine.

STATISTICAL SUMMARY

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

Although crude mineral production may be measured at any of several stages of extraction and processing, the stage of measurement used in this annual report is what is termed "mine output." It usually refers to minerals or ores in the form in which they are first extracted from the ground, but customarily includes the output from auxiliary processing at or near the mines.

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

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

TABLE 1

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS							
Beryllium concentrates	metric tons	4,339	$5	4,826	$5	4,939	$5
Copper[2]	do.	1,631,078	3,931,305	[r]1,764,756	[r]4,178,942	1,801,382	3,636,188
Gold[2]	kilograms	295,957	3,456,786	[r]330,212	[r]3,662,390	331,013	3,840,876
Iron ore (usable)	thousand metric tons	56,775	1,674,100	55,569	1,732,416	56,251	1,642,842
Iron oxide pigments (crude)	metric tons	40,220	4,485	39,272	4,669	35,842	5,021
Lead[2]	do.	465,931	343,948	[r]397,076	[r]307,337	355,185	248,540
Magnesium metal	do.	131,288	336,577	136,947	359,534	132,144	377,287
Mercury	do.	58	206	64	376	W	W
Molybdenum[3]	do.	53,607	249,909	49,554	208,657	39,208	165,096
Nickel ore[4]	do.	5,523	NA	6,671	W	2,464	W
Palladium	kilograms	6,050	16,923	6,470	18,097	6,500	25,287
Platinum	do.	1,730	20,635	1,840	21,060	1,800	21,412
Silver[2]	metric tons	1,855	240,908	1,804	228,563	1,645	227,378
Zinc[2]	do.	517,804	602,426	523,430	673,686	488,283	496,795
Combined value of antimony, bauxite, manganiferous ore (5% to 35%), rare-earth metal concentrates, tin, titanium concentrates (ilmenite and rutile), tungsten, vanadium, zircon concentrates, and values indicated by symbol W		XX	143,298	XX	151,091	XX	130,199
Total[5]		XX	11,022,000	XX	[r]11,547,000	XX	10,817,000
INDUSTRIAL MINERALS (EXCLUDING FUELS)							
Abrasives[6]	metric tons	2,205	161	1,732	239	528	330
Asbestos	do.	W	W	15,573	6,138	13,404	5,957
Barite	thousand metric tons	448	21,310	326	19,633	315	19,265
Boron minerals (B_2O_3)	metric tons	1,240,158	442,531	1,008,889	338,700	1,054,615	372,839
Bromine[e]	do.	170,000	167,000	171,000	170,000	177,000	123,000
Cement:							
Masonry	thousand metric tons	[e]2,392	[e]187,679	2,658	195,000	2,962	228,893
Portland	do.	[e]62,344	[e]3,343,223	66,058	3,500,150	71,570	3,915,736
Clays	do.	44,092	1,505,088	40,712	1,481,893	41,074	1,487,474
Diatomite	metric tons	609,652	139,857	595,122	[r]141,097	598,931	150,133
Feldspar	do.	580,000	26,000	[7]726,000	[7]28,500	[7]770,000	[7]31,400
Garnet (abrasive)	do.	50,860	7,534	54,139	4,842	W	W
Gemstones		NA	84,386	NA	66,195	NA	57,681
Gypsum (crude)	thousand metric tons	14,021	94,199	14,759	100,583	15,812	106,539

See footnotes at end of table.

TABLE 1—Continued

NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS (EXCLUDING FUELS)—Continued							
Helium:							
Crude	million cubic meters	W	W	W	W	29	$25,763
Grade-A	do.	88	$174,706	94	$187,179	96	189,492
Iodine	metric tons	1,999	31,389	1,995	20,877	1,935	15,443
Lime	thousand metric tons	15,667	890,482	[r]16,199	[r]949,674	16,932	977,079
Mica (scrap)	do.	103	5,542	85	4,638	88	4,453
Peat	do.	705	17,887	652	16,747	612	16,841
Perlite	metric tons	514,047	15,086	541,164	16,368	568,581	17,425
Phosphate rock	thousand metric tons	48,096	1,030,913	46,965	1,058,393	35,494	758,983
Potash (K_2O equivalent)	do.	1,709	304,500	1,767	334,407	1,636	286,002
Pumice	metric tons	401,376	9,190	480,855	14,903	469,030	12,045
Salt	thousand metric tons	35,902	801,507	34,784	802,563	38,665	892,979
Sand and gravel:							
Construction	do.	[e]828,713	[e]$3,267,500	833,975	$3,341,300	[e]868,700	[e]$3,530,100
Industrial	do.	23,224	390,477	[r]25,195	[r]434,474	26,220	454,431
Sodium compounds:							
Soda ash	do.	9,005	835,577	9,379	836,431	8,959	734,157
Sodium sulfate (natural)	do.	354	30,903	337	26,262	W	W
Stone:[8]							
Crushed	do.	1,000,514	5,186,821	[e]1,053,695	[e]5,593,700	1,116,000	5,915,500
Dimension	metric tons	1,152,343	209,611	[e]980,604	[e]180,942	1,231,864	215,574
Sulfur (Frasch)	thousand metric tons	3,119	271,598	2,600	158,727	1,904	100,664
Tripoli	metric tons	88,642	3,271	84,924	3,256	93,988	4,093
Vermiculite	do.	167,923	13,410	190,052	15,062	187,121	14,869
Zeolites	do.	NA	NA	W	NA	41,002	NA
Combined value of aplite,[7] brucite, calcium chloride [natural[9] (1991-92)], emery, fluorspar, greensand marl, kyanite, lithium minerals, magnesite, magnesium compounds, olivine, pyrites, staurolite, wollastonite, and values indicated by symbol W		XX	[r]571,075	XX	[r]524,763	XX	429,702
Total[5]		XX	[r]20,080,000	XX	[r]20,574,000	XX	21,095,000
Grand total[5]		XX	[r]31,102,000	XX	[r]32,121,000	XX	31,912,000

[e]Estimated. [r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; value included with "Combined value" data. XX Not applicable.

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

[2] Recoverable content of ores, etc.

[3] Content of ore and concentrate.

[4] The Riddle nickel smelter uses lateritic ore mined on Nickel Mountain, lateritic ore imported from New Caledonia, and small tonnages of recycled Ni-bearing catalysts. In 1989, the Glenbrook Nickel Co. purchased the idled mining and smelting complex and restarted the operation. Production of ferronickel on a contained Ni basis has been as follows: 1991—7,065 metric tons (mt) valued at $57.6 million; 1992—8,962 mt valued at $62.7 million; and 1993—4,878 mt valued at $28.0 million.

[5] Rounded.

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

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

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

[9] Canvassing discontinued beginning 1993.

TABLE 2
TOTAL U.S. NONRENEWABLE ORGANIC MATERIALS PRODUCTION, BY QUANTITY AND VALUE[1]

(Million metric tons, unless otherwise specified)

Category	1991		1992[r]		1993[p]	
	Quantity	Value (millions)	Quantity	Value (millions)	Quantity	Value (millions)
Asphalt and road oil	25.85	$2,979	25.28	$2,798	27.18	$2,693
Lubricants, waxes, and miscellaneous products	[r]13.42	[r]1,748	12.43	1,534	12.67	1,373
Petrochemical industries	[r]64.03	[r]7,470	66.61	7,540	66.00	6,824
Petroleum coke and coal	[r]8.77	[r]754	12.71	1,113	12.89	986
Total	[r]112.07	[r]12,951	117.03	12,986	118.74	11,877

[p] Preliminary. [r] Revised.

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

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

TABLE 3
NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1993

Mineral	Principal producing States, in order of quantity	Other producing States
Abrasives[1]	AR, WI, OH	
Antimony[2]	ID	
Asbestos	CA and VT	
Barite	GA, NV, MO, MT	IL.
Bauxite	AL and GA	
Beryllium concentrate	UT	
Boron minerals	CA	
Bromine[e]	AR	
Brucite	NV	
Calcium chloride (natural)	(3)	
Cement:		
Masonry	FL, IN, AL, PA	All other States except AK, CT, DE, IL, LA, MA, MN, MS, MT, NV, NH, NJ, NC, ND, OR, RI, VT, WI, WY.
Portland	CA, TX, MI, PA	All other States except AK, CT, DE, LA, MA, MN, NM, NJ, NC, ND, RI, VT, WI.
Clays	GA, AL, WY, NC	All other States except AK, DE, HI, RI, VT, WI.
Copper[2]	AZ, UT, NM, MI	CO, ID, IL, MO, MT, NV, OR, TN, and WI.
Diatomite	CA, NV, WA, OR	
Emery	NY and OR	
Feldspar	NC, VA, CA, OK	GA, ID, SD.
Fluorspar	IL, TX, NV	
Garnet (abrasive)	NY and ID	
Gemstones (natural)[4]	TN, ME, AZ, AR	All other States.
Gold[2]	NV, CA, UT, SD	AK, AZ, CO, ID, MT, NM, SC, WA, WI.
Greensand marl	NJ	

See footnotes at end of table.

TABLE 3—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1993

Mineral	Principal producing States, in order of quantity	Other producing States
Gypsum (crude)	OK, MI, IA, TX	AR, AZ, CA, CO, IN, KS, LA, NM, NV, NY, OH, SD, UT, VA, WY.
Helium (crude and Grade-A)	KS, WY, TX, CO	
Iodine	OK	
Iron ore (usable)[6]	MN, MI, MO, UT	CA, MI, MO, MT, NM, SD, TX.
Iron oxide pigments (crude)	MO, GA, VA, MI	AZ.
Kyanite	VA	
Lead[2]	MO, AK, ID, MT	CO, IL, NY, TN, WA.
Lime	TX, OH, MO, PA	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, DE, UT	FL and TX.
Magnesium metal	TX, UT, WA	
Manganiferous ore	SC	
Mercury	NV, UT, CA	
Mica (scrap)	NC, NM, GA, SC	SD.
Molybdenum	AZ, CO, UT, MT	NM.
Nickel ore	OR	
Olivine	WA and NC	
Palladium metal	MT	
Peat	MI, FL, MN, IL	CO, IA, IN, MA, ME, MT, NC, ND, NJ, NY, OH, PA, SC, WA, WI, WV.
Perlite	NM, AZ, CA, NV	CO.
Phosphate rock	FL, NC, ID, UT	MT.
Platinum metal	MT	
Potash	NM, UT, CA, MI	
Pumice	CA, OR, AZ, NM	ID and KS.
Pyrites (ore and concentrate)	AZ	
Rare-earth metal concentrates	CA and FL	
Salt	NY, OH, LA, MI	AL, AZ, CA, KS, NM, NV, OK, TX, UT, WV.
Sand and gravel:		
Construction	CA, OH, TX, NY	All other States.
Industrial	IL, CA, WI, NJ	All other States except AK, DE, HI, KY, ME, NH, NM, OR, SD, UT, VT, WY.
Silver[2]	NV, AZ, ID, UT	AK, CA, CO, IL, MI, MO, MT, NM, NY, SC, SD, TN, WA, WI.
Sodium compounds:		
Soda ash	WY and CA	
Sodium sulfate (natural)	CA, TX, UT	
Staurolite	FL	
Stone:		
Crushed	PA, IL, FL, NC	All other States except DE.
Dimension	VT, IN, MA, GA	All other States except AK, DE, FL, HI, KY, LA, MS, NE, NV, NJ, ND, OR, RI, WV, WY.

See footnotes at end of table.

TABLE 3—Continued

NONFUEL MINERALS PRODUCED IN THE UNITED STATES AND PRINCIPAL PRODUCING STATES IN 1993

Mineral	Principal producing States, in order of quantity	Other producing States
Sulfur (Frasch)	TX and LA	
Talc and pyrophyllite	MT, NY, TX, VT	AR, CA, NC, OR, VA.
Tin	AK	
Titanium concentrates	FL and CA	
Tripoli	IL, WI, AR, OK	PA.
Tungsten[2]	CA	
Vanadium[2]	ID	
Vermiculite (crude)	SC and VA	
Wollastonite	NY	
Zeolites	TX, NM, OR, AZ	ID.
Zinc[2]	AK, TN, NY, MO	CO, ID, IL, MT, WA.
Zircon concentrates	FL	

[e] Estimated.

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

[2] Content of ores, etc.

[3] Canvassing discontinued.

[4] Principal producing States based on value.

[5] No production reported.

[6] Includes byproduct material.

TABLE 4

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1993

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Alabama	$561,776	18	1.76	Cement (portland), stone (crushed and broken), lime, sand and gravel (construction).
Alaska	377,616	29	1.18	Zinc, sand and gravel (construction), gold, lead.
Arizona	2,775,840	2	8.70	Copper, sand and gravel (construction), cement (portland), molybdenum.
Arkansas	347,081	30	1.09	Bromine, stone (crushed and broken), sand and gravel (construction), cement (portland).
California	2,440,234	3	7.65	Sand and gravel (construction), gold, boron.
Colorado	399,485	25	1.25	Sand and gravel (construction), cement (portland), stone (crushed and broken), gold.
Connecticut	90,676	44	.28	Stone (crushed and broken), sand and gravel (construction), sand and gravel (industrial), clays.
Delaware[1]	10,301	50	.03	Sand and gravel (construction), magnesium compounds, gemstones.
Florida	1,310,623	8	4.11	Phosphate rock, stone (crushed and broken), cement (portland), sand and gravel (construction).
Georgia	1,431,718	6	4.49	Clays, stone (crushed and broken), cement (portland), barite.
Hawaii	138,704	41	.43	Stone (crushed and broken), cement (portland), sand and gravel (construction), cement (masonry).
Idaho	274,210	35	.86	Phosphate rock, sand and gravel (construction), gold, silver.

See footnotes at end of table.

TABLE 4—Continued

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1993

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Illinois	$734,305	16	2.30	Stone (crushed and broken), sand and gravel (construction), cement (portland), sand and gravel (industrial).
Indiana	472,994	22	1.48	Stone (crushed and broken), cement (portland), sand and gravel (construction), lime.
Iowa	397,526	26	1.25	Stone (crushed and broken), cement (portland), sand and gravel (construction), gypsum.
Kansas	442,112	24	1.39	Helium (Grade-A), salt, stone (crushed and broken), cement (portland).
Kentucky	387,503	28	1.21	Stone (crushed and broken), lime, cement (portland), sand and gravel (construction).
Louisiana	231,609	37	.73	Salt, sand and gravel (construction), sulfur (Frasch), sand and gravel (industrial).
Maine	60,128	45	.19	Sand and gravel (construction), cement (portland), stone (crushed and broken), gemstones.
Maryland	313,519	32	.98	Stone (crushed and broken), cement (portland), sand and gravel (construction), cement (masonry).
Massachusetts	160,212	39	.50	Stone (crushed and broken), sand and gravel (construction), stone (dimension), lime.
Michigan	1,504,245	4	4.71	Iron ore (usable), cement (portland), sand and gravel (construction), magnesium compounds.
Minnesota	1,298,724	9	4.07	Iron ore (usable), sand and gravel (construction), stone (crushed and broken), sand and gravel (industrial).
Mississippi[1]	103,651	43	.32	Sand and gravel (construction), clays, cement (portland), stone (crushed and broken).
Missouri	855,424	12	2.68	Stone (crushed and broken), cement (portland), lead, lime.
Montana	484,030	21	1.52	Gold, copper, cement (portland), sand and gravel (construction).
Nebraska	126,176	42	.40	Cement (portland), sand and gravel (construction), stone (crushed and broken), lime.
Nevada	2,828,551	1	8.86	Gold, sand and gravel (construction), silver, diatomite.
New Hampshire	37,193	47	.12	Sand and gravel (construction), stone (dimension), stone (crushed and broken), clays.
New Jersey	262,347	36	.82	Stone (crushed and broken), sand and gravel (construction), sand and gravel (industrial), clays.
New Mexico	804,049	15	2.52	Copper, potash, sand and gravel (construction), cement (portland).
New York	851,507	13	2.67	Stone (crushed and broken), salt, sand and gravel (construction), cement (portland).
North Carolina	617,390	17	1.93	Stone (crushed and broken), phosphate rock, lithium minerals, sand and gravel (construction).
North Dakota	25,043	48	.08	Sand and gravel (construction), lime, sand and gravel (industrial), clays.
Ohio	850,634	14	2.67	Stone (crushed and broken), sand and gravel (construction), salt, lime.
Oklahoma	298,339	34	.93	Stone (crushed and broken), cement (portland), sand and gravel (construction), sand and gravel (industrial).
Oregon	226,108	38	.71	Stone (crushed and broken), sand and gravel (construction), cement (portland), diatomite.

See footnotes at end of table.

TABLE 4—Continued

VALUE OF NONFUEL MINERAL PRODUCTION IN THE UNITED STATES AND PRINCIPAL NONFUEL MINERALS PRODUCED IN 1993

State	Value (thousands)	Rank	Percent of U.S. total	Principal minerals, in order of value
Pennsylvania	$913,162	10	2.86	Stone (crushed and broken), cement (portland), lime, sand and gravel (construction).
Rhode Island[1]	23,152	49	.07	Sand and gravel (construction), stone (crushed and broken), sand and gravel (industrial), gemstones.
South Carolina	391,047	27	1.23	Stone (crushed and broken), cement (portland), gold, clays.
South Dakota	337,156	31	1.06	Gold, cement (portland), sand and gravel (construction), stone (crushed and broken).
Tennessee	509,665	19	1.60	Stone (crushed and broken), zinc, cement (portland), sand and gravel (construction).
Texas	1,448,113	5	4.54	Cement (portland), stone (crushed and broken), sand and gravel (construction), magnesium metal.
Utah	1,313,537	7	4.12	Copper, gold, magnesium metal, cement (portland).
Vermont[1]	52,706	46	.17	Stone (dimension), stone (crushed and broken), sand and gravel (construction), talc and pyrophyllite.
Virginia	464,747	23	1.46	Stone (crushed and broken), cement (portland), sand and gravel (construction), lime.
Washington	505,193	20	1.58	Sand and gravel (construction), magnesium metal, gold, stone (crushed and broken).
West Virginia	149,452	40	.47	Stone (crushed and broken), cement (portland), sand and gravel (construction), salt.
Wisconsin	313,312	33	.98	Stone (crushed and broken), sand and gravel (construction), copper, sand and gravel (industrial).
Wyoming	856,485	11	2.68	Soda ash, clays, helium (Grade-A), cement (portland).
Undistributed	102,530	—	.32	
Total[2]	31,912,000	XX	100.00	

XX Not applicable.

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

[2] Rounded.

TABLE 5

VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1993, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Alabama	51,705	4,136	$561,776	10,865	25	136	17
Alaska	591,004	587	377,616	639	49	643	5
Arizona	114,000	3,832	2,775,840	24,349	5	724	4
Arkansas	53,187	2,399	347,081	6,526	31	145	15
California	158,706	30,867	2,440,234	15,376	17	79	31
Colorado	104,091	3,470	399,485	3,838	42	115	19
Connecticut	5,018	3,281	90,676	18,070	13	28	47
Delaware	2,044	689	[1]10,301	5,040	37	15	50
Florida	58,664	13,488	1,310,632	22,341	7	97	24
Georgia	58,910	6,751	1,431,718	24,303	6	212	11
Hawaii	6,471	1,160	138,704	21,435	8	120	18
Idaho	83,564	1,067	274,210	3,281	44	257	10

See footnotes at end of table.

TABLE 5—Continued

VALUE OF NONFUEL MINERAL PRODUCTION PER CAPITA AND PER SQUARE MILE IN 1993, BY STATE

State	Area (square miles)	Population (thousands)	Total value (thousands)	Per square mile		Per capita	
				Dollars	Rank	Dollars	Rank
Illinois	56,345	11,631	$734,305	13,032	19	63	38
Indiana	36,185	5,662	472,994	13,072	18	84	28
Iowa	56,275	2,812	397,526	7,064	29	141	16
Kansas	82,277	2,523	442,112	5,373	36	175	12
Kentucky	40,409	3,755	387,503	9,590	26	103	21
Louisiana	47,751	4,267	231,609	4,850	38	54	40
Maine	33,265	1,235	60,128	1,808	47	49	41
Maryland	10,460	4,908	313,519	29,973	2	64	37
Massachusetts	8,284	5,998	160,212	19,340	11	27	48
Michigan	58,527	9,437	1,504,245	25,702	3	159	14
Minnesota	84,402	4,480	1,298,724	15,387	16	290	9
Mississippi	47,689	2,614	[1]103,651	2,173	45	40	42
Missouri	69,697	5,193	855,424	12,273	21	165	13
Montana	147,046	824	484,030	3,292	43	587	6
Nebraska	77,355	1,606	126,176	1,631	48	79	32
Nevada	110,561	1,327	2,828,551	25,584	4	2,132	1
New Hampshire	9,279	1,111	37,193	4,008	41	33	46
New Jersey	7,787	7,789	262,347	33,690	1	34	45
New Mexico	121,593	1,581	804,049	6,613	30	509	7
New York	49,107	18,119	851,507	17,340	14	47	43
North Carolina	52,669	6,843	617,390	11,722	23	90	27
North Dakota	70,703	636	25,043	354	50	39	44
Ohio	41,330	11,016	850,634	20,582	9	77	33
Oklahoma	69,956	3,212	298,339	4,265	40	93	25
Oregon	97,073	2,977	226,108	2,329	46	76	35
Pennsylvania	45,308	12,009	913,162	20,155	10	76	34
Rhode Island	1,212	1,005	[1]23,152	19,102	12	23	49
South Carolina	31,113	3,603	391,047	12,569	20	109	20
South Dakota	77,116	711	337,156	4,372	39	474	8
Tennessee	42,144	5,024	509,665	12,093	22	101	22
Texas	266,807	17,656	1,448,113	5,428	35	82	30
Utah	84,899	1,813	1,313,537	15,472	15	725	3
Vermont	9,614	570	[1]52,706	5,482	34	92	26
Virginia	40,767	6,377	464,747	11,400	24	73	36
Washington	68,138	5,136	505,193	7,414	28	98	23
West Virginia	24,231	1,812	149,452	6,168	32	82	29
Wisconsin	56,153	5,007	313,312	5,580	33	63	39
Wyoming	97,809	466	856,485	8,757	27	1,838	2
Undistributed	XX	XX	102,530	XX	XX	XX	XX
Total[2] or average	3,618,700	254,472	[3]31,912,000	8,819	XX	125	XX

XX Not applicable.

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

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

[3] Rounded.

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

TABLE 6
NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
ALABAMA							
Cement:							
Masonry	thousand metric tons	^{e}216	^{e}\$14,042	193	\$11,105	277	\$21,908
Portland	do.	^{e}3,572	^{e}181,102	3,721	180,763	3,748	190,770
Clays[2]	do.	2,124	22,103	2,381	20,914	2,492	23,195
Lime	do.	1,370	75,506	1,454	82,619	1,625	89,457
Sand and gravel:							
Construction	do.	^{e}11,521	^{e}45,700	11,153	42,038	^{e}10,300	^{e}39,100
Industrial	do.	482	6,133	605	6,768	559	6,802
Stone:							
Crushed[3]	do.	^{r}27,057	^{r}173,864	^{e}25,945	^{e}175,600	28,863	175,607
Dimension	metric tons	8,665	2,449	W	W	W	W
Combined value of bauxite, clays [bentonite, kaolin (1991-92)], gemstones, salt, stone [crushed dolomite and granite (1991-92)], talc and pyrophyllite (1991), and values indicated by symbol W		XX	31,037	XX	22,907	XX	14,937
Total		XX	^{r}551,936	XX	542,714	XX	561,776
ALASKA							
Gemstones		NA	5	NA	10	NA	10
Gold[4]	kilograms	3,200	37,376	5,003	55,492	2,777	32,223
Sand and gravel (construction)	thousand metric tons	^{e}12,701	^{e}39,200	13,613	43,335	^{e}13,100	^{e}42,600
Stone (crushed)[3]	do.	^{r}1,011	^{r}4,788	^{e}2,722	^{e}13,400	2,425	11,294
Combined value of cement [portland (1991-92)], lead, silver, stone [crushed sandstone (1992-93)], tin, and zinc		XX	412,840	XX	413,875	XX	291,489
Total		XX	^{r}494,209	XX	526,112	XX	377,616
ARIZONA							
Clays	thousand metric tons	228	3,830	^{2}102	^{2}463	^{2}97	^{2}451
Copper[4]	metric tons	1,024,066	2,468,255	^{r}1,152,878	^{r}2,730,015	1,158,759	2,339,018
Gemstones		NA	3,173	NA	5,416	NA	5,626
Gold[4]	kilograms	6,195	72,362	6,656	73,818	2,711	31,459
Iron oxide pigments (crude)	metric tons	18	22	77	62	77	62
Sand and gravel (construction)	thousand metric tons	^{e}20,412	^{e}79,400	30,701	123,517	^{e}35,000	^{e}138,300
Silver[4]	metric tons	148	19,212	165	20,873	200	27,684
Stone (crushed)	thousand metric tons	6,405	32,842	^{e}4,990	^{e}26,300	6,430	36,823
Combined value of cement, clays [bentonite (1992-93)], gypsum, iron ore [usable (1991)], lead (1991-92), lime, molybdenum, perlite, pumice, pyrites, salt, sand and gravel (industrial), stone (dimension), and tin (1992)		XX	198,230	XX	184,337	XX	196,417
Total		XX	2,877,326	XX	^{r}3,164,801	XX	2,775,840
ARKANSAS							
Abrasives[5]	metric tons	W	154	W	W	W	W
Bromine^{e}	thousand kilograms	170,000	167,000	171,000	170,000	177,000	123,000
Clays[2]	thousand metric tons	857	8,048	837	2,972	1,026	2,357
Gemstones		NA	1,846	NA	1,493	NA	5,532
Sand and gravel:							
Construction	thousand metric tons	^{e}7,530	^{e}31,100	9,896	39,627	^{e}10,100	^{e}40,900
Industrial	do.	677	7,738	^{r}806	10,458	642	7,597

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
ARKANSAS—Continued							
Stone (crushed)[5]	thousand metric tons	[r]20,084	[r]$101,428	[e]22,861	[e]$118,900	21,706	$102,555
Combined value of cement, clays [fire, kaolin (1992-93)], gypsum, lime, stone [crushed dolomite and quartzite (1993), crushed dolomite and traprock (1991-92), dimension], talc and pyrophyllite (1993), tripoli, and values indicated by symbol W		XX	[r]43,676	XX	60,372	XX	65,140
Total		XX	[r]360,990	XX	403,822	XX	347,081
CALIFORNIA							
Asbestos	metric tons	W	W	10,998	4,452	10,043	4,426
Boron minerals	do.	1,240,158	442,531	1,008,889	338,700	1,054,615	372,839
Cement (portland)	thousand metric tons	[e]7,894	[e]522,120	7,289	428,016	8,511	468,349
Clays[2]	do.	2,075	27,464	1,906	26,173	1,961	26,482
Gemstones		NA	10,450	NA	9,916	NA	673
Gold[4]	kilograms	30,404	355,125	33,335	369,723	35,763	414,977
Lime	thousand metric tons	279	20,389	254	18,072	193	14,751
Mercury	metric tons	(6)	1	(6)	(6)	W	W
Pumice	do.	61,237	4,372	W	W	W	W
Rare-earth metal concentrates	do.	16,465	W	20,699	W	17,754	W
Sand and gravel:							
Construction	thousand metric tons	[e]92,442	[e]489,100	102,410	522,108	[e]96,300	[e]475,700
Industrial	do.	1,909	41,690	[r]1,915	[r]42,512	1,797	41,668
Silver[4]	metric tons	W	W	18	2,259	14	2,002
Stone:							
Crushed	thousand metric tons	[r]41,546	[r]216,052	[e]37,013	[e]198,300	38,167	294,740
Dimension	metric tons	40,603	5,254	[e]21,130	[e]4,148	29,082	6,299
Combined value of calcium chloride[7] (1991-92), cement (masonry), clays (fuller's earth), copper (1991), diatomite, feldspar, gypsum, iron ore (usable), magnesium compounds, mica (1991), molybdenum (1991-92), perlite, potash, salt, silver (1991), soda ash, sodium sulfate, talc and pyrophyllite, titanium (ilmenite), tungsten, and values indicated by symbol W		XX	403,592	XX	[r]402,975	XX	362,328
Total		XX	[r]2,538,140	XX	[r]2,367,354	XX	2,440,234
COLORADO							
Clays	thousand metric tons	[2]264	[2]1,964	[2]242	[2]1,796	281	2,158
Gemstones		NA	287	NA	225	NA	258
Gold[4]	kilograms	3,181	37,154	3,763	41,741	W	W
Peat	thousand metric tons	W	396	W	333	W	W
Sand and gravel (construction)	do.	[e]23,950	[e]88,200	26,721	105,281	[e]29,000	[e]117,500
Silver[4]	metric tons	20	2,565	W	W	W	W
Stone:							
Crushed	thousand metric tons	7,621	41,022	[e]10,886	[e]60,400	10,338	61,950
Dimension	metric tons	W	W	[e]5,855	[e]252	4,315	1,374
Combined value of cement, clays [bentonite (1991), fire (1992)], copper, gypsum, helium, lead, lime, molybdenum, perlite, sand and gravel (industrial), stone [dimension (1991)], zinc, and values indicated by symbol W		XX	166,817	XX	[r]174,761	XX	216,245
Total		XX	338,405	XX	[r]384,789	XX	399,485

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
CONNECTICUT							
Gemstones		NA	$62	NA	$5	NA	$5
Sand and gravel (construction)	thousand metric tons	•4,899	•24,800	5,466	30,107	•6,400	•34,900
Stone:							
Crushed[3]	do.	5,328	52,701	•5,352	•54,500	4,599	39,525
Dimension	metric tons	15,009	1,739	W	W	W	W
Combined value of clays (common), feldspar (1991), mica [scrap (1991)], [1990-91]), sand and gravel (industrial), stone (crushed dolomite and other), and values indicated by symbol W		XX	[r]11,531	XX	13,451	XX	16,246
Total		XX	[r]90,833	XX	98,063	XX	90,676
DELAWARE							
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand metric tons	•1,451	•5,100	2,257	8,574	•2,500	•10,300
Total[8]		XX	5,101	XX	8,575	XX	10,301
FLORIDA							
Cement:							
Masonry	thousand metric tons	•194	•13,482	310	22,424	351	27,264
Portland	do.	•2,742	•142,081	2,898	161,969	4,195	210,762
Clays[2]	do.	363	39,150	367	37,201	407	52,699
Gemstones		NA	6	NA	1	NA	W
Peat	thousand metric tons	221	3,991	191	3,158	219	3,781
Sand and gravel:							
Construction	do.	•14,515	•51,400	21,107	66,141	•22,800	•73,100
Industrial	do.	500	5,989	433	5,167	504	5,911
Stone (crushed)[3]	do.	[r]55,005	[r]264,847	•53,796	•266,900	64,926	313,270
Combined value of clays (common), magnesium compounds, phosphate rock, rare-earth metal concentrates, staurolite, stone [crushed dolomite and limestone (1993), crushed marl (1991-92)], titanium concentrates (ilmenite and rutile), zircon concentrates, and value indicated by symbol W		XX	879,164	XX	876,799	XX	623,845
Total		XX	[r]1,400,110	XX	1,439,760	XX	1,310,632
GEORGIA							
Clays	thousand metric tons	9,518	949,737	[2]8,962	[2]970,905	[2]9,759	[2]995,013
Gem stones		NA	10	NA	645	NA	51
Sand and gravel:							
Construction	thousand metric tons	•4,264	•14,500	4,409	15,581	•4,600	•16,600
Industrial	do.	W	W	533	8,783	491	7,941
Stone:							
Crushed	do.	[3]37,502	[r][3]222,901	•[3]39,916	•[3]244,200	49,353	292,144
Dimension[3]	metric tons	196,803	21,282	•144,327	•13,138	176,291	18,746
Combined value of barite, bauxite, cement, clays [fire (1992-93)], felspar, iron oxide pigments (crude), mica (scrap), stone [crushed marl, marble and miscellaneous (1991-92), dimension marble], and value indicated by symbol W		XX	[r]97,116	XX	93,002	XX	101,223
Total		XX	[r]1,305,546	XX	1,346,254	XX	1,431,718

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
HAWAII							
Cement:							
Masonry	thousand metric tons	[e]9	[e]$600	7	$1,421	7	$880
Portland	do.	[e]496	[e]47,589	520	53,936	451	48,269
Gemstones		NA	60	NA	W	NA	W
Sand and gravel (construction)	thousand metric tons	[e]363	[e]2,300	W	W	W	W
Stone (crushed)[3]	do.	[r]10,025	[r]95,990	[e]9,525	[e]93,500	8,456	81,412
Combined value of other industrial minerals and values indicated by symbol W		XX	(9)	XX	(9)	XX	8,143
Total		XX	[r][8]146,539	XX	[8]148,857	XX	138,704
IDAHO							
Clays	thousand metric tons	[2]1	W	W	W	W	W
Gemstones		NA	426	NA	390	NA	566
Gold[4]	kilograms	3,348	39,107	[r]4,037	[r]44,774	W	W
Lime	thousand metric tons	136	9,124	W	W	W	W
Phosphate rock	do.	5,921	86,328	5,208	84,000	4,355	78,432
Pumice	metric tons	36,868	267	55,525	401	43,438	327
Sand and gravel:							
Construction	thousand metric tons	[e]10,523	[e]31,300	13,522	40,728	[e]13,600	[e]44,900
Industrial	do.	W	W	728	9,214	W	W
Silver[3]	metric tons	337	43,807	254	32,131	190	26,232
Stone:							
Crushed	thousand metric tons	[r]2,701	[r]12,614	[e]3,629	[e]19,200	4,602	20,770
Dimension	metric tons	9,873	970	W	W	W	W
Combined value of antimony, cement, clays, [common, kaolin (1991)], copper, feldspar, garnet (abrasive), lead, molybdenum (1991-92), perlite (1991-92), vanadium ore, zinc, and values indicated by symbol W		XX	71,147	XX	[r]78,980	XX	102,983
Total		XX	[r]295,090	XX	[r]309,818	XX	274,210
ILLINOIS							
Cement (portland)	thousand metric tons	[e]2,408	[e]108,814	2,595	118,982	2,430	122,779
Clays	do.	935	38,877	[2]535	[2]2,362	[2]477	[2]1,086
Gemstones		NA	547	NA	715	NA	328
Sand and gravel:							
Construction	thousand metric tons	[e]23,859	[e]90,400	32,382	123,720	[e]34,500	[e]137,300
Industrial	do.	3,761	57,210	[r]4,241	[r]57,454	4,224	61,734
Stone (crushed)[3]	do.	[r]58,133	[r]309,610	[e]65,952	[e]322,800	61,487	315,149
Combined value of barite, cement [masonry (1991-92)], clays fuller's earth (1992-93)], copper (1992-93), fluorspar, lead 1992-93), lime, peat, silver (1992-93), stone [crushed sandstone (1993), crushed sandstone and limestone (1991-92), dimension], tripoli, and zinc		XX	82,081	XX	108,252	XX	95,929
Total		XX	[r]687,539	XX	[r]734,285	XX	734,305
INDIANA							
Cement:							
Masonry	thousand metric tons	[e]288	[e]24,092	337	24,822	W	W
Portland	do.	[e]2,043	[e]105,844	2,237	110,737	2,065	108,702
Clays[2]	do.	930	3,516	842	3,016	600	2,540
Gemstones		NA	561	NA	720	NA	47
Peat	thousand metric tons	24	W	24	512	24	W

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
INDIANA—Continued							
Sand and gravel:							
Construction	thousand metric tons	[e]16,420	[e]$60,400	26,183	$95,889	[e]27,000	[e]$102,600
Industrial	do.	W	W	107	1,278	W	W
Stone:							
Crushed	do.	[r]32,752	[r]144,298	[e]39,009	[e]178,000	36,862	165,861
Dimension	metric tons	[3]171,467	[3]27,596	[e]172,739	[e]26,767	[3]155,616	[3]22,876
Combined value of clays (ball), gypsum (crude), lime, stone [crushed limestone and dolomite (1991), dimension limestone and sandstone (1991), dimension sandstone (1993)], and values indicated by symbol W		XX	[r]36,988	XX	35,145	XX	70,368
Total		XX	[r]403,295	XX	476,886	XX	472,994
IOWA							
Cement:							
Masonry	thousand metric tons	[e]31	[e]3,264	45	4,120	W	W
Portland	do.	[e]2,087	[e]112,749	2,562	116,477	2,302	136,316
Clays	do.	530	2,226	389	1,612	358	1,667
Gemstones		NA	8	NA	1,606	NA	46
Gypsum (crude)	thousand metric tons	1,961	12,285	1,989	11,626	1,988	12,280
Sand and gravel (construction)	do.	[e]15,785	[e]55,800	15,263	58,382	[e]16,600	[e]64,700
Stone (crushed)	do.	[r][3]28,903	[r][3]151,690	[e][2]34,473	[e][2]186,200	30,500	168,597
Combined value of lime, peat, sand and gravel [industrial (1992-93)], stone [crushed dolomite and sandstone (1991-92), dimension], and value indicated by symbol W		XX	[r]9,897	XX	11,140	XX	13,920
Total		XX	[r]347,919	XX	391,163	XX	397,526
KANSAS							
Cement:							
Masonry	thousand metric tons	[e]27	[e]1,530	31	1,914	35	2,408
Portland	do.	[e]1,330	[e]65,970	1,551	79,464	1,383	73,914
Clays	do.	607	2,828	544	3,921	[2]513	[2]1,965
Gemstones		NA	527	NA	W	NA	W
Helium:							
Crude	million cubic meters	W	W	W	W	23	20,378
Grade-A	do.	39	76,540	W	W	52	103,949
Salt[10]	thousand metric tons	2,101	97,713	1,852	98,620	2,316	103,019
Sand and gravel (construction)	do.	[e]8,709	[e]22,100	10,867	27,289	[e]11,900	[e]30,700
Stone:							
Crushed[3]	do.	[r]15,242	67,249	[e]15,331	[e]69,600	18,847	90,663
Dimension	metric tons	[3]27,948	[3]3,128	W	W	24,728	2,539
Combined value of clays [fuller's earth (1993)], gypsum (crude), pumice, salt (brine), sand and gravel (industrial), stone [crushed quartzite (1991-92), crushed sandstone (1993), dimension sandstone (1991, 1993)], and values indicated by symbol W		XX	29,156	XX	124,274	XX	12,577
Total		XX	366,741	XX	405,082	XX	442,112
KENTUCKY							
Clays[2]	thousand metric tons	708	2,942	760	3,777	768	3,057
Gemstones		NA	548	NA	W	NA	W
Sand and gravel (construction)	thousand metric tons	[e]6,985	[e]27,200	6,710	24,412	[e]7,700	[e]29,900

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
KENTUCKY—Continued							
Stone (crushed)	thousand metric tons	41,972	$191,893	[e]53,342	[e]$251,100	[3]49,028	[3]$226,058
Combined value of cement, clays (ball), lime, sand and gravel [industrial (1991)], stone [crushed sandstone (1993)], and values indicated by symbol W		XX	120,541	XX	121,285	XX	128,488
Total		XX	343,124	XX	400,574	XX	387,503
LOUISIANA							
Clays	thousand metric tons	360	3,646	384	3,589	375	496
Gemstones		NA	27	NA	3,960	NA	141
Salt	thousand metric tons	13,240	130,587	12,054	112,334	12,374	115,464
Sand and gravel:							
Construction	do.	[e]12,066	[e]48,900	11,489	48,698	[e]11,900	[e]51,500
Industrial	do.	W	W	471	9,267	465	9,359
Sulfur (Frasch)	do.	1,063	W	1,105	W	740	W
Combined value of gypsum (crude), lime, stone [crushed limestone, shell, and miscellaneous (1993), crushed miscellaneous (1991), shell and miscellaneous (1992)], and values indicated by symbol W		XX	168,642	XX	131,432	XX	54,649
Total		XX	351,802	XX	309,280	XX	231,609
MAINE							
Gemstones		NA	174	NA	108	NA	9,685
Sand and gravel (construction)	thousand metric tons	[e]3,538	[e]14,800	6,081	26,932	[e]4,400	[e]18,900
Stone:							
Crushed	do.	1,548	9,899	[e]1,724	[e]11,400	1,832	10,359
Dimension	metric tons	66	88	W	W	W	W
Combined value of cement, clays (common), peat, and values indicated by symbol W		XX	16,343	XX	17,479	XX	21,184
Total		XX	41,304	XX	55,919	XX	60,128
MARYLAND							
Cement (portland)	thousand metric tons	[e]1,433	[e]80,580	1,514	84,191	1,634	81,639
Clays	do.	[e]259	[e]1,141	227	980	294	705
Gemstones		NA	3	NA	1	NA	1
Sand and gravel (construction)	thousand metric tons	[e]11,793	[e]72,800	10,875	69,297	[e]11,200	[e]72,200
Stone:							
Crushed	do.	23,174	[r]150,887	[e]21,591	[e]180,400	23,051	152,273
Dimension	metric tons	11,208	1,067	[e]10,310	[e]1,024	19,345	2,024
Combined value of other industrial minerals		XX	4,720	XX	3,473	XX	4,677
Total		XX	[r]311,198	XX	339,366	XX	313,519
MASSACHUSETTS							
Gemstones		NA	1	NA	1	NA	W
Sand and gravel:							
Construction	thousand metric tons	[e]9,163	[e]39,400	10,916	48,671	[e]10,800	[e]51,300
Industrial	do.	27	401	8	151	2	42
Stone:							
Crushed	do.	6,469	51,362	[e]9,435	[e]77,200	[3]9,455	[3]76,267
Dimension	metric tons	62,897	11,646	[e]59,725	[e]9,292	152,536	21,323

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MASSACHUSETTS—Continued							
Combined value of clays (common), lime, peat, and stone [crushed dolomite and miscellaneous (1993)], and value indicated by symbol W		XX	$8,787	XX	$12,086	XX	$11,280
Total		XX	111,597	XX	147,401	XX	160,212
MICHIGAN							
Cement:							
Masonry	thousand metric tons	[e]204	[e]22,440	212	20,381	216	17,376
Portland	do.	[e]4,477	[e]222,075	4,998	262,063	5,116	313,246
Clays	do.	2,062	8,770	1,265	4,345	1,234	4,848
Gemstones		NA	10	NA	1	NA	1
Gypsum (crude)	thousand metric tons	1,561	13,052	1,606	13,889	1,687	14,230
Iron ore (usable)	do.	[e]12,662	W	12,881	W	12,940	W
Lime	do.	556	30,959	577	31,253	596	30,926
Peat	do.	226	6,442	181	5,894	186	6,114
Sand and gravel:							
Construction	do.	[e]40,642	[e]132,200	43,539	143,107	[e]45,000	[e]157,500
Industrial	do.	1,899	18,464	[r]1,954	[r]22,585	2,567	25,129
Stone (crushed)	do.	[r]30,737	[r]105,254	[e]35,017	[e]125,500	31,019	111,763
Combined value of calcium chloride [natural[2] (1991-92)], copper, iron oxide pigments (crude), magnesium compounds, potash, salt, silver, stone [crushed marble and miscellaneous (1991), (dimension), and values indicated by symbol W		XX	[r]920,005	XX	961,038	XX	823,112
Total		XX	[r]1,479,671	XX	[r]1,590,056	XX	1,504,245
MINNESOTA							
Gemstones		NA	62	NA	686	NA	65
Iron ore (usable)	thousand metric tons	[e]42,966	[e]1,157,920	42,348	1,180,563	42,459	1,126,576
Peat	do.	32	1,910	36	2,764	33	1,931
Sand and gravel (construction)	do.	[e]22,226	[e]58,800	34,114	98,673	[e]30,500	[e]85,400
Stone:							
Crushed	do.	[r]7,601	30,624	[e]9,525	[e]39,500	9,423	[3]7,736
Dimension	metric tons	41,545	13,962	[e]32,833	[e]11,436	33,466	11,766
Combined value of clays (common, kaolin), lime, and sand and gravel (industrial)		XX	25,607	XX	[r]30,364	XX	35,250
Total		XX	1,288,885	XX	[r]1,363,986	XX	1,298,724
MISSISSIPPI							
Clays	thousand metric tons	[2]1,172	[2]34,382	[2]1,120	[2]38,090	1,100	38,228
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand metric tons	[e]8,981	[e]33,000	10,403	44,124	[e]14,500	[e]57,300
Stone (crushed)	do.	1,481	6,603	[e]2,268	[e]10,400	2,102	8,122
Combined value of cement [masonry (1992), portland], clays [ball (1991-92), kaolin (1991)], and sand and gravel (industrial)		XX	27,873	XX	[r]28,780	XX	(9)
Total		XX	101,859	XX	[r]121,395	XX	[8]103,651
MISSOURI							
Cement (portland)	thousand metric tons	[e]3,879	[e]171,040	4,286	196,073	4,057	201,016
Clays[2]	do.	2,002	11,060	1,195	8,327	1,184	7,737
Copper[4]	metric tons	W	W	10,766	25,497	6,982	14,094

See footnotes at end of table.

TABLE 6—Continued
NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
MISSOURI—Continued							
Gemstones		NA	W	NA	$862	NA	$46
Iron ore (usable)	thousand metric tons	^{e}224	W	19	W	287	W
Lead[4]	metric tons	351,995	$259,841	^{r}299,741	^{r}231,946	277,427	194,129
Sand and gravel:							
Construction	thousand metric tons	^{e}6,713	^{e}20,100	8,186	26,457	^{e}6,400	^{e}19,800
Industrial	do.	W	W	644	10,931	520	9,389
Silver[4]	metric tons	35	4,483	32	4,084	40	5,578
Stone (crushed)	thousand metric tons	^{r}44,091	^{r}169,419	^{e}47,355	^{e}187,400	53,368	239,297
Zinc[4]	metric tons	42,506	49,453	44,031	56,670	40,171	40,872
Combined value of barite, cement (masonry), clays (fuller's earth), iron oxide pigments (crude), lime, stone (dimension), and values indicated by symbol W		XX	197,141	XX	148,286	XX	123,466
Total		XX	^{r}882,537	XX	^{r}896,533	XX	855,424
MONTANA							
Clays	thousand metric tons	363	11,332	[2]35	[2]101	W	W
Gemstones		NA	2,796	NA	674	NA	281
Gold[4]	kilograms	13,715	160,197	13,994	155,210	14,325	166,219
Palladium metal	do.	6,050	16,923	6,470	18,097	6,500	25,287
Platinum metal	do.	1,730	20,635	1,840	21,060	1,800	21,412
Sand and gravel (construction)	thousand metric tons	^{e}4,354	^{e}13,700	10,078	31,375	^{e}10,000	^{e}32,000
Silver[4]	metric tons	222	28,893	197	24,990	127	17,566
Stone (crushed)	thousand metric tons	^{r}1,912	5,725	^{e}1,996	^{e}6,200	2,816	10,375
Talc and pyrophyllite	metric tons	W	W	407,657	16,162	349,559	11,892
Zinc[4]	do.	W	W	20,588	26,498	W	W
Combined value of barite, cement [masonry (1991-92), portland], clays [bentonite (1992-93), common (1993), fire (1993)], copper, iron ore (usable), lead, lime, molybdenum, peat, phosphate rock, sand and gravel (industrial), stone (dimension), vermiculite (1991-92), and values indicated by symbol W		XX	274,082	XX	238,787	XX	198,998
Total		XX	534,283	XX	539,154	XX	484,030
NEBRASKA							
Clays	thousand metric tons	198	909	183	879	192	932
Gemstones		NA	1	NA	645	NA	W
Lime	thousand metric tons	W	W	26	1,741	24	1,233
Sand and gravel (construction)	do.	^{e}9,163	^{e}27,300	11,980	38,108	^{e}12,900	^{e}41,900
Stone (crushed)	do.	4,410	23,328	^{e}5,352	^{e}29,100	6,763	38,871
Combined value of cement, sand and gravel (industrial), and values indicated by symbol W		XX	37,854	XX	44,317	XX	43,240
Total		XX	89,392	XX	114,790	XX	126,176
NEVADA							
Barite	thousand metric tons	374	11,933	W	W	242	9,100
Clays[2]	do.	16	3,204	51	7,722	16	3,434
Gemstones		NA	958	NA	661	NA	660
Gold[4]	kilograms	180,382	2,106,866	^{r}203,393	^{r}2,255,837	210,763	2,445,590
Mercury	metric tons	57	202	64	373	W	W

See footnotes at end of table.

TABLE 6—Continued
NONFUEL MINERAL PRODUCTION[1] IN THE UNITED STATES, BY STATE

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
NEVADA—Continued							
Sand and gravel:							
Construction	thousand metric tons	[e]18,416	[e]$69,000	22,020	$93,585	[e]24,900	[e]$107,600
Industrial	do.	495	W	482	W	480	W
Silver[4]	metric tons	578	75,050	614	77,724	713	98,546
Stone (crushed)	thousand metric tons	[r]986	6,527	[e]1,089	[e]6,700	1,067	12,529
Combined value of brucite, cement (portland), clays [fuller's earth (1991, 1993), kaolin], copper, diatomite, fluorspar (1993), gypsum (crude), lead (1991), lime, lithium minerals, magnesite, molybdenum (1991), perlite, salt, zinc (1991), and values indicated by symbol W		XX	155,018	XX	148,181	XX	151,092
Total		XX	2,428,758	XX	[r]2,590,783	XX	2,828,551
NEW HAMPSHIRE							
Clay (common)	thousand metric tons	W	W	W	W	3	16
Gemstones		NA	31	NA	4	NA	9
Sand and gravel (construction)	thousand metric tons	[e]4,264	[e]16,200	5,839	25,570	[e]4,800	[e]20,700
Stone:							
Crushed	do.	[r]1,131	[r]6,818	[e]1,542	[e]11,000	1,390	7,794
Dimension	metric tons	31,573	5,013	[e]34,153	[e]5,460	53,106	8,674
Combined value of other industrial minerals and values indicated by symbol W		XX	(8)	XX	(8)	XX	—
Total		XX	[r][8]28,062	XX	[8]42,034	XX	37,193
NEW JERSEY							
Gemstones		NA	3	NA	1	NA	1
Peat	thousand metric tons	W	541	W	W	W	W
Sand and gravel:							
Construction	do.	[e]9,344	[e]47,900	14,892	79,993	[e]14,700	[e]80,100
Industrial	do.	1,482	23,738	1,377	24,727	1,826	28,640
Stone (crushed)[3]	do.	15,132	[r]119,286	[e]15,513	[e]126,000	16,702	137,872
Combined value of clays (common, fire), greensand marl, stone (crushed sandstone and other), titanium concentrates [ilmenite and rutile (1991-92)], zircon concentrates (1991-92), and values indicated by symbol W		XX	[r]13,520	XX	9,718	XX	15,734
Total		XX	[r]204,988	XX	240,439	XX	262,347
NEW MEXICO							
Clays[2]	thousand metric tons	28	74	33	79	33	101
Copper[4]	metric tons	252,859	609,454	211,337	500,504	224,305	452,771
Gemstones		NA	100	NA	34	NA	10
Gold[4]	kilograms	W	W	W	W	995	11,550
Iron ore (usable)	thousand metric tons	W	W	—	—	12	165
Lead[4]	metric tons	193	142	W	W	—	—
Potash	thousand metric tons	1,469	250,900	1,436	256,620	1,311	215,858
Sand and gravel (construction)	do.	[e]8,346	[e]35,900	10,170	46,176	[e]11,100	[e]51,100
Silver[4]	metric tons	W	W	W	W	22	3,089
Stone (crushed)	thousand metric tons	2,541	13,089	[e]2,722	[e]14,400	[3]3,503	[3]18,411

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
NEW MEXICO—Continued							
Combined value of cement, clays (fire), gypsum (crude), helium [Grade-A (1990-91)], mica (scrap), molybdenum, perlite, pumice, salt, stone [crushed quartzite (1993), dimension], zinc (1993), and values indicated by symbol W		XX	$75,851	XX	$53,466	XX	$50,994
Total		XX	985,510	XX	871,279	XX	804,049
NEW YORK							
Cement:							
Masonry	thousand metric tons	W	W	W	W	75	5,422
Portland	do.	W	W	W	W	2,966	149,491
Clays	do.	421	2,417	415	2,412	508	9,250
Gemstones		NA	125	NA	170	NA	W
Peat	thousand metric tons	1	21	W	W	W	W
Salt	do.	4,534	173,837	4,703	164,729	5,619	191,491
Sand and gravel (construction)	do.	^{e}21,500	^{e}95,500	28,538	130,379	^{e}34,900	^{e}161,500
Stone:							
Crushed	do.	31,634	195,639	^{e}33,384	^{e}212,700	38,448	223,293
Dimension	metric tons	16,292	3,162	^{e}16,526	^{e}2,779	19,275	3,436
Combined value of emery (1993), garnet (abrasive), gypsum (crude), lead, sand and gravel (industrial), silver, stone [crushed traprock (1993)], talc and pyrophyllite, wollastonite, zinc, and values indicated by symbol W		XX	228,142	XX	252,578	XX	107,624
Total		XX	698,843	XX	765,747	XX	851,507
NORTH CAROLINA							
Clays[2]	thousand metric tons	2,064	9,015	2,120	9,775	2,381	11,165
Feldspar	metric tons	402,448	13,027	438,624	15,498	471,879	16,687
Gemstones		NA	785	NA	1,219	NA	546
Mica (scrap)	thousand metric tons	64	3,747	51	2,967	51	2,696
Peat	do.	19	W	W	108	W	162
Sand and gravel:							
Construction	do.	^{e}8,981	^{e}35,000	9,283	42,717	^{e}11,100	^{e}53,800
Industrial	do.	1,065	15,565	1,088	17,533	1,344	18,597
Stone:							
Crushed[3]	do.	^{r}42,196	^{r}243,919	^{e}44,089	^{e}262,400	47,787	297,657
Dimension	metric tons	33,617	10,568	^{e}23,014	^{e}7,469	31,733	12,268
Combined value of clays (kaolin), lithium minerals, olivine, phosphate rock, stone [crushed quartzite, slate, and volcanic cinder (1993), volvanic cinder (1991-92)], talc and pyrophyllite, and values indicated by symbol W		XX	^{r}221,712	XX	235,962	XX	203,812
Total		XX	^{r}553,338	XX	595,648	XX	617,390
NORTH DAKOTA							
Clays	thousand metric tons	28	W	W	W	W	W
Gemstones		NA	6	NA	643	NA	W
Lime	thousand metric tons	89	5,360	101	4,288	W	4,512
Peat	do.	—	—	W	W	(6)	W
Sand and gravel (construction)	do.	^{e}4,536	^{e}12,000	7,929	20,609	^{e}7,700	^{e}20,400
Stone (crushed)	do.	10	W	10	W	W	W

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
NORTH DAKOTA—Continued							
Combined value of other industrial minerals and values indicated by symbol W		XX	(9)	XX	$210	XX	$131
Total		XX	[8]$17,366	XX	25,750	XX	25,043
OHIO							
Cement:							
Masonry	thousand metric tons	[e]99	[e]9,591	103	10,260	93	11,305
Portland	do.	[e]1,230	[e]69,156	1,320	77,053	1,494	90,305
Clays	do.	2,205	11,015	2,288	12,062	[2]2,161	[2]12,023
Gemstones		NA	57	NA	5	NA	5
Lime	thousand metric tons	1,618	85,976	1,670	96,739	1,699	100,721
Peat	do.	8	222	W	W	W	W
Sand and gravel:							
Construction	do.	[e]38,374	[e]160,100	42,874	177,508	[e]46,400	[e]202,900
Industrial	do.	1,174	23,462	1,276	26,445	1,360	27,533
Stone:							
Crushed	do.	[r,3]43,221	[r,3]184,159	[e,3]43,998	[e,3]194,500	52,167	228,364
Dimension	metric tons	[3]42,666	[3]2,443	[e]31,805	[e]2,244	[3]25,738	[3]1,207
Combined value of abrasives, clays [ball (1993)], gypsum (crude), salt, stone [crushed limestone and dolomite (1991-92), dimension limestone (1991, 1993)], and values indicated by symbol W		XX	[r]137,549	XX	145,087	XX	176,271
Total		XX	[r]683,730	XX	741,903	XX	850,634
OKLAHOMA							
Cement:							
Masonry	thousand metric tons	W	W	W	W	85	6,719
Portland	do.	[e]1,470	[e]63,180	931	39,280	1,696	77,624
Clays	do.	824	4,178	622	3,296	613	2,938
Gemstones		NA	W	NA	1,863	NA	W
Gypsum (crude)	thousand metric tons	2,137	12,925	2,361	14,915	2,651	15,434
Iodine (crude)	thousand kilograms	1,999	31,389	1,995	20,877	1,935	15,443
Sand and gravel:							
Construction	thousand metric tons	[e]8,165	[e]22,300	8,985	24,204	[e]9,700	[e]27,300
Industrial	do.	1,126	20,918	972	19,011	1,208	23,155
Stone:							
Crushed	do.	[r,3]25,676	[r,3]104,481	[e,3]24,948	[e,3]105,300	27,055	113,958
Dimension	metric tons	[3]3,426	[3]596	[e]4,701	[e]706	[3]2,350	[3]838
Tripoli	do.	15,885	141	W	W	W	W
Combined value of feldspar, lime, salt, stone (crushed stone [dolomite (1991), crushed granite [1992], dimension limestone and sandstone (1993), dimension sandstone (1991)], tripoli (1992), and values indicated by symbol W		XX	24,390	XX	23,144	XX	14,930
Total		XX	[r]284,498	XX	252,596	XX	298,339
OREGON							
Cement (portland)	thousand metric tons	[e]226	[e]18,675	W	W	W	W
Clays	do.	213	1,086	[2]203	[2]326	221	1,410
Copper[4]	metric tons	W	W	152	361	703	1,420

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
OREGON—Continued							
Gemstones		NA	$2,758	NA	$2,723	NA	$2,143
Nickel ore[11]	metric tons	5,523	NA	6,671	W	2,464	W
Sand and gravel (construction)	thousand metric tons	[e]14,152	[e]62,800	14,958	69,536	[e]15,800	[e]74,800
Silver[4]	metric tons	—	—	([6])	1	—	—
Stone (crushed)	thousand metric tons	[r][3]18,773	[r][3]89,847	[r][3]15,241	[e][3]74,900	18,891	84,655
Talc and pyrophyllite	metric tons	63	67	64	67	64	67
Zinc[4]	do.	751	873	—	—	—	—
Combined value of cement [masonry (1992)], clay [bentonite (1992)], diatomite, emery, gold (1992), lime, pumice, stone [crushed slate (1991-92)],and values indicated by symbol W		XX	22,347	XX	66,256	XX	61,613
Total		XX	[r]198,453	XX	214,170	XX	226,108
PENNSYLVANIA							
Cement:							
Masonry	thousand metric tons	[e]230	[e]18,975	296	21,924	248	18,741
Portland	do.	[e]4,428	[e]248,931	5,016	258,887	5,365	282,630
Clays	do.	[2]701	[2]2,890	649	3,455	765	3,777
Gemstones		NA	5	NA	1	NA	1
Lime	thousand metric tons	1,538	95,328	1,506	94,543	1,535	95,377
Peat	do.	9	207	15	250	9	249
Sand and gravel (construction)	do.	[e]16,601	[e]87,800	17,540	94,643	[e]16,100	[e]83,900
Stone:							
Crushed[3]	do.	[r]65,366	[r]366,360	64,954	380,200	69,361	405,346
Dimension	metric tons	38,086	10,459	37,855	10,822	35,665	9,892
Combined value of clays [kaolin (1991)], mica [scrap(1991)], sand and gravel (industrial), stone [limestone, dolomite, and quartzite (1991-92), quartzite (1993)], and tripoli		XX	[r]13,428	XX	[r]16,218	XX	13,249
Total		XX	[r]844,383	XX	[r]880,943	XX	913,162
RHODE ISLAND							
Gemstones		NA	1	NA	1	NA	1
Sand and gravel (construction)	thousand metric tons	[e]1,179	[e]6,000	2,227	11,964	[e]2,500	[e]13,900
Stone (crushed)	do.	1,077	7,262	[e]1,361	[e]9,500	1,291	9,251
Total[8]		XX	13,263	XX	21,465	XX	23,152
SOUTH CAROLINA							
Cement (portland)	thousand metric tons	[e]2,009	[e]99,675	2,083	93,385	2,132	109,369
Clays	do.	1,709	25,662	1,608	27,694	1,539	31,304
Gemstones		NA	10	NA	641	NA	W
Gold[4]	kilograms	W	W	6,747	74,832	W	W
Sand and gravel:							
Construction	thousand metric tons	[e]5,987	[e]18,900	6,256	19,923	[e]6,800	[e]21,800
Industrial	do.	746	16,348	770	17,316	749	18,964
Stone:							
Crushed	do.	[3]16,525	[3]84,260	[3]15,966	[3]83,800	19,765	120,939
Dimension	metric tons	8,010	854	W	W	W	W
Combined value of cement (masonry), manganiferous ore, mica (scrap), peat, silver, stone [crushed dolomite (1991-92)], vermiculite, and values indicated by symbol W		XX	94,364	XX	29,305	XX	88,671
Total		XX	340,073	XX	346,896	XX	391,047

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
SOUTH DAKOTA							
Gemstones		NA	W	NA	$967	NA	$163
Gold[4]	kilograms	16,371	$191,217	18,681	207,195	19,241	223,267
Sand and gravel (construction)	thousand metric tons	[e]7,893	[e]20,800	7,511	22,187	[e]8,300	[e]25,000
Silver[4]	metric tons	7	944	6	802	5	651
Stone (crushed)	thousand metric tons	4,376	19,657	[e]4,082	[e]18,900	[3]4,227	[3]18,684
Combined value of cement, clays (common), feldspar, gypsum (crude), iron ore (usable), lime, mica (scrap), stone (dimension), and values indicated by symbol W		XX	57,304	XX	50,619	XX	69,391
Total		XX	289,922	XX	300,670	XX	337,156
TENNESSEE							
Clays[2]	thousand metric tons	829	44,572	574	24,097	607	25,703
Gemstones		NA	W	NA	23,347	NA	21,795
Sand and gravel:							
Construction	thousand metric tons	[e]6,078	[e]21,100	7,691	35,077	[e]7,200	[e]34,000
Industrial	do.	W	W	614	10,665	644	11,736
Stone:							
Crushed	do.	39,996	223,561	[e]42,366	[e]243,800	43,534	226,521
Dimension	metric tons	3,139	260	[e]3,084	[e]320	4,553	552
Combined value of cement, clays [bentonite (1992-93), common, fuller's earth (1992-93), kaolin (1991)], copper, lead, lime, silver, zinc, and values indicated by symbol W		XX	258,294	XX	238,498	XX	189,358
Total		XX	547,787	XX	575,804	XX	509,665
TEXAS							
Cement:							
Masonry	thousand metric tons	W	W	W	W	245	18,365
Portland	do.	[e]6,802	[e]289,341	6,840	308,749	8,127	397,600
Clays[2]	do.	2,266	13,247	2,237	12,610	2,183	17,441
Gemstones		NA	W	NA	3,834	NA	400
Gypsum (crude)	thousand metric tons	1,460	9,240	1,624	9,920	1,756	10,088
Helium (crude)	million cubic meters	W	W	W	W	6	5,385
Lime	thousand metric tons	1,246	69,400	1,337	83,359	1,604	103,274
Salt	do.	8,106	73,117	7,985	76,125	8,253	76,054
Sand and gravel:							
Construction	do.	[e]35,199	[e]135,800	41,404	166,362	[e]47,100	[e]195,000
Industrial	do.	1,412	27,002	[r]1,392	[r]26,501	1,433	28,558
Stone (crushed)	do.	[r]59,964	[r]225,664	[e]64,682	[e]253,100	70,772	279,245
Sulfur (Frasch)	do.	2,056	W	1,495	W	1,164	W
Talc and pyrophyllite	metric tons	212,887	4,561	235,919	5,720	235,857	5,662
Combined value of clays [ball, bentonite, fuller's earth, kaolin), fluorspar (1993), helium (Grade-A), iron ore (usable), magnesium compounds, magnesium metal, sodium sulfate (natural), stone (dimension), and values indicated by symbol W		XX	417,067	XX	357,458	XX	311,041
Total		XX	[r]1,264,439	XX	[r]1,303,738	XX	1,448,113
UTAH							
Beryllium concentrates	metric tons	4,339	5	4,826	5	4,939	5
Clays[2]	thousand metric tons	210	1,028	243	2,714	216	3,129
Gemstones		NA	489	NA	634	NA	1,156

See footnotes at end of table.

TABLE 6—Continued

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

Mineral		1991		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
UTAH—Continued							
Lime	thousand metric tons	295	$18,634	W	W	W	W
Potash	do.	W	W	W	W	210	$49,690
Salt	do.	1,310	29,959	1,367	$44,498	2,251	46,759
Sand and gravel (construction)	do.	[e]13,063	[e]48,200	16,037	54,819	[e]16,000	[e]56,000
Silver[4]	metric tons	W	W	W	W	135	18,703
Stone:							
Crushed	thousand metric tons	4,037	18,259	[e]4,808	[e]22,400	4,555	29,400
Dimension	metric tons	20,937	1,429	—	—	W	W
Combined value of cement, clays [bentonite, fuller's earth (1992-93)], copper, gold, gypsum (crude), iron ore (usable), magnesium compounds, magnesium metal, mercury (1992-93), molybdenum, phosphate rock, sodium sulfate (natural), and values indicated by symbol W		XX	1,067,184	XX	[r]1,221,160	XX	1,108,695
Total		XX	1,185,187	XX	[r]1,346,230	XX	1,313,537
VERMONT							
Asbestos	metric tons	W	W	4,575	1,686	3,661	1,531
Gemstones		NA	5	NA	1	NA	1
Sand and gravel (construction)	thousand metric tons	[e]2,722	[e]9,900	3,152	11,291	[e]3,000	[e]10,400
Stone:							
Crushed	do.	[r]2,291	[r]11,616	[e]2,268	[e]12,200	2,520	12,899
Dimension	metric tons	84,058	31,013	[e]113,398	[e]34,639	97,352	27,875
Combined value of other industrial minerals		XX	[r]7,286	XX	(8)	XX	(8)
Total		XX	[r]59,820	XX	[8]59,817	XX	[8]52,706
VIRGINIA							
Clays[2]	thousand metric tons	723	3,248	754	3,367	775	2,950
Gemstones		NA	70	NA	W	NA	W
Lime	thousand metric tons	748	39,612	764	40,271	756	40,039
Sand and gravel (construction)	do.	[e]8,800	[e]36,900	8,659	37,336	[e]9,000	[e]40,500
Stone:							
Crushed	do.	[r]44,378	[r]262,577	[e]43,091	[e]261,300	50,998	292,345
Dimension	metric tons	10,021	3,061	W	W	W	W
Combined value of aplite[12] (1991), cement, clays [bentonite (1992-93), fuller's earth], feldspar,[3] gypsum (crude), iron oxide pigments (crude), kyanite, sand and gravel (industrial), talc and pyrophyllite, vermiculite, and values indicated by symbol W		XX	84,188	XX	119,589	XX	88,913
Total		XX	[r]429,656	XX	461,863	XX	464,747
WASHINGTON							
Clays	thousand metric tons	263	2,633	306	[2]1,889	[2]238	[2]1,373
Gemstones		NA	85	NA	379	NA	24
Gold[4]	kilograms	9,954	116,260	8,802	97,619	7,108	82,469
Lime	thousand metric tons	W	W	W	W	213	W
Sand and gravel (construction)	do.	[e]36,469	[e]140,700	37,134	140,994	[e]40,200	[e]158,000
Silver[4]	metric tons	W	W	W	W	14	1,939

See footnotes at end of table.

TABLE 6—Continued

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

Mineral	1991		1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
WASHINGTON—Continued						
Stone (crushed) thousand metric tons	[r]11,945	[r]$59,751	[e]12,247	[e]$63,200	13,204	$68,648
Combined value of cement, clays [fire (1992-93)], diatomite, gypsum [crude (1991)], lead, magnesium metal, olivine, peat, sand and gravel (industrial), stone (dimension), zinc, and values indicated by symbol W	XX	163,395	XX	164,958	XX	192,740
Total	XX	[r]482,824	XX	469,039	XX	505,193
WEST VIRGINIA						
Clays thousand metric tons	134	322	80	221	115	334
Gemstones	NA	2	NA	1	NA	1
Sand and gravel (construction) thousand metric tons	[e]2,812	[e]14,300	1,256	5,730	[e]1,400	6,700
Stone (crushed) do.	[r]9,354	[r]50,768	[e]10,342	[e]57,800	[3]10,313	79,661
Combined value of cement, lime, peat, salt, sand and gravel (industrial), and stone [crushed dolomite (1993)]	XX	51,802	XX	47,846	XX	62,756
Total	XX	[r]117,194	XX	111,598	XX	149,452
WISCONSIN						
Gemstones	NA	542	NA	5	NA	45
Lime thousand metric tons	486	23,225	473	26,579	511	30,880
Peat do.	8	227	56	553	W	W
Sand and gravel:						
Construction do.	[e]26,853	[e]77,500	26,415	77,066	[e]27,600	[e]82,800
Industrial do.	W	W	[r]1,303	[r]26,026	1,479	31,399
Stone:						
Crushed do.	[r,3]21,478	[r,3]80,476	[e,3]23,133	[e,3]89,300	26,248	98,026
Dimension metric tons	[3]55,238	[3]6,221	[e]32,809	[e]4,227	121,573	13,098
Combined value of other industrial minerals and values indicated by symbol W	XX	[r]27,533	XX	(8)	XX	57,064
Total	XX	[r]215,724	XX	[r,8]223,756	XX	313,312
WYOMING						
Cement (portland) thousand metric tons	W	W	438	30,182	W	W
Clays[2] do.	2,496	81,573	2,535	83,094	2,407	73,399
Gemstones	NA	61	NA	12	NA	13
Lime thousand metric tons	34	2,729	W	W	W	W
Sand and gravel (construction) do.	[e]3,175	[e]11,900	2,855	11,438	[e]3,400	[e]15,000
Stone (crushed) do.	[r]2,626	[r]13,595	[e]4,082	[e]19,900	3,456	19,837
Combined value of cement [masonry (1992-93)], clays (common), gypsum (crude), helium (Grade-A), soda ash, and values indicated by symbol W	XX	820,268	XX	806,131	XX	748,236
Total	XX	[r]930,126	XX	950,757	XX	856,485

See footnotes at end of table.

TABLE 6—Continued

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

Mineral	1991 Quantity	1991 Value (thousands)	1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
UNDISTRIBUTED						
Delaware, Hawaii (1991-92), Mississippi (1993), New Hampsire (1991-92), North Dakota (1991), Rhode Island, Vermont, Wisconsin (1991-92), and Undistributed (1991)	XX	[r]$77,972	XX	[r]$94,923	XX	$102,530

[e] Estimated. [r] Revised. NA Not available. W Withheld to avoid disclosing company proprietary data, value included with "Combined value" data. XX Not applicable.
[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[2] Excludes certain clays; kind and value included with "Combined value" data.
[3] Excludes certain stones; kind and value included with "Combined value" data.
[4] Recoverable content of ores, etc.
[5] Grindstones, pulpstones, and sharpening stones; excludes mill liners and grinding pebbles.
[6] Less than 1/2 unit.
[7] Calcium chloride (natural) canvassing discontinued beginning 1993.
[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" data.
[11] The Riddle nickel smelter uses lateritic ore mined on Nickel Mountain, lateritic ore imported from New Caledonia, and small tonnages of recycled Ni-bearing catalysts. In 1989, the Glenbrook Nickel Co. purchased the idled mining and smelting complex and restarted the operation. Production of ferronickel on a contained Ni basis has been as follows: 1991—7,060 metric tons (mt) valued at $57.6 million; 1992—8,962 mt valued at $62.7 million; and 1993—4,878 mt valued at $28.0 million.
[12] Aplite combined with feldspar beginning 1992.

TABLE 7

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

Mineral		1991 Quantity	1991 Value (thousand)	1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
PUERTO RICO							
Cement (portland)	thousand metric tons	[e]1,254	[e]$110,560	1,298	$119,643	1,310	$72,619
Clays	do.	145	355	W	527	155	508
Lime	do.	27	4,440	27	3,717	—	—
Sand and gravel (industrial)	do.	50	825	W	W	58	1,396
Stone:							
Crushed	do.	[r]8,008	49,839	NA	NA	7,845	51,059
Dimension	metric tons	—	—	—	—	W	W
Total		XX	166,019	XX	[2]123,887	XX	[2]125,582
ADMINISTERED ISLANDS							
American Samoa: Stone (crushed)	thousand metric tons	W	W	—	—	83	W
Guam: Stone (crushed)	do.	W	18,038	—	—	1,373	15,095
Virgin Island: Stone (crushed)	do.	—	—	—	—	W	W
Total		XX	[r][2]18,038	XX	—	XX	[2]15,095

[e] Estimated. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total." XX Not applicable.
[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[2] Total does not include value of item withheld.

TABLE 8

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

Mineral	1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS				
Aluminum:				
Aluminum oxide (alumina, includes hydroxide [calcined equivalent]) thousand metric tons	1,143	$306,513	1,237	$305,829
Crude and semicrude metric tons	1,452,695	2,680,202	1,206,539	2,228,744
Manufactures do.	^{r}74,755	231,190	98,510	270,200
Speciality compounds (aluminum sulfate, aluminum chloride, aluminum oxide abrasives, and various fluorine-based compounds) do.	NA	NA	52,200	NA
Antimony:				
Metal, alloys, waste and scrap do.	947	1,619	315	871
Oxide (antimony content) do.	4,817	10,443	3,896	8,889
Arsenic metal do.	94	783	364	1,208
Bauxite (dried and calcined) thousand metric tons	^{r}63	NA	90	NA
Beryllium (alloys, wrought or unwrought, and waste and scrap) kilograms	41,109	5,277	19,714	1,763
Bismuth (metal, alloys, waste and scrap) do.	90,320	577	70,070	790
Cadmium (alloys, dross, flue dust, metal, residues, and scrap) metric tons	178	244	11	137
Chromium:				
Chemicals do.	22,820	29,325	20,001	34,919
Chromite ore and concentrate do.	7,042	1,602	10,011	2,136
Metal and alloys do.	11,122	14,909	15,734	18,413
Pigments do.	2,554	10,413	2,312	9,403
Cobalt:				
Metal (unwrought, powders, waste and scrap, and mattes and other intermediate products of metallurgy) do.	485	20,180	435	10,928
Metal (wrought and cobalt articles) do.	405	13,200	249	11,400
Ores and concentrates do.	6	83	9	78
Oxides and hydroxides do.	999	11,797	308	6,081
Other forms (acetates and chlorides) do.	897	7,729	563	4,096
Columbium:				
Ferrocolumbium thousand kilograms	902	8,254	815	7,313
Ores and concentrates do.	—	—	6	46
Copper:				
Scrap (alloyed and unalloyed) metric tons	246,636	281,882	262,102	279,786
Semimanufactures (bare wire [includes wire rod], bars, cable [stranded], foil, hydroxides, oxides, pipes, plates, sheets, tubing, and wire [stranded]) do.	108,734	400,522	348,192	407,514
Sulfate do.	1,049	NA	334	NA
Unmanufactured (anodes, ash, blister, ore, concentrate, matte, precipitates, and refined) do.	472,571	791,697	468,195	727,975
Gold:				
Bullion (refined) kilograms	256,845	2,877,377	658,120	7,611,318
Doré and precipitates do.	51,008	518,661	64,797	685,506
Ores and concentrates do.	30	221	216	1,880
Waste and scrap do.	60,968	548,873	66,847	615,689
Iron ore and agglomerates thousand metric tons	5,055	186,864	5,061	166,904
Iron and steel:				
Direct-reduced iron metric tons	14,105	6,233	22,541	5,173

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Iron and steel—Continued:					
Ferroalloys not elsewhere listed:					
Ferrophosphorous	metric tons	2,142	$1,470	1,806	$1,035
Ferrozirconium	do.	88	130	20	54
Ferroalloys (n.e.c.)	do.	2,217	3,497	2,028	2,821
Pig iron	do.	32,742	3,196	27,111	3,035
Products:					
Cast (granules-shot, grinding balls, grit, fittings, pipe, rolls, and other)	thousand metric tons	201	403,831	180	348,099
Fabricated steel	do.	609	1,938,148	631	1,961,142
Steel mill	do.	3,890	3,032,072	3,600	2,494,548
Other steel	do.	NA	NA	57	44,288
Scrap:					
Borings, bundles, heavy melting, iron, shredded, shovelings, stainless, turnings, and other steel	do.	9,262	1,099,802	9,805	1,316,104
Ships, boats, and other vessels for scrapping	do.	92	7,622	162	13,213
Used rails for rerolling and other uses (contains used plus new rails)	do.	22	5,998	43	11,760
Lead:					
Ash and residues (lead content)	do.	2,141	1,031	1,728	1,326
Ore and concentrate (lead content)	do.	72,323	22,202	41,766	7,839
Scrap	do.	63,212	15,165	54,101	14,431
Unwrought metal and alloys (lead content)	do.	64,340	44,624	51,443	32,240
Wrought metal and alloys (lead content)	do.	5,251	19,637	7,141	19,703
Magnesium:					
Alloys	do.	1,473	5,365	1,953	8,219
Metal	do.	35,824	96,221	26,518	71,852
Powder, sheets, tubing, ribbons, wire, and other forms	do.	12,158	24,367	8,337	18,772
Waste and scrap	do.	2,496	5,907	2,007	4,636
Manganese:					
Ferromanganese (all grades)	do.	13,404	12,996	18,040	14,842
Metal (including alloys, waste, and scrap)	do.	5,005	11,946	3,835	9,397
Ore and concentrates	do.	13,086	2,295	15,923	1,791
Silicomanganese	do.	9,171	6,500	9,420	6,717
Mercury	do.	977	2,760	389	1,229
Molybdenum (molybdenum content):					
Ferromolybdenum	do.	^{r}320	^{r}4,404	224	2,958
Ore and concentrates	do.	^{r}33,439	125,405	28,280	74,225
Oxides and hydroxides	do.	^{r}557	^{r}2,890	1,042	5,611
Molybdates (all)	do.	1,030	4,976	958	4,783
Powder	do.	350	5,811	226	4,191
Unwrought	do.	74	640	52	801
Wire	do.	^{r}356	14,972	260	10,266
Wrought	do.	144	5,772	93	4,791

See footnotes at end of table.

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Nickel (nickel content):					
Alloyed (bars, foil, ingot [unwrought], pipes, profiles, rods, sheets, strip, tubes, wire, and other articles)	metric tons	15,184	$208,105	14,941	$230,359
Unwrought:					
Primary (briquets, cathodes, chemicals [catalysts and salts], ferronickel, flakes, oxide (metallurgical grade), pellets, powder, and shot)	do.	8,560	84,175	7,183	80,137
Secondary (scrap [stainless steel and waste])	do.	25,307	187,797	26,016	187,904
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire)	do.	447	7,955	551	5,755
Platinum-group metals (concentrates, iridium, ores, osmium, palladium, platinum, rhodium, ruthenium, and waste and scrap)	kilograms	[r]57,830	382,016	78,521	441,053
Rare-earth metals (rare-earth oxide content):					
Cerium compounds	do.	1,935,021	10,089	1,621,942	11,717
Compounds (inorganic and organic)	do.	1,306,463	12,771	1,087,584	14,123
Ferrocerium and pyrophoric alloys	do.	2,737,342	15,842	4,806,785	20,382
Metals (includes scandium and yttrium)	do.	36,452	1,098	161,421	2,395
Selenium (metal, waste and scrap, selenium content)	do.	174,788	1,658	261,393	2,195
Silicon:					
Ferrosilicon	metric tons	55,996	45,825	39,506	36,759
Metal	do.	8,531	93,813	10,618	133,297
Silver:					
Bullion (refined)	kilograms	910,587	125,531	705,225	100,191
Doré and precipitates	do.	88,894	16,104	103,289	16,032
Ores and concentrates	do.	8,505	1,503	2,269	395
Waste and scrap	do.	745,221	110,381	892,407	141,921
Tantalum:					
Ores and concentrates (includes synthetic)	thousand kilograms	19	50	11	111
Unwrought (alloys, metal, powders, and waste and scrap)	do.	131	24,329	242	24,876
Wrought	do.	66	22,668	50	18,674
Thorium:					
Compounds	kilograms	93	12	189	68
Ore (monazite concentrate)	do.	5,000	11	W	W
Tin:					
Ingots and pigs	metric tons	1,888	8,957	2,598	11,377
Tin scrap and other tin bearing material (except tinplate scrap, includes bars, rods, profiles, wire, powders, flakes, tubes, and pipes)	do.	127,191	89,298	92,585	63,240
Tinplate and terneplate	do.	272,549	162,302	200,794	120,068
Titanium:					
Metal:					
Scrap	do.	2,770	7,201	3,892	9,074
Sponge	do.	178	1,102	104	748
Other unwrought (billet, blooms and sheet bars, ingots, etc.)	do.	2,640	43,372	1,511	27,113
Wrought (bars, rods, etc.)	do.	2,431	[r]81,027	2,386	72,678
Ores and concentrates	do.	34,665	10,566	15,202	4,893
Pigments (dioxides and oxides)	do.	270,422	420,372	290,192	405,165

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Tungsten (tungsten content):					
Ammonium paratungstate	metric tons	470	$3,354	166	$2,211
Carbide powder	do.	715	18,098	1,250	22,484
Metal and alloy powder	do.	316	8,380	416	7,859
Miscellaneous tungsten-bearing materials (ferrotungsten and ferrosilicon tungsten, unwrought, wire [metal and alloy], wrought, other compounds [other tungstates], and other metal)	do.	684	28,332	550	24,029
Ore and concentrate	do.	38	284	63	309
Vanadium:					
Aluminum-vanadium master alloy	kilograms	545,198	9,564	865,291	10,757
Compounds (pentoxide [anhydride], and other [excludes vanadates], vanadium content)	do.	1,138,653	4,921	1,020,590	5,255
Ferrovanadium	do.	325,656	3,727	290,845	2,776
Zinc:					
Compounds (chloride, lithopone, oxide, sulfate, sulfide, and compounds n.s.p.f.)	metric tons	16,081	59,593	17,270	50,400
Ore and concentrates	do.	[r]307,118	[r]212,203	311,278	117,137
Zirconium:					
Ore and concentrates	do.	27,853	14,323	35,932	13,177
Unwrought and waste and scrap	do.	389	13,070	248	6,145
Total[1]		XX	18,450,000	XX	22,387,000
INDUSTRIAL MINERALS					
Abrasive materials (includes reexports):					
Natural		XX	177,542	XX	202,549
Manufactured		XX	205,732	XX	218,741
Asbestos (includes reexports):					
Manufactured		XX	134,102	XX	141,087
Unmanufactured	metric tons	24,860	6,724	27,643	8,435
Barite: Natural barium sulfate	do.	12,469	1,806	18,486	2,608
Boron:					
Boric acid	thousand metric tons	80	53,652	74	50,498
Sodium borates	do.	489	159,492	481	181,310
Bromine:					
Compounds (contained bromine)	thousand kilograms	16,946	26,445	13,351	21,750
Elemental	do.	5,320	5,542	6,013	7,441
Calcium chloride	metric tons	38,365	8,808	(2)	(2)
Cement: Hydraulic and clinker	thousand metric tons	747	48,720	625	47,772
Clays:					
Ball	do.	49	3,120	60	3,197
Bentonite	do.	591	53,652	606	55,392
Fire clay	do.	228	23,537	148	14,842
Fuller's earth	do.	27	4,022	63	7,632
Kaolin	do.	3,000	490,869	2,984	488,053
Other (includes chamotte or dinas earth, activated clays and earths, and artificially activated clays)	do.	262	88,278	293	100,404

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Diatomite	thousand metric tons	163	$50,704	165	$49,874
Feldspar	metric tons	17,700	2,212	17,669	1,835
Fluorspar	do.	13,646	1,983	12,739	2,126
Gemstones (includes reexports):					
Diamonds (excludes industrial diamond)	carats	[r]1,924,578	[r]1,361,400	1,630,447	1,499,100
Other precious stones (cut but unset, or rough other than diamonds, pearls, and synthetics)		XX	241,200	XX	103,100
Synthetic		XX	21,200	XX	19,300
Natural, cultured, and imitation pearls (not set or strung)		XX	6,700	XX	7,300
Graphite:					
Artifical (includes artifical, and colloidal or semicolloidal)[3]	metric tons	34,487	32,689	17,358	11,149
Natural (amorphous, crystalline flake, lump or chip, and natural n.e.c.)	do.	20,217	12,244	35,039	30,851
Gypsum:					
Boards	thousand metric tons	137	39,177	91	24,618
Crude	do.	98	3,946	69	3,640
Plasters	do.	137	22,303	156	21,173
Other	do.	XX	31,557	XX	28,198
Helium (Grade-A)	million cubic meters	31	72,108	28	67,000
Iodine:					
Crude-resublimed	thousand kilograms	1,625	15,139	1,016	8,557
Potassium iodide	do.	182	402	203	1,178
Iron oxide pigments:					
Pigment grade	metric tons	21,117	32,173	22,368	32,022
Other grade	do.	172,162	115,935	139,461	92,539
Lime	do.	58,513	7,540	69,045	7,825
Lithium compounds:					
Carbonate	kilograms	8,225,957	27,008	6,255,942	22,238
Hydroxide	do.	2,911,116	13,183	3,058,801	13,176
Metal	do.	62,232	NA	NA	NA
Magnesium compounds:					
Calcined dolomite	metric tons	19,584	3,314	13,744	2,818
Caustic-calcined magnesia	do.	5,262	2,404	4,453	2,459
Compounds (chlorides, hydroxide and peroxide, and sulfates)	do.	9,586	8,253	9,892	7,932
Dead-burned and fused magnesia	do.	56,758	22,257	59,847	21,807
Magnesite (crude)	do.	5,926	[r]4,218	7,390	2,911
Other magnesia	do.	19,075	11,540	22,014	11,148
Mica:					
Scrap and flake:					
Powder	do.	3,954	2,054	4,614	2,604
Waste	do.	475	204	335	99
Sheet:					
Unworked	do.	170	307	292	511
Worked	do.	436	7,180	617	9,019
Nitrogen compounds (major):					
Anhydrous ammonia	thousand metric tons	431	NA	460	NA

See footnotes at end of table.

TABLE 8—Continued

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

Mineral		1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
INDUSTRIAL MINERALS—Continued					
Nitrogen compounds (major)—Continued:					
Fertilizer materials	thousand metric tons	12,205	NA	10,877	NA
Industrial chemicals	do.	142	$120,731	149	$119,075
Peat	do.	22	NA	8	NA
Perlite (crude)	metric tons	^{e}29,000	^{e}825	26,000	1,000
Phosphorus:					
Diammonium and monoammonium phosphates	thousand metric tons	9,161	NA	8,459	NA
Elemental phosphorous	metric tons	17,880	32,784	18,353	32,188
Phosphate rock:					
Ground	thousand metric tons	288	NA	107	NA
Unground	do.	3,689	NA	3,464	NA
Phosphoric acid	do.	602	NA	498	NA
Superphosphates	do.	1,114	NA	762	NA
Potash:					
Potassium chloride (all grades)	metric tons	^{r}708,474	NA	361,193	NA
Potassium magnesium sulfate	do.	^{r}292,630	NA	332,855	NA
Potassium nitrate	do.	^{r}18,597	NA	8,002	NA
Potassium sulfate	do.	^{r}309,812	NA	223,180	NA
Pumice and pumicite	thousand metric tons	^{e}11	^{e}341	^{e}18	^{e}462
Quartz crystal (cultured)	thousand kilograms	15	1,278	24	2,264
Salt	thousand metric tons	992	32,193	688	34,806
Sand and gravel:					
Construction:					
Gravel	do.	550	5,364	534	4,995
Sand	do.	870	12,599	597	10,599
Industrial	do.	1,337	90,403	1,751	90,990
Sodium compounds:					
Soda ash	do.	2,955	433,606	2,798	376,206
Sodium sulfate	do.	155	^{r}11,865	89	8,540
Stone:					
Crushed	metric tons	3,656,800	43,400	4,824,400	39,300
Dimension		NA	54,904	NA	57,888
Strontium compounds (precipitated carbonate, oxide, hydroxide, and peroxide)	kilograms	1,186,259	2,193	427,871	451
Sulfur:					
Elemental	thousand metric tons	966	69,662	656	39,726
Sulfuric acid (100% H_2SO_4)	metric tons	139,456	^{r}11,867	141,800	11,169
Talc (excludes talcum in packages, face, and compact)	thousand metric tons	175	30,070	135	27,167
Vermiculite	do.	^{e}8	NA	^{e}7	NA
Total[1]		XX	4,619,000	XX	4,517,000
Grand total[1]		XX	23,069,000	XX	26,904,000

^{r}Revised. NA Not available. XX Not applicable.

[1] Rounded.

[2] Commodity coverage discontinued beginning 1993.

[3] Artificial graphite includes large amounts of materials made from petroleum coke.

TABLE 9

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS					
Aluminum:					
Aluminum oxide (alumina)	thousand metric tons	4,701	$886,613	3,936	$754,452
Crude and semicrude	metric tons	1,724,624	2,462,070	2,544,954	3,260,523
Manufactures	do.	47,204	147,566	55,977	162,959
Antimony:					
Metal	do.	15,100	26,077	14,364	25,594
Ore and concentrate (antimony content)	do.	1,923	3,710	543	1,066
Oxides (antimony content)	do.	14,181	22,619	16,037	24,847
Arsenic:					
Acid	do.	40	34	—	—
Metal	do.	740	2,550	767	2,401
Sulfides	do.	(1)	31	—	—
Trioxide	do.	30,671	16,342	27,530	15,871
Bauxite:					
Calcined	thousand metric tons	346	23,289	237	16,998
Crude and dried	do.	10,939	NA	11,621	NA
Beryllium:					
Beryl	metric tons	61	NA	58	NA
Metal and compounds	kilograms	108,392	1,237	116,102	1,694
Bismuth metals and alloys	do.	1,620,534	7,681	1,334,647	6,252
Cadmium metal	metric tons	1,958	3,842	1,415	1,689
Chromium:					
Chemicals	do.	9,948	20,278	15,464	21,733
Chromite ore	do.	219,474	15,299	254,802	16,506
Ferrochromium (all grades)	do.	410,798	235,140	387,015	183,816
Metals and alloys (metal [waste and scrap and other], and ferrochroumim-silicon)	do.	14,830	44,027	14,921	44,082
Pigments and preparations based chromium	do.	6,943	15,308	4,981	12,693
Cobalt:					
Metal (alloys, articles, matte, wrought, and waste and scrap)	do.	805	19,200	752	16,900
Metal (unwrought, excluding alloys and waste and scrap)	do.	5,274	246,393	5,388	166,284
Oxide and hydroxides	do.	431	18,651	444	12,612
Other forms (acetates, carbonates, chlorides, and sulfates)	do.	629	7,779	842	7,315
Columbium:					
Ferrocolumbium	thousand kilograms	3,767	31,075	3,367	28,997
Ores and concentrates	do.	2,428	8,764	2,348	8,614
Oxide	do.	792	13,473	301	5,392
Unwrought (alloys, metals, and powders)	do.	1	101	111	2,381
Copper:					
Scrap (alloyed and unalloyed)	metric tons	168,750	284,144	199,847	307,186
Semimanufactures (bare wire [includes wire rod], bars, cable [stranded], foil, hydroxides, oxides, pipes, plates, tubing, sheets, and wire [stranded])	do.	67,507	275,504	73,774	266,836

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Copper—Continued:					
Sulfate	metric tons	8,290	NA	9,431	NA
Unmanufactured (anode, ash, blister, concentrates, matte, ore, precipitates, and refined, copper content)	do.	457,233	$923,815	480,251	$919,870
Gallium (unwrought, waste and scrap)	kilograms	8,479	3,126	15,585	4,128,242
Germanium materials	do.	13,229	4,871	15,499	5,295
Gold:					
Bullion (refined)	do.	141,251	1,568,186	130,045	1,495,434
Doré and precipitates	do.	17,092	175,542	12,539	134,904
Ore and concentrates	do.	351	3,877	1,240	13,531
Waste and scrap	do.	15,649	66,376	25,480	65,360
Hafnium (unwrought, and waste and scrap)	metric tons	2	431	3	669
Indium (unwrought, and waste and scrap)	kilograms	54,417	10,824	73,426	11,464
Iron ore:					
Pellets	thousand metric tons	8,880	314,372	9,794	332,973
Usable (agglomerates, byproduct ore, concentrates, and direct-shipping ore, [less than 5% manganese])	do.	12,504	395,791	14,097	420,799
Iron and steel:					
Direct-reduced iron	metric tons	544,715	56,445	924,046	90,796
Ferroalloys not elsewhere listed:					
Ferrophosphorus	do.	7,492	1,920	9,973	2,325
Ferrotitanium and ferrosilicon-titanium	do.	1,357	3,202	45,428	8,068
Ferrozirconium	do.	1	2	267	506
Ferroalloys (n.e.c.)	do.	16,518	23,830	16,521	34,909
Pig iron	do.	496,547	[r]72,784	828,168	116,736
Products:					
Cast	thousand metric tons	191	196,428	228	217,478
Fabricated	do.	1,762	2,887,517	2,054	3,756,072
Steel mill	do.	15,490	7,892,621	17,691	8,626,028
Other steel	do.	NA	NA	28	59,709
Scrap:					
Iron and steel	do.	1,316	147,616	1,545	175,825
Ships, boats, and other vessels for scrapping	do.	([1])	31	([1])	82
Used rails for rerolling and other uses	do.	78	15,583	70	13,571
Stainless steel (bars, pipe, plate, semifinished, shapes, sheet, strip, tube, wire and wire rods)	metric tons	400,077	NA	611,030	NA
Lead:					
Base bullion (lead content)	do.	218	94	18	62
Ore and concentrates (lead content)	do.	5,310	3,422	483	347
Pigments and compounds	do.	30,239	36,197	30,892	33,640
Pigs and bars (lead content)	do.	190,723	106,433	195,572	85,100
Scrap (reclaimed, includes ash and residues, lead content)	do.	236	65	90	39
Wrought (all forms, including wire and powders, gross weight)	do.	7,094	10,548	6,889	10,288

See footnotes at end of table.

TABLE 9—Continued

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

Mineral	1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued				
Magnesium:				
Alloys (magnesium content) metric tons	3,839	$14,545	8,084	$27,544
Metal do.	4,244	11,030	24,236	53,100
Powder, sheets, tubing, ribbons, wire, and other forms (magnesium content) do.	1,336	4,281	1,469	4,622
Waste and scrap do.	2,425	2,821	3,459	4,522
Manganese:				
Chemicals (manganese dioxide and potassium permanganate) do.	22,193	33,024	25,397	38,200
Metal do.	13,952	21,991	15,124	22,476
Ore and concentrates (manganese content) do.	240,800	59,934	231,540	49,855
Ferromanganese (all grades, manganese content) do.	476,940	333,631	541,939	335,190
Silicomanganese (manganese content) do.	169,047	118,464	208,266	133,413
Mercury (metal, mercury-bearing waste and scrap) do.	92	403	40	143
Molybdenum (molybdenum content):				
Ferromolybdenum do.	1,096	6,974	2,190	12,725
Molybdates (all) do.	86	763	317	2,634
Ore and concentrates do.	831	4,081	3,398	16,976
Oxides and hydroxides (gross weight) do.	1,032	3,928	622	2,875
Powder do.	52	1,784	52	2,086
Unwrought do.	46	1,437	136	1,753
Wire (gross weight) do.	1	177	3	308
Wrought (gross weight) do.	46	3,004	49	3,426
Other (inorganic compounds, orange, waste and scrap, and other, gross weight) do.	1,029	4,476	1,879	5,549
Nickel (nickel content):				
Alloyed (bars, foil, ingot [unwrought], pipes, profiles, rods, sheets, strips, tubes, wires, and other articles) do.	5,944	72,517	7,049	80,827
Ore do.	3,584	W	2,966	W
Unwrought:				
Primary (briquets, cathodes, chemicals [catalysts and salts], ferronickel, flakes, oxide [metallurgical grade], pellets, powder and shot) do.	118,760	871,086	126,352	739,305
Secondary (scrap [stainless steel and waste]) do.	9,506	47,791	6,713	39,305
Wrought (bars, foil, pipes, profiles, rods, sheets, strips, tubes, and wire) do.	951	15,319	991	15,436
Platinum-group metals (iridium, ores, osmium, palladium, platinum, rhodium, ruthenium, ores, and waste and scrap) kilograms	132,006	1,483,680	153,165	1,310,895
Rare-earth metals (rare-earth oxide content):				
Cerium compounds (includes chlorides, hydroxides, nitrates, oxides, oxilate, and sulfates) do.	[r]806,241	[r]8,010	1,267,784	10,025
Compounds (includes hydroxides, nitrates, oxides, and others, except chlorides) do.	[r]4,132,819	[r]34,572	4,976,002	39,401
Chloride mixtures (except cerium chloride) do.	1,583,402	7,692	2,355,802	8,088
Ferrocerium and other pyrophoric alloys do.	105,630	1,613	118,082	1,654
Oxide mixtures (except cerium oxides) do.	294,971	14,853	249,493	10,557
Rare-earth metals (whether intermixed or alloyed) do.	[r]293,093	[r]3,167	195,866	2,644

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Rhenium:					
Ammonium perrhenate	kilograms	5,694	$2,833	3,168	$1,601
Metal	do.	6,385	7,522	2,698	3,333
Selenium: (selenium content)					
Selenium dioxide	do.	9,484	196	14,518	143
Unwrought, and waste and scrap	do.	361,043	6,776	367,195	6,884
Silicon:					
Ferrosilicon	metric tons	247,601	113,911	20,014	110,528
Metal	do.	32,716	92,734	72,232	125,613
Silver:					
Bullion (refined)	kilograms	2,661,622	340,898	2,183,146	296,716
Doré and precipitates	do.	528,715	102,118	281,217	78,590
Ore and concentrates	do.	25,352	3,885	35,692	6,405
Waste and scrap	do.	1,774,085	54,492	1,270,486	46,036
Tantalum:					
Ores and concentrates (includes synthetic)	thousand kilograms	1,367	35,600	1,294	32,740
Unwrought (alloys, metal, powders, and waste and scrap)	do.	103	5,757	165	14,770
Wrought	do.	2	768	3	547
Tellurium (unwrought, and waste and scrap)	kilograms	48,384	3,700	44,997	3,183
Thallium (unwrought waste and scrap)	do.	838	NA	273	35
Thorium:					
Compounds	do.	13,505	526	18,330	479
Ore metal (excludes monazite)	do.	186,803	36	—	—
Tin:					
Compounds	metric tons	510	3,883	431	3,145
Metal (unwrought)	do.	27,314	163,023	33,682	174,497
Miscellaneous tin and tin manufactures (alloys [n.s.p.f.], dross, flitters, foil, metallics, powder, residues, scrap, skimmings, and manufactures [n.s.p.f.])	do.	XX	60,208	XX	30,305
Tinplate and terneplate	do.	[r]295,231	200,534	237,356	160,714
Tinplate scrap	do.	28,500	7,070	12,559	1,424
Titanium:					
Concentrates:					
Ilmenite	do.	294,585	20,414	301,447	18,426
Rutile (natural and synthetic)	do.	317,399	129,758	371,481	135,028
Titaniferous iron ore	do.	32,381	1,564	66,253	2,854
Titanium slag	do.	537,118	155,943	475,522	150,401
Metal:					
Ingots and billets	do.	241	2,062	272	3,034
Powder	do.	50	886	37	813
Unwrought	do.	684	5,363	2,163	10,473
Waste and scrap	do.	6,257	19,436	5,519	18,105
Wrought (bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other)	do.	456	12,830	600	17,237
Other (includes bars, blooms, sheet, slabs, and other unwrought)	do.	78	491	131	761
Pigments (dioxides and oxides)		169,260	284,843	171,939	284,046

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
METALS—Continued					
Tungsten (tungsten content):					
Ammonium paratungstate	metric tons	378	$2,647	1,176	$6,481
Ferrotungsten	do.	414	2,194	652	2,827
Miscellaneous tungsten-bearing materials (carbide, chlorides, oxides, unwrought, tungstates [calcium and sodium], waste and scrap, wrought, and other tungsten-bearing material)	do.	3,375	50,152	3,960	42,306
Ore and concentrates	do.	2,477	16,265	1,721	7,843
Vanadium:					
Ferrovanadium (vanadium content)	kilograms	592,490	7,038	1,627,897	12,235
Pentoxide (anhydride, vanadium content)	do.	205,956	1,364	69,830	381
Vanadium-bearing materials (ash, residues, slag, other [includes spent catalyst], pentoxide content)	do.	1,495,199	3,500	2,594,973	3,316
Zinc:					
Compounds (chloride, lithopone, oxide, sulfate, sulfide, and compounds n.s.p.f.)	metric tons	49,072	59,594	48,572	53,210
Zirconium:					
Ore and concentrates	do.	37,439	6,906	70,035	9,323
Unwrought and waste and scrap	do.	115	821	121	1,164
Total[2]		XX	24,938,000	XX	30,989,000
INDUSTRIAL MINERALS					
Abrasive materials (natural and artificial)		XX	482,134	XX	529,003
Asbestos (unmanufactured)	metric tons	31,602	7,210	30,840	6,956
Barite:					
Barium chemicals	do.	32,173	24,322	30,347	24,520
Crude and ground	do.	353,665	17,324	803,766	34,180
Boron (contained boric oxide):					
Borax	thousand metric tons	16	5,328	40	1,226
Boric acid	do.	6	4,337	17	11,910
Colemanite	do.	30	[r]16,050	90	48,600
Ulexite	do.	42	[r]11,340	149	40,677
Bromine:					
Compounds (contained bromine)	thousand kilograms	14,646	32,559	18,399	47,741
Elemental	do.	851	522	850	513
Calcium:					
Metal	kilograms	815,264	4,452	(3)	(3)
Chloride (crude)	metric tons	128,253	17,653	(3)	(3)
Other compounds	do.	69,818	32,825	(3)	(3)
Cement: Hydraulic and clinker	thousand metric tons	[r]6,166	297,174	7,060	331,337
Clays:					
Kaolin (China clay)	do.	4,221	2,122	7,622	3,461
Fire clay	do.	8,089	937	1,096	282
Fuller's earth and decolorizing earths	do.	160	31	101	29
Bentonite	do.	2,527	1,257	1,994	664
Ball and common blue clay	do.	753	262	687	228
Other (chamotte or dina's earth, artifically activated clay and activated earth)	do.	25,553	10,926	27,930	12,900

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
INDUSTRIAL MINERALS—Continued					
Diatomite	metric tons	182	$128	1,882	$338
Feldspar	do.	12,965	923	7,054	514
Fluorspar:					
Aluminum fluoride	do.	32,274	29,268	39,397	31,119
Cryolite	do.	4,067	3,897	3,780	3,070
Fluorspar	do.	[r]407,239	[r]42,505	398,322	38,761
Hydrofluoric acid	do.	67,135	67,051	62,949	59,977
Gemstones (diamonds, emeralds, coral and similar materials, jade, rubies and sapphires, pearls, and other precious and semiprecious stones)		XX	[r]4,948,722	XX	5,850,894
Graphite:					
Natural (amorphous, crystalline flake, lump or chippy dust, and other nautral [crude and refined])	metric tons	49,744	25,538	52,172	29,850
Electrodes (electric furnace)	do.	27,388	43,740	33,989	57,778
Gypsum:					
Boards	thousand metric tons	96	8,803	171	16,241
Crude	do.	7,180	52,972	7,393	58,221
Plasters	do.	6	660	23	1,665
Other	do.	XX	33,600	XX	34,870
Iodine:					
Crude	thousand kilograms	3,652	32,911	3,501	27,673
Potassium iodide	do.	93	891	114	997
Iron oxide pigments:					
Natural	metric tons	3,428	[r]1,383	4,837	1,376
Synthetic	do.	41,648	48,487	38,778	55,943
Kyanite (andalucite)	do.	6,380	1,126	12,201	2,134
Lime:					
Hydrated	do.	40,877	3,661	45,468	3,301
Quicklime	do.	151,918	11,322	155,119	9,998
Lithium:					
Carbonate	kilograms	4,052,048	10,617	4,288,561	12,120
Hydroxide	do.	36,430	294	23,794	238
Magnesium compounds:					
Calcined dolomite	metric tons	23,904	[r]3,245	35,796	4,430
Caustic-calcined magnesia	do.	83,051	12,309	140,654	15,709
Compounds (chlorides, hydroxide, peroxide, and sulfates)	do.	28,475	5,817	34,043	6,138
Dead-burned and fused magnesia	do.	210,415	37,928	279,321	48,673
Magnesite (crude)	do.	3,407	623	332	251
Other magnesia	do.	3,284	6,160	5,119	6,265
Mica:					
Scrap and flake:					
Powder	do.	11,568	7,479	13,098	8,070
Waste	do.	3,786	974	4,765	1,307
Sheet:					
Unworked	do.	2,054	2,011	2,956	2,524
Worked	do.	1,407	9,011	1,352	9,338
Nepheline syenite (crushed and ground)	do.	335,000	14,749	289,000	15,447

See footnotes at end of table.

TABLE 9—Continued

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

Mineral		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
NDUSTRIAL MINERALS—Continued					
Nitrogen compounds:					
Anhydrous ammonia	thousand metric tons	3,271	$365,826	3,233	$414,669
Fertilizer materials	do.	6,505	818,978	8,269	1,090,257
Industrial chemicals	do.	49	47,321	51	48,789
Peat moss (poultry and fertilizer grade)	do.	[r]638,671	110,749	647,921	118,286
Perlite (crude)	metric tons	[e]65,000	[e]1,900	70,000	2,000
Phosphate rock and phosphate materials	thousand metric tons	1,560	74,582	632	56,044
Potash:					
Potassium chloride	metric tons	[r]6,869,502	[r]551,808	7,050,036	548,639
Potassium nitrate	do.	[r]39,067	[r]11,267	28,140	7,827
Potassium sodium nitrate mixtures	do.	[r]36,914	[r]5,581	38,907	5,971
Potassium sulfate	do.	[r]67,746	[r]11,779	87,308	15,437
Pumice:					
Crude or unmanufactured	thousand metric tons	254	[r]6,785	142	6,429
Wholly or partially manufactured	do.	3	[r]1,230	1	635
Salt	do.	5,394	87,714	5,868	99,963
Sand and gravel:					
Construction	do.	1,311	15,463	1,316	15,445
Industrial	do.	164	2,454	44	2,439
Sodium compounds:					
Soda ash	do.	72	12,772	89	17,084
Sodium sulfate	do.	158	13,444	163	13,637
Stone:					
Crushed and calcium carbonate fines	thousand metric tons	7,000	60,700	8,400	74,300
Dimension		NA	403,922	NA	397,821
Strontium:					
Celestite (strontium sulfate)	metric tons	44,810	3,026	26,367	1,930
Compounds (carbonate and nitrate)	kilograms	22,370,558	13,877	26,302,881	15,826
Sulfur:					
Elemental	thousand metric tons	2,725	129,894	2,039	49,627
Sulfuric acid (100% H_2SO_4)	metric tons	1,985,414	68,496	2,438,592	70,698
Talc (unmanufactured)	do.	79,560	12,408	99,806	10,762
Vermiculite	thousand metric tons	[e]40	NA	[e]30	NA
Total[2]		XX	9,270,000	XX	10,594,000
Grand total[2]		XX	34,208,000	XX	41,583,000

[r] Revised. NA Not available. XX Not applicable.

[1] Less than 1/2 unit.

[2] Rounded.

[3] Commodity coverage discontinued beginning 1993.

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

(Metric tons unless otherwise specified)

Mineral		1992			1993		
		World production[r] [1]	U.S. production	U.S. percent of world production	World production[e] [1]	U.S. production	U.S. percent of world production
METALS, MINE BASIS							
Antimony[2]		75,011	W	NA	73,288	W	NA
Arsenic trioxide		48,197	—	—	47,740	—	—
Bauxite[3]	thousand tons	101,145	W	NA	105,550	W	NA
Beryl[4]		6,952	[5]4,826	69	6,766	[5]4,939	73
Chromite	thousand tons	10,993	—	—	10,001	—	—
Cobalt[2] [4]		27,131	—	—	22,224	—	—
Columbium-tantalum concentrate (gross weight)[6]		37,118	—	—	30,513	—	—
Copper[2]	thousand tons	9,453	[r]1,765	19	9,352	1,801	19
Gold[2]	kilograms	2,298,809	[r]330,212	14	2,330,321	331,013	14
Iron ore (gross weight)	thousand tons	963,159	55,593	6	988,797	55,651	6
Lead[2]	do.	3,109	[r]407	13	2,926	362	12
Manganese ore (gross weight)	do.	21,608	—	—	21,757	—	—
Mercury		2,108	64	3	2,563	W	NA
Molybdenum[2]		107,610	49,725	46	95,286	36,803	39
Nickel[2]		974,342	[5]6,671	1	899,149	[5]2,464	(7)
Platinum-group metals	kilograms	281,438	[e]8,310	3	250,718	[e]8,300	3
Silver[2]		14,737	1,804	12	14,089	1,645	12
Tin[2]		178,365	W	NA	178,207	W	NA
Titanium concentrates (gross weight):							
Ilmenite (including leucoxene)	thousand tons	3,384	W	NA	3,579	W	NA
Rutile	do.	453	W	NA	464	W	NA
Tungsten[2]		37,452	W	NA	29,509	W	NA
Vanadium[2]		28,150	1,347	5	28,937	2,867	10
Zinc[2]	thousand tons	7,227	552	8	6,895	513	7
METALS, REFINERY BASIS							
Aluminum	do.	19,467	4,042	21	19,816	3,695	19
Bismuth		3,164	W	NA	3,351	W	NA
Cadmium		20,201	1,620	8	18,913	1,094	6
Cobalt		21,901	—	—	16,893	—	—
Copper (primary and secondary)[8]	thousand tons	11,163	[r]2,144	19	11,375	2,253	20
Lead (primary and secondary)[9]	do.	5,517	[r]1,221	22	5,420	1,239	23
Magnesium (primary)		306,381	136,947	45	283,944	132,144	47
Nickel[10]		885,322	8,962	1	806,972	4,878	1
Selenium[6]	kilograms	1,732,169	242,797	14	1,709,848	283,248	17
Tellurium[4]	do.	97,585	W	NA	87,398	W	NA
Tin[11]		198,015	W	NA	192,992	W	NA
Zinc (primary and secondary)	thousand tons	7,136	400	6	7,177	382	5
IRON AND STEEL							
Direct-reduced iron	thousand tons	20,883	390	2	23,816	440	2
Iron, pig	do.	496,395	47,377	10	504,091	48,155	10
Steel, raw	do.	722,384	84,322	12	725,129	88,793	12

See footnotes at end of table.

TABLE 10—Continued

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

(Metric tons unless otherwise specified)

Mineral		1992			1993		
		World production r[1]	U.S. production	U.S. percent of world production	World production e[1]	U.S. production	U.S. percent of world production
INDUSTRIAL MINERALS							
Asbestos	thousand tons	3,271	[12]16	(7)	2,775	[12]14	(7)
Barite	do.	5,118	r[12]326	6	4,890	[12]315	6
Boron minerals	do.	2,660	[12]1,009	38	2,178	[12]1,055	48
Bromine		392,703	[12]171,000	44	392,650	e[12]177,000	45
Cement, hydraulic[13]	thousand tons	1,241,217	71,426	6	1,300,643	e72,400	6
Clays:							
Bentonite[4]	do.	8,292	r2,954	36	7,949	3,093	39
Fuller's earth[6]	do.	3,572	[12]2,413	68	3,613	[12]2,454	68
Kaolin[4]	do.	22,726	r[12]8,735	38	24,568	[12]8,958	36
Diamond, natural	thousand carats	105,521	—	—	107,620	—	—
Diatomite	thousand tons	1,506	[12]595	40	1,463	[12]599	41
Feldspar	do.	6,035	725	12	6,009	770	13
Fluorspar	do.	4,054	e[5]51	1	4,031	e[5]60	1
Graphite, natural		755,905	—	—	741,040	—	—
Gypsum	thousand tons	101,671	14,759	15	103,203	15,812	15
Iodine, crude		16,581	1,995	12	16,625	1,935	12
Lime[13]	thousand tons	125,955	[12]16,227	13	124,395	[12]16,959	14
Magnesite, crude	do.	10,501	W	NA	10,136	W	NA
Mica (including scrap and flake)		199,502	85,338	43	190,314	87,931	46
Nitrogen: N content of ammonia	thousand tons	93,253	r[14]13,643	15	91,497	[14]12,865	14
Peat[15]	do.	153,798	599	(7)	140,288	616	(7)
Perlite[4]		1,538,417	r[12]541,000	35	1,584,722	[12]568,600	36
Phosphate rock (gross weight)	thousand tons	146,004	46,965	32	131,641	35,494	27
Potash (K_2O equivalent)	do.	24,044	1,705	7	20,864	1,506	7
Pumice[16]	do.	10,758	[12]481	4	10,735	[12]469	4
Salt[13]	do.	181,270	34,829	19	186,190	e38,710	21
Sand and gravel, industrial (silica)[4]	do.	108,305	r[12]25,195	23	108,053	[12]26,220	24
Sodium compounds, n.e.s. (natural and manufactured):							
Soda ash	do.	31,712	9,379	30	31,136	8,959	29
Sulfate	do.	4,405	609	14	4,356	651	15
Strontium[4]		139,223	—	—	145,828	—	—
Sulfur, all forms	thousand tons	52,740	10,663	20	52,270	10,959	21
Talc and pyrophyllite[17]	do.	8,756	997	11	8,696	968	11
Vermiculite		470,075	[12]190,000	40	489,334	[12]190,000	39

See footnotes at end of table.

TABLE 10—Continued

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

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

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

[2] Content of ore and concentrate.

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

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

[5] Shipments.

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

[7] Less than 1/2 unit.

[8] 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.

[9] Includes bullion.

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

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

[12] Quantity sold or used by producers.

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

[14] Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

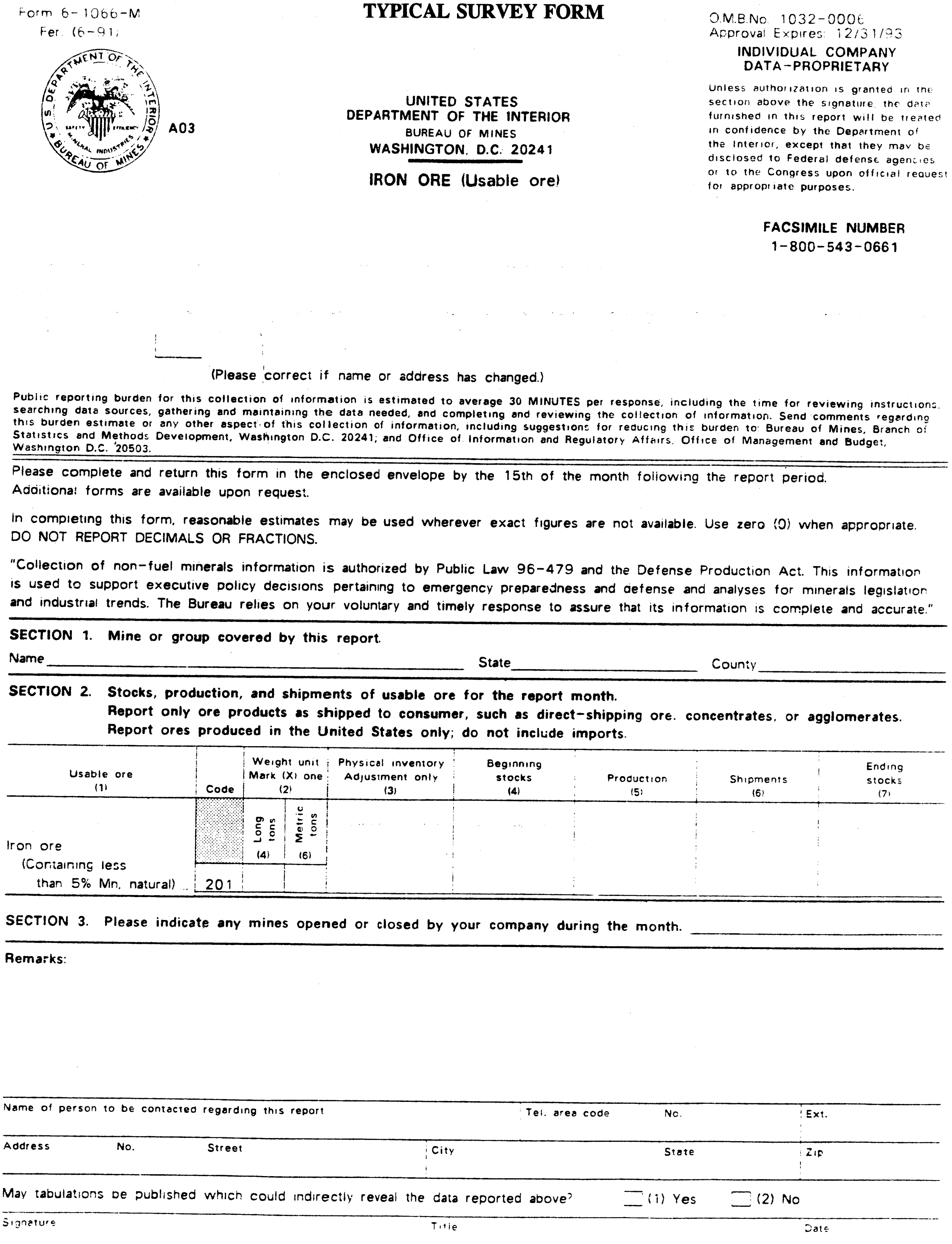
[15] Data for the United States exclude proprietary amounts of fuel peat.

[16] World total does not include an estimate for output in the former U.S.S.R.

[17] Data for the United States exclude proprietary pyrophyllite production.

FIGURE 1

TYPICAL SURVEY FORM



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

A03

O.M.B.No. 1032-0006
Approval Expires: 12/31/93

INDIVIDUAL COMPANY DATA-PROPRIETARY

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

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

IRON ORE (Usable ore)

FACSIMILE NUMBER
1-800-543-0661

(Please correct if name or address has changed.)

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

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

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

SECTION 1. Mine or group covered by this report.

Name ____________________ State ____________ County ____________

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

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

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

Remarks:

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

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

Signature Title Date

MINING AND QUARRYING TRENDS IN THE METALS AND INDUSTRIAL MINERALS INDUSTRIES

By Donald P. Mickelsen and Jean K. Moore

Mr. Mickelsen, a supervisory data analyst with 22 years of U.S. Bureau of Mines experience, has been with the Branch of Data Collection and Coordination since 1991. Survey data were prepared by Miss Moore, an industry data analyst with 23 years of U.S. Bureau of Mines experience.

The mining and quarrying trends data shown in this report were reported to the U.S. Bureau of Mines (USBM) by mining and quarrying companies on the Mine Information Supplement survey, as well as by mineral producers on 58 annual USBM production and consumption surveys covering 59 nonfuel mineral commodities. The 1993 data, presented in the tables of this chapter, were processed for the first time using the USBM Automated Mineral Information System.

Domestic mining of nonfuel mineral materials totaled 3.7 billion metric tons in 1993, including 2.2 billion tons of crude ore mined or quarried and 1.5 billion tons of mine waste and ore from development. This was an overall increase of 11% over that of 1992. These data do not include construction sand and gravel which until 1993 has been surveyed biennially. Starting in 1994, construction sand and gravel and the stones, which were also surveyed biennially, will be surveyed annually.

Of the nonfuel mineral materials mined, 57% was for the production of metals and 43% was for the production of industrial minerals. Crude ore mining alone increased 24% for industrial minerals but remained practically unchanged for metals.

Surface mining and quarrying of nonfuel materials increased overall 9% to 3.6 billion tons and underground mining although small, almost doubled, increasing to 129 million tons. Surface mining for industrial minerals totaled 1.5 billion tons, of which 1.2 billion tons was crude ore mined and the remainder was waste and ore from development. Underground mining for industrial minerals was minor, amounting to 94 million tons, practically all of which was crude ore.

Surface mining for metal ores totaled 2.1 billion tons, of which about 921 million tons amounted to crude ore mined, while the remaining 1.1 billion tons was waste and ore from development. Underground mining of metal ores was small, amounting to 35 million tons, almost all of which was crude ore.

The major States in which mining for nonfuel materials occurred were Nevada, Arizona, Florida, Minnesota, and California. These States accounted for slightly over one-half of the mining conducted in the United States and three of these five States have shown significant decreases from mining in the previous year. Virtually all of the mining in these five States was surface mining.

The overall average value of mineral products of surface and underground nonfuel minerals mined in the United States remained virtually unchanged at $10.23 per ton. The average value of principle mineral products, including industrial sand and gravel and stone, increased slightly to $9.47 per ton while mineral byproducts were valued at $0.76 per ton. Average values for metal ore products increased slightly to $11.68 per ton overall, $10.74 for principle mineral products, and, $0.93 for byproducts; average values for industrial mineral products also increased slightly to $9.22 per ton overall, $8.57 for principle mineral products, and $0.64 for byproduct materials.

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

(Million metric tons)

Type and year	Surface[1]			Underground[2]			All mines[3]		
	Crude ore	Waste[4]	Total[3]	Crude ore	Waste[4]	Total[3]	Crude ore	Waste[4]	Total
Metal:									
1989	725	1,009	1,734	45	5	50	770	1,013	1,783
1990	706	1,219	1,925	54	4	57	760	1,222	1,982
1991	737	1,313	2,050	72	2	74	809	1,315	2,124
1992[r]	916	1,078	1,994	36	2	38	953	1,080	2,032
1993	921	1,138	2,060	34	2	35	955	1,140	2,095
Industrial minerals:									
1989[r 5]	1,354	525	1,878	59	2	62	1,413	527	1,940
1990[r 6]	1,088	93	1,181	43	(7)	44	1,131	94	1,225
1991[5]	1,211	132	1,342	62	(7)	62	1,272	132	1,404
1992[r 6]	996	267	1,263	36	(7)	37	1,033	267	1,300
1993	1,184	310	1,494	93	(7)	94	1,277	311	1,588
All mineral commodities:									
1989[r]	2,079	1,534	3,612	104	7	112	2,183	1,540	3,723
1990[r]	1,794	1,312	3,106	97	4	101	1,891	1,316	3,207
1991	1,948	1,445	3,392	134	2	136	2,081	1,447	3,528
1992[r]	1,913	1,345	3,257	73	2	75	1,985	1,347	3,332
1993	2,105	1,449	3,554	127	2	129	2,232	1,451	3,683

[r] Revised.

[1] Includes materials from wells, ponds, and pumping operations.

[2] Includes solution mining.

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

[4] Includes ore and waste from development operations.

[5] Construction sand and gravel data were not available because of biennial canvassing.

[6] Crushed and broken and dimension stone data were not available because of biennial canvassing.

[7] Less than 1/2 unit.

TABLE 2

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE[1]

(Thousand metric tons)

	Surface[2]			Underground[3]			All mines		
	Crude ore	Waste[4]	Total	Crude ore	Waste[4]	Total	Crude ore	Waste[4]	Total
METALS									
Copper	469,186	237,811	706,997	W	W	W	469,186	237,811	706,997
Gold	245,883	778,441	1,024,324	2,531	426	2,957	248,414	778,867	1,027,281
Iron	181,297	102,771	284,068	W	—	W	181,297	102,771	284,068
Lead	—	—	—	4,008	337	4,344	4,008	337	4,344
Nickel	355	178	533	—	—	—	355	178	533
Zinc	W	W	W	5,942	355	6,298	5,942	355	6,298
Other[5]	24,545	19,243	43,788	21,338	476	21,815	45,883	19,720	65,603
Total	921,266	1,138,444	2,059,710	33,819	1,594	35,414	955,085	1,140,039	2,095,124
INDUSTRIAL MINERALS									
Asbestos	60	10	70	—	—	—	60	10	70
Barite	622	526	1,147	—	—	—	622	526	1,147
Clays	37,739	32,830	70,569	86	W	86	37,825	32,830	70,655
Feldspar[6]	776	W	776	—	—	—	776	W	776
Gypsum	13,481	6,525	20,006	2,552	6	2,557	16,033	6,531	22,564
Magnesium compounds	1,618	W	1,618	—	—	—	1,618	W	1,618
Mica (scrap)	420	W	420	—	—	—	420	W	420
Perlite	761	89	850	W	W	W	761	89	850
Phosphate rock	35,521	W	35,521	W	—	W	35,521	W	35,521
Potash	W	—	W	7,396	—	7,396	7,396	—	7,396
Pumice[7]	470	67	536	—	—	—	470	67	536
Salt	5,802	—	5,802	27,641	—	27,641	33,442	—	33,442
Sand and gravel (industrial)	26,295	W	26,295	—	—	—	26,295	W	26,295
Sodium compounds	—	—	—	8,172	—	8,172	8,172	—	8,172
Stone:									
Crushed	1,042,546	85,885	1,128,431	46,874	328	47,201	1,089,420	86,212	1,175,632
Dimension	1,192	601	1,793	W	—	W	1,192	601	1,793
Talc and pyrophyllite	919	4,718	5,637	W	W	W	919	4,718	5,637
Vermiculite	190	—	190	—	—	—	190	—	190
Other[8]	15,560	178,822	194,384	644	134	780	16,205	178,956	195,164
Total	1,183,972	310,073	1,494,045	93,365	468	93,833	1,277,337	310,540	1,587,878
Grand total	2,105,238	1,448,517	3,553,755	127,184	2,062	129,247	2,232,423	1,450,579	3,683,002
STATES									
Alabama	31,853	4,580	36,433	W	—	W	31,853	4,580	36,433
Alaska	11,281	19,735	31,016	W	W	W	11,281	19,735	31,016
Arizona	363,146	W	363,146	W	W	W	363,146	W	363,146
Arkansas	25,276	4,734	30,010	—	—	—	25,276	4,734	30,010
California	79,902	88,762	168,665	514	W	514	80,416	88,762	169,179
Colorado	14,418	W	14,418	W	W	W	14,418	W	14,418
Connecticut	5,387	488	5,876	—	—	—	5,387	488	5,876
Florida	97,662	W	97,662	253	2	255	97,915	2	97,917
Georgia	57,776	12,672	70,448	2,354	16	2,371	60,130	12,689	72,819
Hawaii	8,881	710	9,591	—	—	—	8,881	710	9,591
Idaho	13,828	10,814	24,642	W	W	W	13,828	10,814	24,642
Illinois	62,817	5,342	68,159	4,074	W	4,074	66,891	5,342	72,233

See footnotes at end of table.

TABLE 2—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE[1]

(Thousand metric tons)

	Surface[2]			Underground[3]			All mines		
	Crude ore	Waste[4]	Total	Crude ore	Waste[4]	Total	Crude ore	Waste[4]	Total
STATES—Continued									
Indiana	35,479	3,400	38,879	3,345	W	3,345	38,824	3,400	42,224
Iowa	24,232	4,014	28,246	6,958	43	7,001	31,190	4,057	35,248
Kansas	19,249	1,908	21,157	3,358	W	3,358	22,607	1,908	24,515
Kentucky	37,452	3,686	41,137	12,539	88	12,627	49,991	3,773	53,764
Louisiana	4,210	394	4,604	11,375	—	11,375	15,585	394	15,980
Maine	1,860	170	2,030	—	—	—	1,860	170	2,030
Maryland	20,843	1,907	22,751	W	W	W	20,843	1,907	22,751
Massachusetts	8,805	793	9,599	—	—	—	8,805	793	9,599
Michigan	75,947	51,006	126,953	W	W	W	75,947	51,006	126,953
Minnesota	152,529	57,172	209,701	—	—	—	152,529	57,172	209,701
Mississippi	3,232	1,121	4,353	—	—	—	3,232	1,121	4,353
Missouri	49,740	5,276	55,016	10,173	436	10,609	59,913	5,712	65,625
Montana	41,066	66,983	108,048	1,363	W	1,363	42,429	66,983	109,411
Nebraska	4,920	545	5,465	W	W	W	4,920	545	5,465
Nevada	179,323	591,589	770,913	271	109	380	179,594	591,698	771,292
New Hampshire	1,442	140	1,582	—	—	—	1,442	140	1,582
New Jersey	17,130	1,325	18,454	—	—	—	17,130	1,325	18,454
New Mexico	W	W	W	7,746	11	7,756	7,746	11	7,756
New York	36,831	4,355	41,186	5,879	—	5,879	42,710	4,355	47,065
North Carolina	58,227	9,465	67,692	—	—	—	58,227	9,465	67,692
Ohio	51,860	5,662	57,523	W	W	W	51,860	5,662	57,523
Oklahoma	29,217	2,690	31,907	W	W	W	29,217	2,690	31,907
Oregon	19,076	1,890	20,966	W	W	W	19,076	1,890	20,966
Pennsylvania	68,492	6,041	74,533	2,661	19	2,680	71,153	6,060	77,213
Rhode Island	1,342	103	1,445	—	—	—	1,342	103	1,445
South Carolina	27,486	7,591	35,076	—	—	—	27,486	7,591	35,076
South Dakota	11,469	17,534	29,003	1,358	180	1,538	12,827	17,714	30,541
Tennessee	42,039	4,266	46,306	7,222	W	7,222	49,261	4,266	53,528
Texas	72,984	8,929	81,913	8,831	W	8,831	81,815	8,929	90,744
Vermont	2,888	261	3,149	—	—	—	2,888	261	3,149
Virginia	51,407	4,712	56,119	W	W	W	51,407	4,712	56,119
Washington	13,945	1,237	15,182	W	W	W	13,945	1,237	15,182
West Virginia	11,098	946	12,044	3,249	18	3,267	14,347	964	15,311
Wisconsin	27,762	2,138	29,900	—	—	—	27,762	2,138	29,900
Wyoming	6,209	2,389	8,598	8,043	—	8,043	14,252	2,389	16,640
Undistributed[9]	123,220	429,042	552,259	25,618	1,140	26,759	148,839	430,182	579,018
Grand total	2,105,238	1,448,517	3,553,755	127,184	2,062	129,247	2,232,423	1,450,579	3,683,002

See footnotes at end of table.

TABLE 2—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE[1]

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

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

[2] Includes materials from wells, ponds, and pumping operations.

[3] Includes solution mining.

[4] Includes ore and waste from development operations.

[5] Includes bauxite, beryllium, gold-silver ore, lead-zinc ore, magnesium metal, manganiferous ore, molybdenum, platinum-group metals, rare earths, titanium, uranium, and metal items indicated by symbol W.

[6] Includes aplite.

[7] Excludes volcanic cinder and scoria, included with crushed and broken stone.

[8] Includes boron, fluorspar, greensand marl, iron oxide, kyanite, lithium, magnesite, olivine, sulfur (Frasch), wollastonite, zeolites, and industrial mineral items indicated by symbol W.

[9] Includes Delaware, North Dakota, Utah, and State items indicated by symbol W.

TABLE 3
VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES MINED IN THE UNITED STATES IN 1993

(Dollars per metric ton)

	Surface			Underground			All mines		
	Principal mineral product	By-product	Total[1]	Principal mineral product	By-product	Total[1]	Principal mineral product	By-product	Total[1]
METALS									
Copper	7.79	0.89	8.68	W	W	W	7.79	0.89	8.68
Gold	13.31	.42	13.72	69.49	1.14	70.62	13.87	.43	14.29
Iron	9.02	—	9.02	W	W	W	9.02	W	9.02
Lead	—	—	—	37.72	11.29	49.01	37.72	11.29	49.01
Zinc	W	W	W	33.12	W	33.12	33.12	W	33.12
Average[2]	9.96	.75	10.71	31.62	5.89	37.50	10.74	.93	11.68
INDUSTRIAL MINERALS									
Asbestos	131.62	—	131.62	—	—	—	131.62	—	131.62
Barite	24.81	—	24.81	—	—	—	24.81	—	24.81
Clays	38.58	W	38.58	W	—	W	38.58	W	38.58
Feldspar[3]	38.53	W	38.53	—	—	—	38.53	W	38.53
Gypsum	6.65	W	6.65	6.78	—	6.78	6.67	W	6.67
Magnesium compounds	86.31	—	86.31	—	—	—	86.31	—	86.31
Mica (scrap)	8.36	W	8.36	—	—	—	8.36	W	8.36
Perlite	30.12	—	30.12	W	—	W	30.12	—	30.12
Phosphate rock	21.36	W	21.36	W	—	W	21.36	W	21.36
Potash	W	W	W	15.49	—	15.49	15.49	W	15.49
Pumice[4]	25.70	—	25.70	—	—	—	25.70	—	25.70
Salt	62.47	—	62.47	18.68	W	18.68	26.24	W	26.24
Sand and gravel (industrial)	17.13	W	17.13	—	—	—	17.13	W	17.13
Sodium compounds	—	—	—	W	79.57	79.57	W	79.57	79.57
Stone:									
Crushed	5.25	.03	5.28	6.50	W	6.50	5.30	W	5.30
Dimension	168.85	.42	169.27	W	W	W	168.85	.42	169.27
Talc and pyrophyllite	26.55	W	26.55	W	—	W	26.55	W	26.55
Vermiculite	78.36	—	78.36	—	—	—	78.36	—	78.36
Average[2]	8.41	.14	8.55	10.74	7.20	17.94	8.57	.64	9.22
Average, industrial minerals (excluding sand and gravel and stone)[2]	34.75	(5)	34.75	15.00	14.48	29.48	29.03	5.03	34.06
Average, metals and industrial minerals[2]	9.06	.40	9.46	16.27	6.85	23.12	9.47	.76	10.23
Average, metals and industrial minerals (excluding sand and gravel and stone)[2]	12.76	.80	13.55	21.98	10.87	32.85	13.44	1.54	14.97

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

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

[2] Includes unpublished data.

[3] Includes aplite.

[4] Excludes volcanic cinder and scoria; included with crushed and broken stone.

[5] Withheld to avoid disclosing company proprietary data; included in "All mines."

TABLE 4

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE

	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
METALS							
Bauxite	5	—	2	3	—	—	—
Beryllium concentrate	1	—	—	—	1	—	—
Copper	24	1	—	1	4	7	11
Gold	100	10	6	13	18	46	7
Gold-silver	5	—	2	—	1	2	—
Iron	18	—	3	2	3	3	7
Lead	7	—	—	—	6	1	—
Lead-zinc	2	—	—	—	2	—	—
Magnesium metal	3	—	—	2	—	1	—
Manganiferous	1	—	1	—	—	—	—
Molybdenum	1	—	—	—	—	1	—
Nickel	1	—	—	—	1	—	—
Platinum-group metals	1	—	—	—	1	—	—
Rare earth metal concentrates	1	—	—	—	1	—	—
Silver	6	1	1	1	3	—	—
Titanium	5	—	1	1	2	1	—
Uranium	6	5	1	—	—	—	—
Zinc	12	—	—	—	9	3	—
Total	199	17	17	23	52	65	25
INDUSTRIAL MINERALS							
Asbestos	1	—	—	1	—	—	—
Barite	6	—	3	1	2	—	—
Boron minerals	5	1	—	1	1	2	—
Bromine	4	—	—	4	—	—	—
Clays	756	29	179	441	107	—	—
Diatomite	11	—	2	5	4	—	—
Feldspar[2]	13	—	1	10	2	—	—
Fluorspar	1	—	—	—	1	—	—
Greensand marl	1	—	1	—	—	—	—
Gypsum	57	—	1	13	43	—	—
Iodine	4	3	1	—	—	—	—
Iron oxide pigments (crude)	3	2	—	1	—	—	—
Kyanite	2	—	—	2	—	—	—
Lithium minerals	2	—	—	2	—	—	—
Magnesite	1	—	—	—	1	—	—
Magnesium compounds	6	—	1	2	3	—	—
Mica (scrap)	7	—	4	1	2	—	—
Olivine	3	—	1	2	—	—	—
Perlite	10	1	2	4	3	—	—
Phosphate rock	24	—	—	1	8	15	—
Potash	10	—	—	3	2	5	—
Pumice[3]	13	—	4	8	1	—	—
Salt	65	—	3	12	40	10	—
Sand and gravel (industrial)	158	2	8	76	70	2	—
Sodium sulfate	6	—	—	—	1	5	—

See footnotes at end of table.

TABLE 4—Continued

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE

	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
INDUSTRIAL MINERALS—Continued							
Stone:							
Crushed	3,581	213	524	961	1,652	231	—
Dimension	245	94	117	33	1	—	—
Sulfur (Frasch)	4	—	—	1	3	—	—
Talc and pyrophyllite	24	3	6	9	6	—	—
Vermiculite	5	—	—	5	—	—	—
Wollastonite	2	—	—	2	—	—	—
Zeolites	3	1	—	2	—	—	—
Total	5,033	349	858	1,603	1,953	270	
Grand total	5,232	366	875	1,626	2,005	335	25
STATES							
Alabama	97	1	8	39	38	11	—
Alaska	41	2	9	18	7	5	—
Arizona	77	12	3	31	18	6	7
Arkansas	76	1	7	27	35	6	—
California	394	45	173	74	83	19	—
Colorado	77	16	16	26	14	5	—
Connecticut	23	1	—	8	14	—	—
Delaware	1	—	1	—	—	—	—
Florida	127	—	1	35	60	31	—
Georgia	218	3	40	85	75	15	—
Hawaii	28	—	5	9	12	2	—
Idaho	87	3	11	50	21	2	—
Illinois	179	2	10	70	80	17	—
Indiana	110	3	12	21	66	8	—
Iowa	164	—	17	64	78	5	—
Kansas	139	9	27	44	56	3	—
Kentucky	105	—	8	17	69	11	—
Louisiana	29	—	2	7	14	6	—
Maine	15	—	3	5	7	—	—
Maryland	44	2	9	9	15	9	—
Massachusetts	32	1	2	10	17	2	—
Michigan	73	2	4	19	35	11	2
Minnesota	65	4	9	24	20	3	5
Mississippi	28	—	—	24	3	1	—
Missouri	224	—	24	72	117	11	—
Montana	51	9	8	6	21	6	1
Nebraska	18	1	4	5	5	3	—
Nevada	82	9	7	17	23	19	7
New Hampshire	13	—	1	7	5	—	—
New Jersey	33	1	3	8	18	3	—
New Mexico	85	12	12	38	16	5	2
New York	127	14	15	20	70	8	—
North Carolina	166	6	15	54	78	13	—
North Dakota	5	—	5	—	—	—	—

See footnotes at end of table.

TABLE 4—Continued

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[1] IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE

	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
STATES—Continued							
Ohio	163	3	10	50	89	11	—
Oklahoma	87	8	7	19	47	6	—
Oregon	438	115	192	70	61	—	—
Pennsylvania	221	3	22	42	146	8	—
Rhode Island	7	—	—	4	3	—	—
South Carolina	76	1	9	27	35	4	—
South Dakota	24	4	4	3	8	5	—
Tennessee	147	1	9	34	95	8	—
Texas	271	38	33	87	96	17	—
Utah	64	6	21	16	14	6	1
Vermont	41	8	9	13	11	—	—
Virginia	130	8	6	30	74	12	—
Washington	147	2	33	68	43	1	—
West Virginia	43	—	2	17	22	2	—
Wisconsin	233	6	13	150	62	2	—
Wyoming	107	3	33	52	13	6	—
Grand total	5,232	366	875	1,626	2,005	335	25

[1] Based on crude ore mined.

[2] Includes aplite.

[3] Excludes volcanic cinder and scoria; included with crushed stone.

TABLE 5

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL MINING OPERATIONS IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT OF CRUDE ORE

Mining operation[1]	State	Operator	Commodity	Mining method
METALS				
Morenci	Arizona	Phelps Dodge Corp.	Copper	Open pit.
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Do.
Bingham Canyon	Utah	Kennecott, Utah Copper Corp.	Copper	Do.
Minntac	Minnesota	USX	Iron ore	Do.
Sierrita	Arizona	Cyprus Climax Metals Co.	Copper	Do.
Cyprus Miami (Inspiration)	do.	do.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Do.
Hoyt Lakes	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Empire	Michigan	Empire Iron Mining Partnership	do.	Do.
Bagdad	Arizona	Cyprus Climax Metals Co.	Copper	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Do.
Pinto Valley	Arizona	Magma Copper Co.	Copper	Do.
Ray	do.	ASARCO Incorporated	do.	Do.
Continental	Montana	Montana Resources Inc.	do.	Do.
Chino	New Mexico	Phelps Dodge Corp.	do.	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Open pit and stoping.
Mission Complex	do.	ASARCO Incorporated	do.	Open pit.
Twin Creeks	Nevada	Santa Fe Pacific Gold Corp.	Gold	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	do.	Do.
NSPC Project	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Thunderbird	do.	Eveleth Mines	do.	Do.
Tilden	Michigan	Tilden Mining Co.	do.	Do.
Peter Mitchell	Minnesota	Cyprus Climax Metals Co.	do.	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Open pit and stoping.
INDUSTRIAL MINERALS[2]				
Florida mines (6)	Florida	IMC-Agrico Co.	Phosphate rock	Open pit.
Reed	Kentucky	Vulcan Materials Co.	Stone	Open quarry.
FEC Hialea	Florida	CSR America Inc.	do.	Do.
McCook	Illinois	Vulcan Materials Co.	do.	Do.
Calcite	Michigan	Michigan Minerals Associates	do.	Do.
Stoneport	do.	Presque Isle Corp.	do.	Do.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
International	New Mexico	IMC Fertilizers Inc.	Potash	Well or pumping operation.
White Rock	Florida	Vecellio & Grogan Inc.	Stone	Dredging.
Eastside	Texas	Redland Stone Products Co.	do.	Open quarry.
Pennsuco	Florida	Tarmac America Inc.	do.	Dredging.
Lee Creek (Aurora)	North Carolina	Texasgulf Chemical Co.	Phosphate rock	Open pit.
Carey 1 and 2	Ohio	National Lime & Stone Co.	Stone	Open quarry.
Thornton	Illinois	General Dynamics Corp., Material Service Corp.	do.	Open quarry and stoping.
St. Genevieve	Missouri	Tower Rock Stone Co.	do.	Open quarry.
Fort Meade	Florida	Cargill Fertilizer Inc.	Phosphate rock	Open pit.
Mount Hope	New Jersey	Mount Hope Rock Products Inc.	Stone	Open quarry.
Clinton	New York	Lone Star Industries, New York Trap Rock Corp.	do.	Do.
Sandusky	Ohio	Rogers Group Inc.	do.	Do.
Kingsford and Payne Creek	Florida	IMC-Agrico Co.	Phosphate rock	Open pit.

See footnotes at end of table.

TABLE 5—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL MINING OPERATIONS IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT OF CRUDE ORE

Mining operation[1]	State	Operator	Commodity	Mining method
INDUSTRIAL MINERALS[2]—Continued				
New Braunf	Texas	Parker Lafarge Inc.	Stone	Open quarry.
Norcross	Georgia	Vulcan Materials Co.	do.	Do.
Millville	West Virginia	Evered Bardon USA Inc. (Millville Quarry Inc.)	do.	Do.
Retsof	New York	Akzo Salt Inc.	Salt	Stoping.
Bridgeport	Texas	Texas Industries Inc.	Stone	Open pit.

[1] Owing to commodity reporting differences, the rank of individual mining operations may not be available.

[2] Construction sand and gravel operations are not included for 1993 because of biennial canvassing.

TABLE 6

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL MINING OPERATIONS IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mining operation[1]	State	Operator	Commodity	Mining method
METALS				
Morenci	Arizona	Phelps Dodge Corp.	Copper	Open pit.
Carlin Mines Complex	Nevada	Newmont Gold Co.	Gold	Do.
Goldstrike	do.	Barrick Goldstrike Mines Inc.	do.	Do.
Chino	New Mexico	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecott Corp.	do.	Do.
Cyprus Miami (Inspiration)	Arizona	Cyprus Climax Metals Co.	do.	Do.
Twin Creeks	Nevada	Santa Fe Pacific Gold Corp.	Gold	Do.
Sierrita	Arizona	Cyprus Climax Metals Co.	Copper	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Gold	Open pit and stoping.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Open pit.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Gold	Do.
Jerritt Canyon (Enfield Bell)	do.	Independence Mining Co. Inc.	do.	Do.
Hoyt Lakes	Minnesota	LTV Steel Mining Co.	Iron ore	Do.
Minntac	do.	USX	do.	Do.
Hibbing	do.	Hibbing Taconite Co.	do.	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Do.
Crofoot/Lewis	Nevada	Hycroft Resources & Development	Gold	Do.
Lone Tree	do.	Santa Fe Pacific Gold Corp.	do.	Do.
Mesquite	California	do.	do.	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
Golden Sunlight	do.	Golden Sunlight Mines Inc.	Gold	Do.
Getchell	Nevada	FMG Inc.	do.	Do.
Bagdad	Arizona	Cyprus Climax Metals Co.	Copper	Do.
Montana Tunnels	Montana	Montana Tunnels Mining, Inc.	Gold-zinc ore.	Do.
Pinto Valley	Arizona	Magma Copper Co.	Copper	Do.
INDUSTRIAL MINERALS[2]				
Florida mines (6)	Florida	IMC-Agrico Co.	Phosphate rock	Do.
Kingsford and Payne Creek	do.	do.	do.	Do.
Fort Meade	do.	Cargill Fertilizer Inc.	do.	Do.
Boron	California	U.S. Borax Inc.	Boron minerals	Do.
Reed	Kentucky	Vulcan Materials Co.	Stone	Open quarry.
FEC Hialea	Florida	CSR America Inc.	do.	Do.
Lee Creek (Aurora)	North Carolina	Texasgulf Chemical Co.	Phosphate rock	Open pit.
McCook	Illinois	Vulcan Materials Co.	Stone	Open quarry.
Calcite	Michigan	Michigan Minerals Associates	do.	Do.
Stoneport	do.	Presque Isle Corp.	do.	Do.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
White Rock	Florida	Vecellio & Grogan Inc.	do.	Dredging.
International	New Mexico	IMC Fertilizers Inc.	Potash	Well or pumping operation.
Eastside	Texas	Redland Stone Products Co.	Stone	Open quarry.
Big Four	Florida	Mobil Mining and Minerals Co.	Phosphate rock	Open pit
Pennsuco	do.	Tarmac America Inc.	Stone	Dredging.
Carey 1 and 2	Ohio	National Lime & Stone Co.	do.	Open quarry.
St. Genevieve	Missouri	Tower Rock Stone Co.	do.	Do.
Thornton	Illinois	General Dynamics Corp., Material Service Corp.	do.	Open quarry and stoping.
Mount Hope	New Jersey	Mount Hope Rock Products Inc.	do.	Open quarry.

See footnotes at end of table.

TABLE 6—Continued

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL MINING OPERATIONS IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mining operation[1]	State	Operator	Commodity	Mining method
INDUSTRIAL MINERALS[2] —Continued				
Clinton	New York	Lone Star Industries, New York Trap Rock Corp.	Stone	Open quarry
Sandusky	Ohio	Rogers Group Inc.	do.	Do.
New Braunf	Texas	Parker Lafarge Inc.	do.	Do.
Norcross	Georgia	Vulcan Materials Co.	do.	Do.
Rockland	Florida	U.S. Agri-Chemicals Corp.	Phosphate rock	Open pit.

[1] Owing to commodity reporting differences, the rank of individual mining operations may not be available.

[2] Construction sand and gravel operations are not included for 1993 because of biennial canvassing.

TABLE 7

MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE

(Thousand metric tons)

	Marketable product			Ore treated or sold		
	Surface	Underground	Total[1]	Surface	Underground	Total[1]
METALS						
Copper	1,572	261	1,834	436,083	W	436,083
Gold	W	W	W	251,862	2,542	254,404
Iron	55,601	W	55,601	180,809	W	180,809
Lead	—	262	262	—	4,202	4,202
Nickel	W	—	W	267	—	267
Zinc	W	187	187	W	5,606	5,606
INDUSTRIAL MINERALS						
Asbestos	14	—	14	45	—	45
Barite	314	—	314	773	—	773
Clays	37,721	104	37,825	37,739	86	37,825
Diatomite	599	—	599	W	—	W
Feldspar[2]	776	—	776	776	—	776
Gypsum	13,363	2,552	15,915	13,380	2,552	15,932
Magnesium compounds	414	—	414	1,627	—	1,627
Mica (scrap)	W	—	W	388	—	388
Perlite	W	W	W	569	W	569
Phosphate rock	35,466	W	35,466	35,466	W	35,466
Potash	W	898	898	W	7,790	7,790
Pumice[3]	469	—	469	469	—	469
Salt	5,461	27,284	32,745	5,647	27,092	32,739
Sand and gravel (industrial)	26,399	—	26,399	26,399	—	26,399
Sodium compounds	—	8,172	8,172	—	8,172	8,172
Stone:						
Crushed	1,066,148	52,675	1,118,824	1,071,950	46,874	1,118,824
Dimension	1,184	W	1,184	1,195	W	1,195
Talc and pyrophyllite	917	W	917	919	W	919
Vermiculite	187	—	187	190	—	190
Zeolites	37	—	37	W	—	W
STATES						
Alabama	32,114	W	32,114	32,129	W	32,129
Alaska	2,694	W	2,694	10,216	W	10,216
Arizona	8,203	W	8,203	352,941	W	352,941
Arkansas	25,337	—	25,337	25,337	—	25,337
California	47,037	W	47,037	80,705	549	81,255
Colorado	11,146	41	11,187	14,521	W	14,521
Connecticut	5,388	—	5,388	5,388	—	5,388
Florida	91,689	W	91,689	99,493	W	99,493
Georgia	57,562	2,354	59,917	58,175	2,354	60,529
Hawaii	8,881	—	8,881	8,881	—	8,881
Idaho	9,427	W	9,427	13,871	W	13,871
Illinois	60,952	W	60,952	62,979	4,074	67,053
Indiana	34,063	4,847	38,911	35,566	3,345	38,911
Iowa	25,937	6,958	32,895	25,937	6,958	32,895
Kansas	19,886	3,288	23,174	19,886	3,273	23,159

See footnotes at end of table.

TABLE 7—Continued

MARKETABLE PRODUCT AND ORE TREATED OR SOLD AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE

(Thousand metric tons)

	Marketable product			Ore treated or sold		
	Surface	Underground	Total[1]	Surface	Underground	Total[1]
STATES—Continued						
Kentucky	36,691	13,306	49,997	37,458	12,539	49,997
Louisiana	4,131	11,369	15,500	4,205	11,295	15,500
Maine	1,860	—	1,860	1,860	—	1,860
Maryland	20,227	W	20,227	20,862	W	20,862
Massachusetts	9,702	—	9,702	9,702	—	9,702
Michigan	49,565	1,203	50,768	75,638	W	75,638
Minnesota	52,765	—	52,765	152,542	—	152,542
Mississippi	3,277	—	3,277	3,277	—	3,277
Missouri	50,014	5,979	55,993	50,530	10,264	60,794
Montana	3,385	143	3,528	39,908	1,363	41,271
Nebraska	5,383	W	5,383	5,383	W	5,383
Nevada	4,184	W	4,184	192,789	285	193,073
New Hampshire	1,446	—	1,446	1,446	—	1,446
New Jersey	19,748	—	19,748	19,749	—	19,749
New Mexico	5,509	927	6,436	28,008	8,147	36,155
New York	40,355	4,886	45,242	40,366	5,473	45,838
North Carolina	58,560	—	58,560	58,576	—	58,576
Ohio	56,643	W	56,643	56,643	W	56,643
Oklahoma	31,353	W	31,353	31,353	W	31,353
Oregon	19,151	W	19,151	19,719	W	19,719
Pennsylvania	68,702	2,661	71,363	68,702	2,661	71,363
Rhode Island	1,347	—	1,347	1,347	—	1,347
South Carolina	22,223	—	22,223	27,547	—	27,547
South Dakota	5,482	(4)	5,482	11,590	1,335	12,926
Tennessee	43,347	2,147	45,494	43,347	6,886	50,233
Texas	76,780	8,934	85,714	76,883	8,831	85,714
Utah	9,102	W	9,102	W	W	W
Vermont	2,838	—	2,838	2,868	—	2,868
Virginia	51,282	1,478	52,760	51,412	W	51,412
Washington	13,783	(4)	13,783	14,325	W	14,325
West Virginia	11,622	3,249	14,871	11,622	3,249	14,871
Wisconsin	27,867	—	27,867	28,062	—	28,062
Wyoming	6,225	8,043	14,268	6,227	8,043	14,270

W Withheld to avoid disclosing company proprietary data.

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

[2] Includes aplite.

[3] Excludes volcanic cinder and scoria; included with crushed and broken stone.

[4] Less than 1/2 unit.

TABLE 8

MINING METHODS USED AT SURFACE OPERATIONS IN THE UNITED STATES, BY COMMODITY, IN 1993

(Percent of total material handled)

	Preceded by drilling and blasting	Not preceded by drilling and blasting[1]
METALS		
Bauxite	—	100
Beryllium concentrate	100	—
Copper	98	2
Gold	97	3
Gold-silver	98	2
Iron	96	4
Magnesium metal	50	50
Manganiferous		100
Nickel	—	100
Rare earth metal concentrates	100	—
Silver	100	—
Titanium	—	100
Uranium	—	100
Zinc	100	—
Average	97	3
INDUSTRIAL MINERALS		
Asbestos	100	—
Barite	11	89
Boron minerals	91	9
Bromine	—	100
Clays	—	100
Diatomite	1	99
Feldspar[2]	100	—
Greensand marl	—	100
Gypsum	91	9
Iodine	—	100
Iron oxide pigments (crude)	100	—
Kyanite	100	—
Lithium minerals	54	46
Magnesite	100	—
Magnesium compounds	54	46
Mica (scrap)	49	51
Olivine	100	—
Perlite	43	57
Phosphate rock	4	96
Potash	—	100
Pumice[3]	5	95
Salt	2	98
Sand and gravel (industrial)	2	98
Stone:		
Crushed	98	2
Dimension	2	98
Sulfur (Frasch)	—	100

See footnotes at end of table.

TABLE 8—Continued

MINING METHODS USED AT SURFACE OPERATIONS IN THE UNITED STATES, BY COMMODITY, IN 1993

(Percent of total material handled)

	Preceded by drilling and blasting	Not preceded by drilling and blasting[1]
INDUSTRIAL MINERALS—Continued		
Talc and pyrophyllite	92	8
Vermiculite	86	14
Wollastonite	100	—
Zeolites	100	—
Average	77	23
Average, metals and industrial minerals	89	11

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

[2] Includes aplite.

[3] Excludes volcanic cinder and scoria; included with crushed and broken stone.

TABLE 9

EXPLORATION ACTIVITY IN THE UNITED STATES IN 1993, BY METHOD, COMMODITY, AND STATE[1]

(Meters)

	Drilling					
	Diamond (core)	Percussion	Rotary and reverse circulation	Other[2]	Trenching	Total
METALS						
Copper	16,797	(3)	16,917	W	(4)	33,714
Gold	259,351	104,218	649,341	W	28,378	1,041,288
Lead	17,964	19,638	15,054	—	—	52,656
Silver	7,675	—	—	W	31	7,706
Zinc	18,688	(3)	3,937	W	—	22,625
Other[5]	5,458	—	45,709	636,420	—	687,587
Total	325,932	123,856	730,958	636,420	28,409	1,845,575
Percent of exploration	17.7	6.7	39.6	34.5	1.5	100
INDUSTRIAL MINERALS						
Perlite	—	—	444	—	—	444
Other[6]	19,231	(3)	(3)	12,474	(3)	31,704
Total	19,231	(3)	444	12,474	(3)	32,148
Percent of exploration	60	(3)	1	39	(3)	100
Grand total	345,163	123,856	731,402	648,894	28,409	1,877,723
Percent of exploration, grand total	18.4	6.6	39.0	34.6	1.5	100
STATES						
Alaska	1,646	20,391	W	—	26,859	48,896
Arizona	15,560	—	W	—	W	15,560
California	914	—	42,161	W	(3)	43,075
Colorado	4,668	—	W	W	W	4,668
Idaho	8,251	—	9,295	W	—	17,546
Missouri	17,964	19,638	15,054	—	—	52,656
Montana	10,647	(3)	14,478	W	W	25,125
Nevada	139,275	15,368	491,876	W	W	646,519
New Mexico	W	W	W	W	31	31
Oregon	18	—	—	W	W	18
South Dakota	68,455	W	2,195	—	—	70,650
Utah	853	W	19,298	—	183	20,334
Washington	45,189	—	3,048	—	—	48,237
Undistributed[7]	31,723	68,459	133,997	648,894	1,336	884,408
Grand total	345,163	123,856	731,402	648,894	28,409	1,877,723
Percent of exploration, grand total	18.4	6.6	39.0	34.6	1.5	100

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

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

[2] Includes churn drilling.

[3] Withheld to avoid disclosing company proprietary data; included with "Other" drilling.

[4] Less than 1/2 unit.

[5] Includes beryllium concentrates, gold-silver ore, iron ore, lead-zinc ore, uranium, zinc ore, and metal items indicated by symbol W.

[6] Includes barite, boron minerals, clays, diatomite, fluorspar, garnet, gypsum, native asphalt and bitumens, phosphate rock, pumice, soda ash, and talc and pyrophyllite.

[7] Includes Florida, Georgia, Illinois, Kansas, Minnesota, Oklahoma, South Carolina, Tennessee, Virginia, Wyoming, and State items indicated by symbol W.

TABLE 10

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT AND TOTAL DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1993, BY COMMODITY AND STATE[1]

	Drifting, crosscutting, or tunneling		Raising		Shaft and winze sinking		Stripping	Other[2]		Total	
	Thousand metric tons	Meters	Thousand metric tons	Meters	Thousand metric tons	Meters	Thousand metric tons	Thousand metric tons	Meters	Thousand metric tons	Meters
COMMODITY											
Beryllium concentrate	—	—	—	—	—	—	(3)	—	—	(3)	—
Copper	W	W	W	W	(3)	62	W	—	—	(3)	62
Gold	211	7,525	11	1,315	(3)	61	33,070	W	W	33,293	8,901
Gold-silver ore	2	158	(3)	40	—	—	—	—	—	3	199
Gypsum	2	61	—	—	—	—	W	W	W	2	61
Lead	333	2,160	—	—	(4)	(4)	—	W	W	333	2,160
Lead-zinc ore	W	W	4	605	—	—	—	—	—	4	605
Silver	35	1,298	2	49	(3)	9	—	—	—	37	1,355
Uranium ore	—	—	—	—	—	—	—	(3)	16,075	(3)	16,075
Zinc	288	5,952	W	W	(4)	(4)	8	W	W	296	5,952
Other[5]	278	8,624	2	133	(4)	(4)	9,186	190	61,983	9,656	70,739
Total	1,149	25,778	19	2,142	(3)	132	42,264	191	78,058	43,624	106,109
Percent of activity, total	XX	24.3	XX	2.0	XX	.1	XX	XX	73.6	XX	100
STATE											
Alaska	(3)	9	—	—	—	—	W	—	—	(3)	9
Arizona	W	W	W	W	1	123	W	—	—	1	123
California	W	W	W	244	—	—	W	—	—	W	244
Colorado	27	4,375	4	646	(3)	9	—	—	—	32	5,030
Idaho	W	W	2	49	—	—	W	—	—	2	49
Michigan	2	61	—	—	—	—	—	—	—	2	61
Missouri	W	2,526	—	—	(4)	(4)	—	W	W	W	2,526
Montana	W	W	1	20	—	—	—	—	—	1	20
Nevada	56	1,384	W	W	—	—	W	W	W	56	1,384
New Mexico	W	W	(3)	17	—	—	W	—	—	(3)	17
South Dakota	63	2,101	5	847	—	—	381	—	—	449	2,947
Tennessee	W	W	W	W	(4)	(4)	8	W	W	W	8
Utah	—	—	—	—	—	—	2	—	—	2	—
Washington	88	2,692	(3)	52	—	—	—	—	—	88	2,745
Wyoming	—	—	—	—	—	—	—	(3)	16,075	(3)	16,075
Undistributed[6]	913	12,630	7	267	—	—	41,873	190	61,983	42,991	74,871
Total	1,149	25,778	19	2,142	(3)	132	42,264	191	78,058	43,624	106,109
Percent of activity, total	XX	24.3	XX	2.0	XX	0.1	XX	XX	73.6	XX	100

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

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

[2] Includes well drilling for solution mining.

[3] Less than 1/2 unit.

[4] Withheld to avoid disclosing company proprietary data; included with "Other" development.

[5] Includes diatomite, fluorspar, iron ore, talc and pyrophyllite, and commodity items indicated by symbol W.

[6] Includes Arkansas, Illinois, Minnesota, New York, North Carolina, Oklahoma, Oregon, and State items indicated by symbol W.

ABRASIVE MATERIALS

By Gordon T. Austin

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

The combined value of production of natural abrasives, which include tripoli, special silica stone, garnet, staurolite, and emery, increased in 1993. The increase in the value of tripoli production was the result of an increase in total production. Special silica stone experienced an increase in unit value but decrease in the quantity produced. Garnet showed a 19% decrease in quantity and an 8% decrease in value. Staurolite increased about 51% in the quantity produced and 136% in value compared with those of 1992. Staurolite's significant increase in value of production resulted from a 56% increase in the unit value.

The fused aluminum oxide industry showed an 8% decrease in the quantity produced and a 13% decrease in the value of production. The silicon carbide industry saw an 11% decrease in the quantity produced and an 8% decrease in the value of production. Combined, the industries decreased 9% in quantity and 11% in value compared with those of 1992.

The quantity of metallic abrasives sold and shipped increased slightly in quantity and decreased 7% in value compared with those of 1992. The industry includes the primary producers of steel, chilled and annealed iron, cut wire shot and grit, and shot and grit reclaimed by primary producers. Shipments in 1993 were about 9% below the industry's high of 239,619 metric tons[1] in 1979. *(See table 1.)*

The United States continued as the world's largest manufacturer, exporter, importer, and consumer of synthetic industrial diamond. The estimated apparent U.S. consumption of industrial diamond stones was 2.0 million carats, a decrease of 60% compared with that of 1992, but was still greater than the 48-year low in 1987.

DOMESTIC DATA COVERAGE

Domestic production data for abrasive materials were from seven separate voluntary U.S. Bureau of Mines (USBM) surveys. Of the 61 operations producing natural and manufactured abrasives canvassed, all responded, representing 100% of the total production shown in tables 1, 5, 6, 8, 12, and 14.

FOREIGN TRADE

The total value of abrasive materials, exports plus reexports, was $421.3 million, about a 10% increase compared with the 1992 value.

The total value of abrasive materials imported was $529 million, an increase of 9% compared with the 1992 value.

The United States has shown a trade deficit in abrasive materials for every year of the past 10 years. In 1993, the deficit was $107.7 million, an increase of 9% compared with that of 1992. *(See tables 2, 3, and 4.)*

TRIPOLI

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

Annual Review

Production.—In 1993, the quantity of crude tripoli produced increased 11% and the value of production increased 7% compared with those of 1992. In the United States four firms produced tripoli. Malvern Minerals Co., Garland County, AR, produced crude and finished material. Malvern also produces a black material from novaculite. American Tripoli Co. produced crude material in Ottawa County, OK, and finished material in Newton County, MO. Unimin Specialty Minerals Inc.'s Alco and Tamms plants, in Alexander County, IL, produced crude and finished material. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processed rottenstone, a decomposed fine-grained siliceous shale, produced by B. J. Ulrich & Sons, also in Northumberland County, PA. *(See table 5.)*

Consumption and Uses.—Processed tripoli, sold or used, increased 3% in quantity and 10% in value compared to those of 1992.

Tripoli is processed in mills that are

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

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

The end-use pattern for tripoli has changed significantly in the past 20 years. In 1970, nearly 70% of the processed tripoli was used as an abrasive. Today, 76% is used as a filler and extender in paint, plastic, rubber, caulking compounds, and enamel.

The largest use of tripoli is as a filler and extender in paints. These uses are estimated to account for as much as 85% of the tripoli used as filler and extender. Its use in exterior latex paints is as a low-micrometer-grade micronized product. In these paints, tripoli aids in tint retention, durability, leveling, and flowability. In enamels, it permits higher loading with no appreciable increase in vehicle demand and improves sheen. Because of its controlled grain or particle size, paints containing tripoli disperse easier and result in a uniform film. Additionally, because of its abrasive qualities, the paints are more resistive to wear and to chemicals than those in which water-ground whitings and other reactive fillers are used.

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

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

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

The use of tripoli as an abrasive increased about 4% in 1993, ending 8 consecutive years of decline. During the 8-year period, consumption declined about 50%.

After 4 consecutive years of decline, from 1988 through 1991, the amount of tripoli used as filler increased. The 2% increase in 1993 followed a 10% increase in 1992, a 7% decrease in 1991, a 10% decrease in 1990, an 8% decrease in 1989, and an additional 4% decrease in 1988. USBM data show that tripoli use in the United States as a filler is about 74% of the total; abrasive, 21%; and other uses, about 1%.

Prices.—The average reported value of abrasive tripoli, sold or used, in the United States was $152 per ton. The value of abrasive tripoli has increased over the past 11 years and the increase has been continuous.

The average reported value of filler tripoli, sold or used, in the United States was $212 per ton. The average reported value has increased for the past 11 years.

SPECIAL SILICA STONE PRODUCTS

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

Annual Review

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

The production of oilstones, hones, whetstones, files, and grindstones decreased about 21% in quantity to 267 tons and 17% in value to $3.8 million. *(See tables 6 and 7.)*

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

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

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

Prices.—The value of crude novaculite suitable for cutting into finished products varied from $13 per ton to $895 per ton. The low value was for Washita grade and the high for Black Hard Arkansas grade. The manufacture of deburring media or special-purpose crushed stone is from material not suited for making oilstones, hones, or whetstones. The value of these materials ranged from $469 per ton to $1,176 per ton. The average value in 1992 of oilstones, hones, whetstones, and grindstones, sold or used by U.S. producers, was $14,107 per ton. New products can be duplicated by competitors quickly because the special silica stone products industry is not high technology. This very quickly results in short-term price pressures.

Foreign Trade.—The value of exported special silica stone products was $7.2 million, a decrease of 5% compared with that of 1992.

The value of imported products was $2.4 million, down 4% from the record high of 1992. 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 1993, the trade surplus in special silica stone products was $4.8 million, a decrease of about 8%.

GARNET

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

Background

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

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

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

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

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

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

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

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

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

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

The U.S. National Institute for Standards and Technology developed an apparatus for evaluating the abrasive quality of corundum. This tester can be adapted for use with any loose-grain abrasive. Testing of loose-grain abrasives also can be performed with various production-scale and laboratory machines where the removal of glass from flat plates is evaluated. Data from such tests can be correlated with the anticipated performance of any abrasive grain relative to the other material to be abraded. In these tests abrasive performance is determined by the amount of stock removed, as found either by weighing or by dimensional measurements.

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

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

Other firms or laboratories that test the quality of loose abrasive grains include three firms involved in the abrasive cutting industry, Flow International Corp., Ingersoll Rand Corp., and Jet-Edge, Inc., that have laboratories for testing and evaluating garnet for use in their systems. Most of the evaluations in these laboratories involve the comparative testing of various abrasive grits, including measurements of particle size distribution and mechanical properties.

KTA-Tator, Inc. of Los Angeles, CA, is a major consulting/engineering/testing firm whose laboratory tests and evaluates the quality of garnet and other abrasives. Much of its work is oriented to the Steel Structures Painting Council (SSPC) specifications. The SSPC also can carry out comparative testing of garnet and other loose-grain abrasives to determine whether they meet military specifications, how clean the material is, how well the material cleans, the amount of degradation during use, and other quality factors. SSPC is part of the Carnegie-Mellon Research Institute and must be careful not to conduct research that favors one abrasives supplier over another supplier who may be a member of the Council.

Industry Structure.—Currently four firms produce garnet from four plants in two States. Each domestic producer has distinctive products. The Barton Mines Corp., Warren County, NY, garnet is a mixture of almandite and pyrope and is at the top of the garnet hardness range. It occurs as large crystals and exhibits incipient lamellar parting planes that break under pressure into sharp chisel-edged plates. It retains this chisel-edged shape even when crushed to a very fine size. Its garnet is used in coated abrasives, glass grinding and polishing, and metal lapping. The NYCO Div. of Processed Minerals Inc., Essex County, NY, and International Garnet Abrasive Inc., Clinton County, NY, garnet is a mixture of andradite and grossularite, and the crude garnet concentrate may contain diopside-hedenbergite ($Ca[MgFe]Si_2O_6$). NYCO recovered garnet as a byproduct from its wollastonite operation. It sold both crude garnet concentrate for additional refining and refined garnet for use as blasting and filtration media. International Garnet Abrasives produced refined garnet from NYCO's crude garnet concentrate for use as blasting and filtration media. Emerald Creek Garnet Milling Co. was purchased by Hawkeye Development Co., an Idaho corporation, in November 1991. Under the new name of Emerald Creek Garnet Co., it continued mining and milling operations in Benewah County, ID. Blasting and filtration media were the primary uses of the garnet.

Abrasive garnet production in the United States began in 1878 at the Gore

Mountain site of Barton Mines, near North Creek, Warren County, NY. During the first year, production was less than 100 tons. It was used in coated abrasives, both paper and cloth.[4] Barton Mines Corp. mined and processed the abrasive-grade garnet on Gore Mountain until the company moved the mining operation and processing plant in 1982 to the adjoining Ruby Mountain. Barton Mines has been a family owned operation since its formation. Reported past domestic garnet production was from California, Connecticut, Florida, Maine, New Hampshire, North Carolina, and Pennsylvania.[5]

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

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

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

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

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

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

The deposit near Gore Mountain is an almandite-bearing diorite of uncertain, igneous or metamorphic origin. The ore body is approximately 2 kilometers long and 15 to 90 meters wide. The ore grade varies from less than 5% to about 20% garnet and averages slightly less than 10%. Hornblende and plagioclase feldspar make up 40% to 80% of the host rock, while hypersthene, magnetite, biotite, apatite, and pyrite are present in minor amounts. A rough estimate suggests that more than 600,000 tons of high-quality garnet can be recovered from the Barton Mines Corp. deposit on Ruby Mountain in New York. The garnet is present as imperfectly developed crystals surrounded by a rim of coarsely crystalline hornblende. The crystals range from about 1 millimeter to almost 1 meter in diameter but average about 100 millimeters in diameter. The garnet has a pronounced laminated structure, which enables it to naturally break into thin plates from about 2 to 6 millimeters in thickness. Garnet fragments maintain this platy particle shape even as they are crushed smaller and smaller.

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

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

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

Reserves are significant in Australia, China, India, and the Newly Independent States, (formerly U.S.S.R.), but accurate data are not available. Huge inferred and undiscovered resources are likely to exist throughout the world.[7]

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

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

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

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

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

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

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

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

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

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

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

3. Quality of the garnet: The garnet in a deposit must be tested to evaluate its performance and marketability as an abrasive. It should be recognized in this regard that most garnet used in abrasive applications is either the almandite or almandite-pyrope type. The garnet should be present in the deposit as discrete crystals that are at least 6 to 13 millimeters in size and that are liberated when the ore is crushed to -2 millimeters. The crystals should be free of any inclusions, such as quartz, mica, hornblende, and feldspar, and also should be free of alteration. The garnet should

be relatively uniform in hardness and density throughout the deposit. It should not be badly weathered or highly friable. If an incipient parting is present in the garnet crystals, the effect this parting has on the quality of the final product and the distribution of such crystals within the deposit should be determined.

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

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

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

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

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

Beneficiation.—The primary factors controlling the behavior of garnet ore during processing are the identity and characteristics of the minerals present, the percentage of each mineral present, and the size of the garnet grains. The major minerals associated with garnet in most deposits are feldspar, mica, hornblende, pyroxene, and quartz. Magnetite, pyrite, ilmenite, limonite, pyrrhotite, and occasionally chalcopyrite, rutile, zoisite, chlorite, and corundum may be present in much smaller amounts. Sodium feldspar is the most common feldspar, biotite is the most common mica, and hypersthene and diopside are the most common varieties of pyroxene present. The most important physical property controlling the behavior of the major and minor minerals during concentration of the garnet is their specific gravity.

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

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

At Emerald Creek Garnet Co.'s operation in Idaho, the ore is first processed through trommels to remove the gravel and is then concentrated in jigs and on shaking tables. The garnet concentrate is dried, crushed, and screened. The maximum grain size of finished products is 46 millimeters.

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

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

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Production.—In 1993, the four U.S. firms produced 43,995 tons of crude garnet concentrate worth $4.4 million, an 18% decrease in quantity and a 4% increase in value compared to those of 1992.

Consumption and Uses.—In 1993, the quantity of garnet sold or used by producers was 55,760 tons, an increase of 21%, and the value increased 18% to $15.4 million. *(See table 8.)*

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

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

Garnet has obtained an intermediate place in the coated-abrasive field between low-cost quartz sand and more costly synthetic abrasives (silicon carbide and fused alumina). Garnet is reportedly more efficient based on unit production costs than quartz sand. It also produces a more desirable finish on items made of wood, leather, hard rubber, felt, and plastic.

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

Prices.—The average value per ton of crude garnet concentrates was $100, a 12% increase compared with the 1992 average. In 1993, the average value per ton of garnet sold or used was $299, a 12% increase from that of 1992.

Foreign Trade.—Garnet exports, as reported to the USBM, by producers were about 11,400 tons, a 50% increase from that of 1992. Export data on garnet were not available from the Bureau of the Census (Department of Commerce). Producers have reported exports to the USBM for the past 7 years. According to reports by producers, exports, with the exception of those for 1992, have increased significantly.

Mineral brokers and other garnet importers reported to the USBM about 12,200 tons of imported garnet, essentially unchanged from that of 1992. Import data for garnet also were not available from the Bureau of the Census. The United States was a net importer of garnet in 1992 for the first time in history and continued this new trend in 1993.

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. Studies are under way on two new garnet operations; Bitteroot Resources Ltd. is evaluating an almandite deposit in Arizona, and Royalstar Resources is evaluating an andradite deposit in New Mexico.

European Garnet Ltd. announced plans to install garnet recovery plants at gravel pits in the Po Valley of northern Italy. The company plans to recover up to 20,000 tons of garnet per year from its first 10 plants.[9]

Target Mines Ltd. (a subsidiary of Barton Mines) continued to produce at near capacity from its Australian garnet sand operation.

The Chinese mines continued to increase production of garnet for the domestic and world market. Two mineral sand mining operations in India continued to produce garnet as a byproduct of mineral sands production. Turkey and the Newly Independent States (formerly the U.S.S.R.), primarily produce for local markets.

Outlook

The U.S. production and consumption of industrial garnet during the next 5 years will be a function of the installed capacity and imports. Currently, the industry is operating at or near capacity. If capacity can be added, production and consumption will increase to approximately 80,000 tons per year by 1998. If garnet were not available, other abrasives could be used in its place, but in many cases with some sacrifices in work volume, quality of work, or cost.

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

EMERY

Emery is a gray to black rock containing various minerals, including corundum, magnetite, hematite, or hercynite, and trace minerals such as mullite, titania, silica, and magnesia. Its hardness ranges between 7 and 9 on the Mohs scale and its specific gravity ranges from 3.2 to 4.5, depending upon its composition. It is used as an abrasive aggregate for nonskid, wear-resistant floors, pavements, and stair treads; as tumbling or deburring media; and in the manufacture of coated abrasives.

Annual Review

Production.—A single firm, Oregon Emery, Albany, OR, produced emery in 1993 using open pit mining methods. U.S. production of emery decreased about 34% in quantity and value compared with those of 1992.

Consumption.—The USBM estimated that the United States consumed approximately 10,000 tons of emery in 1993. 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 1993, nor has it done so in the past 10 years. The Bureau of the Census reports emery imports, exports, and reexports in mineral group categories; thus, exact data on emery are not available.

World Review.—Turkey was the world's largest producer of emery. Its production is handled by Etibank in Ankara, by Ranar Minerals Industries Corp. in Istanbul, and by Lutfullah E. Kitapci Minerals Co., Ltd. in Izmir. Total production in 1993 was estimated to be in excess of 20,000 tons. Prices of Ranar emery ranged from $34 to $48 per ton for crude and from $220 to $460 per ton for micronized grades.

The second largest producer was Greece. In Greece, Government-owned deposits on the Island of Naxos are worked by villagers. It is estimated that 1993 production was about 10,000 tons.

STAUROLITE

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

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Production.—Georgia, North Carolina, and Virginia produced mineral specimen staurolite crystals. The crystals were in the cruciform twinned form commonly called "fairy crosses." E.I. du Pont de Nemours & Co. Inc. produced industrial-grade staurolite in Florida. Publishing production data would disclose company proprietary data, but production of industrial staurolite increased 51% in quantity and 136% in value compared with those of 1992.

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

Consumption.—During 1993, shipments of staurolite decreased 4% in tonnage but increased 49% in value compared with those of 1992. Staurolite, marketed under the trade name Biasill, was used as molding material in nonferrous foundries because of its low thermal expansion, high thermal conductivity, and high melting point. Its low softening temperature often restricts its use to nonferrous casting. The major use of staurolite was as an abrasive for impact finishing of metals and sandblasting of buildings. The blasting media trade names were Starblast (80 mesh) and Siasill (90 mesh). A coarse grade (55 mesh) also was used as an abrasive. Some portland cement formulations consumed a minor amount. As regulations limiting the amounts of free silica in airblasting media became more stringent, the demand for staurolite increased.

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

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

INDUSTRIAL DIAMOND

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

Background

Definitions, Grades, and Specifications.—Natural industrial diamond is diamond that, because of color, structure, size, or shape, is unsuitable for use as gemstones. Major categories are industrial stones (die stones, tool stones, and drilling stones), crushing bort, and grit and powder. The distinction between stone and grit is not well defined; generally, the dividing line is a range of sizes. Stones usually are particles larger than 16 to 20 mesh, grit from 16 to 20 mesh to 325 to 400 mesh, and powder as particles smaller than 325 to 400 mesh. These categories are subdivided further into more than 100 groups.[10]

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

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

The metric carat, 0.2 gram, is the unit of measure for industrial diamond. One pound contains 2,268 carats, and 1 kilogram contains 5,000 carats. The carat is equal to 100 points. Diamond grit and powder sizes are identified by U.S. standard screen classifications, by ANSI Specification B74.16-1971,[11] ANSI Specification B74.20-1981,[12] and by a proposed standard developed by the Industrial Diamond Association[13] for subsieve micron-sized diamond or cubic boron nitride powders. The terms "sand," "grit," and "powder" also describe decreasing orders of fine diamond.

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

Industry Structure.—The original discoveries of diamond in India, Borneo, and Brazil, and later in 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 search by open pit workings and to concentration by hand methods.

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

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

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

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

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

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

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

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

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

Technology.—**Mining.**—Currently, the United States has no commercial deposits of diamond. In other countries, mining methods range from very crude hand mining and panning to block caving of kimberlite pipes. Large-scale surface mining operations in Australia, Zaire, Angola, Namibia, and Sierra Leone[15] use modern equipment, such as continuous bucket wheel excavators, power shovels, draglines, scraper-loaders, and motor trucks, to remove overburden and to mine and transport the diamond ore.

Processing.—The type of ore, size of operation, and other factors decide the types of processing equipment used. Crushing, where necessary, is done mostly with gyratory and roll crushers to avoid impact to diamond stones. Additional grinding is done with attrition and ball mills to further separate the gangue from diamond stones. Clayey ore may require the use of log washers. Diamond washing pans, jigs, heavy-medium separators, or hydrocyclones collect the primary or intermediate concentrates. Depending on the types, shapes, and sizes of diamond present, various final treatments are used. They include the use of grease tables and grease belts, electromagnetic separators, electrostatic separators, optical sorters, X-ray sorters, and other devices. In all processing plants, hand sorting is the final recovery process.[16]

Reclaiming industrial diamond stones from drill bits and grit from the wastes generated in grinding, sawing, and other operations is common. This is because of the high unit value of diamonds. Reclamation processes include physical methods such as distillation to remove coolants and lubricants, followed by electrostatic, magnetic, or flotation separation. Reclamation also uses chemical methods, including combustion, acid treatment, and fusion with alkalies.[17] The treatment used depends primarily on the contaminants present.

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

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

Polycrystalline synthetic diamond compacts are a laminated structure of synthetic diamond powder bonded to a cemented carbide substrate. Their production is by a proprietary high-pressure, high-temperature process that gives the product excellent uniform physical properties.[18]

The polycrystalline synthetic diamond shape is a dense, nonporous, fully intergrown product that is thermally stable to 1,200° C. Production uses a proprietary high-pressure, high-temperature process using a special binder phase that is retained as an integral part of the product and results in high resistance to shock loading.[19]

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Government Programs.—The National Defense Stockpile (NDS) for industrial diamonds, as of December 31, 1993, had a goal of zero and an inventory of 4.0 million carats for crushing bort. The goal for industrial stones was 3.0 million carats and the inventory was 6.46 million carats. There is currently legislative authority for disposal of 4.0 million carats of bort and 3.0 million carats of industrial stones. The inventory of small diamond dies was 25,473 pieces compared with a goal of zero pieces, but no disposal authorization was issued.

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

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

U.S. secondary production of industrial diamond was from six firms. They were Amples Corp., Bloomfield, CT; Diamondsharp Corp., Keene, NH; Industrial Diamond Laboratory Inc., Bronx, NY; Industrial Diamond Powders Co., Pittsburgh, PA; International Diamond Services Inc., Houston, TX; and National Research Co., Fraser, MI. The firms reclaimed a total of about 16.1 million carats from used drill bits, diamond tools, and wet and dry diamond-containing waste.

Consumption and Uses.—The United States continued to be the largest single consumer of industrial diamond. The USBM estimate of apparent consumption of industrial diamond was approximately 149 million carats, an increase of about 51% compared with 1992 consumption.

Diamond is far harder than any other natural or artificial abrasive material, so it was essential for some uses and much more efficient than other abrasives for many others. The principal uses of industrial diamond stones are in drilling bits and reaming shells, single- or multiple-point diamond tools, diamond saws, diamond wheels, abrasive, and diamond wiredrawing dies. Miscellaneous uses include: engraving points, glasscutters, bearings, surgical instruments, and special tools. Changes in technology and conventional wisdom have resulted in an increased use of synthetic industrial diamonds and polycrystalline diamond shapes (PDS) and compacts (PDC) for many of the uses listed. There has been an increased use of PDS, PDC, and matrix set synthetic diamond grit in drilling bits and reaming shells in the past 3 years. Diamond saws, diamond wheels, and diamond abrasive grit and powder are almost exclusively made from synthetic diamond. PDS and PDC are used in the manufacture of single- and multiple-point tools, and PDC is used in a majority of the diamond wiredrawing dies.

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

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

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

Finishing optical surfaces, jewel bearings, gemstones, wiredrawing dies, cutting tools, and metallographic specimens were the primary uses of polishing and lapping powder and compounds. Hundreds of other important items made from metals, ceramics, plastics, and glass also were finished with diamond compounds.

Prices.—The USBM does not collect price data on industrial diamonds. It did track the average import value of various classifications of industrial diamonds. The average value of U.S. imports of natural grit and powder, synthetic grit and powder, and industrial stones was $1.14 per carat, $0.64 per carat, and $4.56, respectively.

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 106.6 million carats of natural and synthetic grit and powder, an increase of 23% over the record set in 1992. The material was worth a record $139.3 million. Additionally, the U.S. exported and reexported approximately 3.4 million carats of industrial stones, valued at $49.1 million.

Imports of dust, grit, and powder in 1993 were about 37% more than those in 1992, a record high 132.8 million carats.

The 1993 imports of diamond stones were about 47% less than 1992 imports. *(See table 9.)*

World Review.—Botswana and the Republic of South Africa were the largest producers of good-quality industrial diamond stones. Australia and Zaire were the world's largest producers of natural industrial diamond and were the primary sources of natural crushing bort as well as substantial producers of industrial stones. Estimates suggest that the former U.S.S.R. was the third largest producer of natural industrial diamond, but reliable data were lacking.[20] The next largest, in order of volume, were Botswana and the Republic of South Africa. Other smaller but significant producers were Angola, Brazil, China, Ghana, and Venezuela.[21] Total world output of natural industrial diamond in 1993 was approximately 50.4 million carats, a 3% increase over that of 1992.

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

Outlook

Diamond grit and powder should experience substantial increases in domestic demand for every end use during the next 5 years. The increases for synthetic grit and powder are expected to be greater than for natural. The constant-dollar prices of these materials, especially the synthetic diamond products, should continue to decrease or at least remain constant. This is because planned production increases will make them more cost-effective. The contract construction industry is an area in which the greatest increases will occur. This is because large quantities of saw-grade diamond will be required for highway and bridge repair and replacement. Large increases also are expected in the dimension stone industry as a cutting and polishing media. The stone, clay, and glass industries will increase their uses in cutting, shaping, and polishing media. Additionally, 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 10%, based on estimates by the U.S. producers. U.S. production of synthetic material is sufficient to supply U.S. diamond grit and powder demand. The United States will continue to be a major exporter.

The major domestic end use for industrial stones in the next 5 years will continue to be in the oil, gas, and mineral industries. These stones are natural and cannot yet be manufactured commercially. Polycrystalline synthetic diamond compacts and shapes have had a major negative impact on the natural industrial diamond stone markets. This will limit the growth of U.S. demand for stone during the next 5 years. U.S. consumption should average between 6 and 7 million carats per year for the next 5 years. Approximately 50% of the potential natural stone applications will be replaced by the synthetic compacts and shapes by the year 2000. *(See table 10.)*

MANUFACTURED ABRASIVES

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

The fused aluminum oxide, silicon carbide, and metallic abrasives industries continued to undergo consolidation and reorganization during the year. *(See table 11.)*

Fused Aluminum Oxide

Government Programs.—The NDS, as of December 31, 1993, contained 223,959 tons of crude fused aluminum oxide and 43,614 tons of abrasive-grain fused aluminum oxide. There is no NDS goal for abrasive-grain fused aluminum oxide or crude fused aluminum oxide; all of the material is targeted for disposal. During 1993 the NDS disposed of 3,193 tons of crude fused aluminum oxide and 2,555 tons of abrasive-grade fused aluminum oxide.

Production.—At yearend, four firms were producing fused aluminum oxide at seven plants in the United States and Canada. Production of regular-grade fused aluminum oxide in 1993 was 132,403 tons, a decrease of about 7% from that of 1992.

Production of high-purity fused aluminum oxide decreased 12% to 21,276 tons. Total 1993 production of 153,680 tons was 8% less than that of 1992.

Consumption and Uses.—Fused aluminum oxide has a number of different end uses in the form of graded grain. The total value of sales of fused aluminum oxide-graded grain for all uses decreased 7% compared to that of 1992, which was a 10-year high. The value of sales for use in bonded abrasives declined 4%, coated abrasives increased 4%, refractories decreased 24%, tumbling media increased 14%, blasting abrasives increased 5%, polishing cake and buffing compounds decreased 21%, antislip abrasives decreased 21%, polishing abrasives decreased 10%, and all other uses increased 13%. *(See table 12.)*

Prices.—The USBM 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 $366 per ton. In 1993, the average value of high-purity fused aluminum was $621. The average value of all grades of fused aluminum oxide in 1993 was $401 per ton. Mineral price quotations in various December issues of trade magazines listed prices for regular-grade fused aluminum oxide of $555 to $660 per ton, while high-purity was quoted at $810 to $938 per ton.

Foreign Trade.—The quantity of exports plus reexports of fused aluminum oxide decreased 8% to 11,019 tons; the value of exports plus reexports increased slightly to $28.5 million. The average value per ton of fused aluminum oxide, exported or reexported, increased 9% to $2,588.

Imports increased about 16% in 1993 to 158,000 tons, and the value of imports increased about 4% to $76.9 million.

Silicon Carbide

Government Programs.—The NDS, as of December 31, 1993, contained 31,508 tons of silicon carbide; the goal was zero. During 1993, the Defense National Stockpile Center of the Defense Logistics Agency disposed of 5,797 tons of silicon carbide. Existing legislation authorizes disposal of all of the silicon carbide.

Production.—During 1993, three firms produced silicon carbide at four plants in the United States and Canada. Production of abrasive-grade material decreased 14% to 38,296 tons. Production of metallurgical-grade silicon carbide decreased about 7% to 36,650 tons. Total production of silicon carbide decreased 11% in 1993 to 74,945 tons.

Consumption and Uses.—Silicon carbide has a number of different end uses in the form of graded grain. The total value of sales of silicon carbide graded grain for all uses decreased 8% in 1993. The total value of sales by individual end use was a mixture of increases and decreases. Sales for use in bonded abrasives were down slightly, coated abrasives were up 3%, refractories increased 8%, tumbling media decreased slightly, blasting abrasive increased 12%, wiresawing abrasive was down 22%, polishing cake and buffing compounds were down 33%, antislip abrasives were up 14%, polishing abrasives were down 24%, metallurgical was up 11%, and all other uses were up 8%. *(See table 12.)*

Prices.—The USBM 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 $539; metallurgical-grade averaged $526; and the average value of all grades was $533. Mineral price quotations in various December issues of trade magazines listed prices for abrasive grade as $900 to $1,425 per ton.

Foreign Trade.—Exports plus reexports of silicon carbide in 1993 were 16,754 tons, a 24% increase compared to that of 1992. While the total value of silicon carbide exported plus reexported increased 31% to $15.8 million, the value per ton increased 6% to $942.

Imports of silicon carbide in 1993 increased 29% in quantity to 115,000 tons, the total value increased 14% to $57.9 million. The average value per ton decreased 23% to $441.

Alumina-Zirconia Oxide

One firm produced fused alumina-zirconia oxide in two plants, one each in the United States and Canada. Abrasive applications accounted for all the production. Publishing production data would disclose company proprietary data. Export and import data were not available.

Metallic Abrasives

Production.—Nine firms produced metallic abrasives in 10 plants in 1993. The quantity and value of steel shot and grit produced decreased about 2% and 6%, respectively. The average value per ton was $389, a 3% decrease compared with that of 1992. Michigan, Pennsylvania, Virginia, and Ohio, in decreasing order of quantity, supplied the production of steel shot and grit.

During 1993, two firms, one in

Michigan and one in New York, reported production of cut wire shot. Production of shot and grit other than steel inclined significantly in 1993, 34% in quantity to 15,389 tons, and decreased 6% in value to $7.7 million. The average value per ton decreased about 30% to $503. *(See tables 13 and 14.)*

Consumption.—The quantity of steel shot and grit sold or used decreased slightly to 202,925 tons, the total value decreased 8% to $79.2 million, and the average value per ton decreased 6% to $390.

The quantity of other shot and grit sold or used increased 31% to 15,855 tons. The value was essentially unchanged at $8.7 million. The average value per ton decreased 24% to $547.

The estimated apparent domestic consumption of all types of metallic shot and grit increased 4% in quantity to 203,555 tons, decreased slightly in total value to $79 million, and decreased 4% in average value per ton to $388. The formula to calculate U.S. estimated apparent consumption is U.S. sold or used plus imports minus exports.

Foreign Trade.—U.S. exports of metallic shot and grit increased 9% to 29,305 tons. The total value of exports decreased 40% to $14.7 million, and the average value per ton decreased 44% to $502.

U.S. imports of metallic abrasives increased 105% in quantity to 26,140 tons, increased about 59% in total value to $14.2 million, and decreased 22% in value per ton to $542.

The United States was a net exporter of metallic abrasives in 1993, a position it has enjoyed for the past 10 years with the exception of 1984.

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

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

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

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

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

[7] Work cited in footnote 4.

[8] Work cited in footnote 5.

[9] Industrial Minerals. No. 318, Mar. 1994, p. 13.

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

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

[12] ———. Specification for Grading of Diamond Powder in Subsieve Size. ANSI B74.20-1981, 12 pp.

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

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

[15] Works cited in footnotes 9 and 13.

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

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

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

[20] Work cited in footnote 14.

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

TABLE 1
SALIENT U.S. ABRASIVES STATISTICS

Abrasive materials		1989	1990	1991	1992	1993
Production of:						
Natural abrasives:						
Tripoli (crude)	metric tons	105,230	94,390	88,642	84,924	93,943
Value	thousands	$2,537	$3,194	$3,271	$3,256	$3,493
Special silica stone (crude)[1]	metric tons	898	3,709	2,205	1,732	528
Value	thousands	$147	$230	$161	$239	$240
Garnet[2]	metric tons	42,605	47,009	50,860	54,139	43,995
Value	thousands	$4,408	$6,939	$7,534	$4,842	$4,441
Emery	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Staurolite	metric tons	W	W	W	W	W
Value	thousands	W	W	W	W	W
Manufactured abrasives[3 4]	metric tons	535,213	514,869	454,572	468,772	447,532
Value	thousands	$227,761	$218,207	$195,635	$208,560	$189,337
Foreign trade (natural and artificial abrasives):						
Exports (value)[5 6]	do.	$260,363	$270,928	$295,743	$351,187	$369,090
Reexports (value)[5 6]	do.	$33,771	$24,545	$24,209	$32,088	$52,200
Imports for consumption (value)[5 7]	do.	$419,084	$512,766	$450,880	$482,134	$529,003

W Withheld to avoid disclosing company proprietary data.

[1] Includes crude material used for producing grindstones, oilstones, whetstones, and deburring media; excludes data on material used for grinding pebbles and tube-mill liners.

[2] "Primary" garnet; denotes the first marketable product and includes crude concentrate.

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

[4] Excludes U.S. and Canadian production and value of aluminum-zirconium oxide.

[5] Source: Bureau of the Census, U.S. Department of Commerce.

[6] F.a.s.

[7] Customs value.

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

Kind		1992		1993	
		Quantity	Value (thousands)	Quantity	Value (thousands)
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	81,474	$119,146	105,233	$136,570
Industrial diamond, natural or synthetic, other	do.	2,920	14,997	1,036	4,982
Natural abrasives, crude	thousand kilograms	2,193	1,741	1,463	1,161
Natural abrasives, other	do.	14,778	13,426	11,613	12,852
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	11,531	27,407	10,719	27,934
Silicon carbide, crude or in grains	do.	13,512	11,844	16,742	15,775
Grinding and polishing wheels and stones:					
Diamond	thousands of items	812	22,973	792	23,811
Polishing stones, whetstones, oilstones, hones, and similar stone	do.	1,969	7,365	1,985	6,758
Wheels and stones, n.e.c.	do.	1,608	7,044	2,280	11,340
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	14,924	101,096	14,507	113,260
Metallic abrasive: Grit and shot, including wire pellets	do.	26,587	24,147	29,183	14,646
Total[1]		XX	351,187	XX	369,090

XX Not applicable.

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

Source: Bureau of the Census.

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

Kind		1992		1993	
		Quantity	Value[1] (thousands)	Quantity	Value[1] (thousands)
NATURAL					
Industrial diamond, natural or synthetic, powder or dust	thousand carats	2,091	$6,233	1,389	$2,683
Industrial diamond, natural or synthetic, other	do.	2,676	21,730	2,328	44,105
Emery, natural corundum, pumice in blocks	thousand kilograms	163	269	16	196
MANUFACTURED					
Artificial corundum (fused aluminum oxide)	do.	437	935	300	585
Silicon carbide, crude or in grains	do.	35	161	12	8
Grinding and polishing wheels and stones:					
Diamond	thousand items	28	579	39	865
Polishing stones, whetstones, oilstones, hones, and similar stone	do.	31	227	73	431
Abrasive paper and cloth, coated with natural or artificial abrasive materials	thousand kilograms	309	1,784	438	3,260
Metallic abrasives: Short grit, pellets, etc.	do.	349	170	122	68
Total		XX	32,088	XX	[2]52,200

XX Not applicable.

[1] F.a.s.

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

Source: Bureau of the Census.

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

Kind		1992		1993	
		Quantity	Value[1] (thousands)	Quantity	Value[1] (thousands)
Silicon carbide, crude	thousand metric tons	83	$36,019	109	$44,574
Aluminum oxide, crude	do.	115	46,310	133	49,342
Abrasives, ground grains, pulverized or refined:					
Silicon carbide	do.	6	14,776	6	13,350
Aluminum oxide	do.	21	27,897	25	27,546
Emery, corundum, flint, garnet, other, including artificial abrasives	do.	21	6,172	31	2,910
Papers, cloths, other materials wholly or partly coated with natural or artificial abrasives	do.	20	132,007	26	155,592
Hones, whetstones, oilstones, polishing stones	thousand items	4	2,505	3	2,394
Abrasive wheels and millstones:					
Burrstones manufactured or bound up into millstones	do.	935	3,890	338	2,870
Solid natural stone wheels	do.	153	796	176	629
Diamond	do.	664	18,918	877	20,624
Abrasive wheels bonded with resins	do.	5,734	29,308	5,050	27,634
Other	do.	(2)	42,204	(2)	50,688
Grit and shot including wire pellets	metric tons	12,779	8,931	26,140	14,156
Diamond, natural and synthetic:					
Natural industrial diamond stones	thousand carats	3,570	21,221	3,281	18,275
Miners' diamond	do.	6,215	23,415	1,924	17,389
Powder and dust, synthetic	do.	86,720	55,739	124,880	69,765
Powder and dust, natural	do.	10,565	12,027	7,952	11,265
Total		XX	[3]482,134	XX	529,003

XX Not applicable.

[1] Customs value.

[2] Quantity not reported.

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

Source: Bureau of the Census.

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

Use		1989	1990	1991	1992	1993
Abrasives	metric tons	26,192	24,090	21,239	18,603	19,385
Value	thousands	$3,172	$3,083	$3,382	$2,779	$2,955
Filler	metric tons	63,080	56,468	52,334	57,603	58,877
Value	thousands	$9,185	$11,041	$10,009	$11,326	$12,571
Total quantity[2]	metric tons	89,272	80,558	73,575	76,205	78,262
Total value	thousands	$12,357	$14,124	$13,391	$14,105	$15,526

[1] Includes amorphous silica and Pennsylvania rottenstone.

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

TABLE 6

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

Year	Quantity (metric tons)	Value (thousands)
1989	377	$5,459
1990	450	6,328
1991	272	3,600
1992	340	4,554
1993	267	3,767

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

TABLE 7

U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1993

Company and location	Type of operation	Product
Arkansas Abrasives, Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Buffalo Stone Corp.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Cleveland Quarries Co.:		
Amherst, OH	Stone cutting and finishing	Grindstones.
Do.	Quarry	Crude silica stone.
Dans Whetstone Cutting Co., Inc.:		
Royal, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
B&J Construction:		
Paron, AR	do.	Do.
Hall's Arkansas Oilstones, Inc.:		
Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
Hardrock Mining, Inc.:		
Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media and deburring media.
Hiram A. Smith Whetstone Co., Inc.:		
Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Ed Kramer & Sons:		
Baraboo, WI	Crushing and sizing	Deburring media.
Do.	Quarry	Crude silica stone.
Norton Co. Oilstones, Norton Pike Div.:		
Hot Springs, AR	do.	Do.
Littleton, NH	Stone cutting and finishing	Whetstones and oilstones.
Pioneer Whetstone Co. (Blue Mountain):		
Hot Springs, AR	do.	Do.
Taylor Made Crafts:		
Lake Hamilton, AR	do.	Do.
Wallis Whetstone:		
Malvern, AR	Quarry	Crude novaculite.

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

Year	Quantity (metric tons)	Value (thousands)
1989	41,320	$9,768
1990	45,935	11,759
1991	48,051	13,044
1992	46,098	13,049
1993	55,760	15,433

TABLE 9

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

(Thousand carats and thousand dollars)

Country	Natural industrial diamond stones (including glazers' and engravers' diamond, unset) (7102.21.3000 and .4000)				Miners' diamond, natural and synthetic (7102.21.1010 and .1020)				Diamond powder and dust, synthetic (7105.10.0020; .0030 and .0050)				Diamond powder and dust, natural (7105.1011 and .0015)			
	1992		1993		1992		1993		1992		1993		1992		1993	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	118	$240	9	$216	3	$24	270	$165	—	—	26	$19	1	$48	1	$6
Belgium	66	504	96	420	339	5,414	528	6,713	536	$208	383	652	2,280	5,653	1,250	2,734
Canada	(2)	2	—	—	14	100	—	—	198	114	176	139	223	44	10	13
China	46	26	39	34	—	—	—	—	1,738	698	5,142	1,709	138	143	43	35
Germany	(2)	7	(2)	104	6	208	(2)	23	4,758	6,068	11,932	9,691	403	798	101	157
Ghana	617	4,397	236	3,303	11	88	6	300	42	55	32	36	180	475	65	111
Hong Kong	11	9	—	—	1	60	—	—	262	71	48	22	7	80	302	53
India	173	207	76	58	—	—	22	5	11	12	—	—	25	19	34	31
Ireland	79	363	169	536	5,293	6,681	94	269	54,928	35,833	76,394	45,827	3,227	2,090	4,085	5,885
Israel	3	390	32	25	—	—	(2)	15	52	58	15	10	(2)	7	154	49
Japan	7	539	9	82	9	108	2	118	2,275	1,952	3,734	2,664	336	438	132	189
Netherlands	8	2,605	47	2,186	128	1,767	203	2,293	—	—	—	—	—	—	—	—
South Africa, Republic of	25	137	23	81	—	—	(2)	38	340	411	389	111	—	—	3	2
United Kingdom	1,224	8,379	1,564	7,116	318	5,178	422	3,855	2,273	2,052	2,650	2,265	800	672	836	1,447
Zaire	1,130	3,198	960	3,776	77	3,379	115	2,384	31	28	—	—	1,131	517	359	234
Other	63	216	21	338	16	409	262	1,211	19,276	8,180	23,959	6,620	1,812	1,043	577	319
Total[3]	3,570	21,221	3,281	18,275	6,215	23,415	1,924	17,389	86,720	55,739	124,880	69,765	10,565	12,027	7,952	11,265

[1] Customs value.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 10
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1989				1990				1991			
	Natural			Synthetic[4]	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	1,165	80	1,245	—	1,060	73	1,133	—	899	62	961	—
Australia	17,540	17,540	35,080	—	17,331	17,331	34,662	—	17,978	17,978	35,956	—
Belarus	—	—	—	—	—	—	—	—	—	—	—	—
Botswana	10,680	4,570	15,252	—	12,150	5,200	17,352	—	11,550	4,950	16,506	—
Brazil	350	150	500	—	600	900	1,500	—	600	900	[e]1,500	—
Central African Republic	334	81	415	—	303	78	381	—	296	82	379	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e] [6]	9	3	[7]12	—	9	3	12	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	—	—	—	—	—
Czechoslovakia[e] [9]	—	—	—	[r]10,000	—	—	—	[r]10,000	—	—	—	[r]10,000
France[e]	—	—	—	4,000	—	—	—	[r]5,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—	400	100	500	—
Ghana[10]	[r]395	[r]99	494	—	[r]520	[r]130	650	—	[r]560	[r]140	700	—
Greece[e]	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[e] [6]	137	10	147	—	119	8	127	—	91	6	97	—
Guyana	3	5	8	—	5	13	18	—	6	16	[r]22	—
India	[r]12	[r]3	15	—	[r]15	[r]3	18	—	[r]15	[r]3	18	—
Indonesia[e]	7	25	32	—	7	23	30	—	8	24	32	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	30,000
Liberia[e] [11]	[7]62	[7]93	[7]155	—	40	60	100	—	40	60	100	—
Namibia	910	20	927	—	750	15	763	—	1,170	20	1,187	—
Romania[e]	—	—	—	[r]5,000	—	—	—	[r]3,000	—	—	—	[r]3,000
Russia[e]	—	—	—	—	—	—	—	—	—	—	—	—
Serbia and Montenegro[12]	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone[6]	90	39	129	—	66	12	78	—	160	83	243	—
Slovakia[9]	—	—	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of:												
Finsch Mine	1,600	3,000	4,610	—	1,480	2,700	4,178	—	1,200	2,280	3,483	—
Premier Mine	700	1,520	2,215	—	720	1,600	2,328	—	700	1,550	2,250	—
Venetia Mine	—	—	—	—	20	40	62	—	100	200	303	—
Other De Beers' properties[13]	1,350	530	1,880	—	1,200	460	1,652	—	1,500	400	1,897	—
Other	350	50	411	—	380	100	488	—	400	100	498	—
Total	4,000	5,100	9,116	[e]60,000	[r]3,800	4,900	8,708	[e]60,000	3,900	4,530	8,431	[e]60,000
Swaziland	33	22	55	—	25	17	42	—	34	23	57	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania	105	45	[e]150	—	60	25	85	—	70	30	100	—
U.S.S.R.[e] [14]	11,500	11,500	23,000	[r]120,000	12,000	12,000	24,000	[r]120,000	10,000	10,000	20,000	[r]120,000
Ukraine	—	—	—	—	—	—	—	—	—	—	—	—
United States	—	—	—	W	—	—	—	W	—	—	—	90,000
Venezuela	70	185	255	—	[r]85	[r]248	333	—	102	112	214	—
Yugoslavia[e] [15]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	[7]2,663	[7]15,092	17,755	—	[7]2,914	[7]16,513	19,427	—	3,000	14,814	17,814	—
Total	[r]50,665	[r]55,562	106,242	[r]325,000	[r]52,459	[r]58,452	110,919	[r]269,000	[r]51,090	[r]54,737	[r]105,832	[r]423,000

See footnotes at end of table.

TABLE 10—Continued

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

(Thousand carats)

Country	1992				1993[e]			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	[r]1,100	[r]80	[r]1,180	—	470	30	500	—
Australia	[r]17,750	[r]22,250	[r][e]40,000	—	19,000	23,200	42,200	—
Belarus	—	—	—	[e]30,000	—	—	—	30,000
Botswana	[r]11,160	[r]4,790	[r]15,946	—	12,000	5,000	17,000	—
Brazil[e]	[r]653	[r]665	[r]1,318	—	600	900	1,500	—
Central African Republic	[r]307	[r]107	[r]414	—	307	106	413	—
China[e]	200	800	1,000	15,000	230	850	1,080	15,500
Côte d'Ivoire[e] [6]	11	4	15	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	5,000
Czechoslovakia[e] [9]	—	—	—	[r]10,000	—	—	—	—
France[e]	—	—	—	[r]3,500	—	—	—	3,500
Gabon[e]	400	100	500	—	400	100	500	—
Ghana[10]	[r]570	[r]140	[r]710	—	600	150	750	—
Greece[e]	—	—	—	750	—	—	—	1,000
Guinea[6]	90	5	95	—	90	5	95	—
Guyana	[r]13	[r]32	[r][e]45	—	14	36	50	—
India	[r]15	[r]3	18	—	16	3	19	—
Indonesia[e]	6	21	27	—	7	20	27	—
Ireland[e]	—	—	—	60,000	—	—	—	66,000
Japan[e]	—	—	—	30,000	—	—	—	32,000
Liberia[e] [11]	[r][7]62	[r][7]93	[r][7]155	—	60	90	150	—
Namibia	[r]1,500	50	[r]1,548	—	1,100	40	[7]1,139	—
Romania[e]	—	—	—	[r][7]—	—	—	—	—
Russia[e]	9,000	9,000	18,000	80,000	8,000	8,000	16,000	80,000
Serbia and Montenegro[12]	—	—	—	5,000	—	—	—	5,000
Sierra Leone[6]	[r]200	[r]96	[r]296	—	90	68	[7]158	—
Slovakia[9]	—	—	—	—	—	—	—	5,000
South Africa, Republic of:								
Finsch Mine	1,200	2,250	3,446	—	700	1,300	[7]2,012	—
Premier Mine	740	1,700	2,444	—	500	1,100	[7]1,596	—
Venetia Mine	660	1,200	1,868	—	1,750	3,200	[7]4,969	—
Other De Beers' properties[13]	1,350	500	1,849	—	900	350	[7]1,249	—
Other	450	100	549	—	450	100	550	—
Total	[r]4,400	[r]5,750	[r]10,166	[e]60,000	4,300	6,050	10,324	75,000
Swaziland	36	24	[r]51	—	27	18	45	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000
Tanzania	[r]48	[r]20	[r]68	—	48	20	68	—
U.S.S.R.[e] [14]	—	—	—	—	—	—	—	—
Ukraine	—	—	—	[e]10,000	—	—	—	10,000
United States	—	—	—	90,000	—	—	—	103,000
Venezuela	[r]302	[r]176	[r]478	—	335	200	535	—
Yugoslavia[e] [15]	—	—	—	—	—	—	—	—

See footnotes at end of table.

TABLE 10—Continued

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

(Thousand carats)

Country	1992				1993[e]			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Zaire	[r][7]8,934	[r][7]4,567	[r]13,501	—	9,500	5,500	15,000	—
Total	[r]56,757	[r]48,773	[r]105,521	[r]419,250	57,205	50,390	107,620	456,000

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

[1] Table includes data available through June 8, 1994. Total natural diamond output (gem plus industrial) for each country actually is reported, except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates except Brazil (1989-90), and Central African Republic (1989-90), for which source publications give details on grade as well as totals. The estimated distribution of total output between gem and industrial diamond is conjectural, and for most countries, is based on the best available data at time of publication.

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

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

[4] Includes all synthetic diamond production.

[5] Figures do not include smuggled artisanal production.

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

[7] Reported figure.

[8] Formerly part of Czechoslovakia.

[9] Dissolved on Dec. 31, 1992.

[10] "Gem" vs. "Industrial" diamond breakdown has been revised to reflect the value of near-gem material, classified as industrial prior to 1991, but which was ultimately being sold for well above industrial prices.

[11] Data for 1989 do not include smuggled production. Data for 1990-92 are estimates of artisanal production, likely smuggled out of Liberia, but which are comparable to that hitherto reported to the Government.

[12] Formerly part of Yugoslavia.

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

[14] Dissolved in Dec. 1991.

[15] Dissolved in Apr. 1992.

TABLE 11

CRUDE ARTIFICIAL ABRASIVES MANUFACTURERS IN 1993

Company	Location	Product
The Exolon-Esk Co.	Hennepin, IL	Silicon carbide.
Do.	Thorold, Ontario, Canada	Fused aluminum oxide (regular).
General Abrasives Triebacher, Inc.	Niagara Falls, NY	Fused aluminum oxide (regular and high-purity).
Do.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular) and silicon carbide.
Praxair Surface Technologies, Inc.	Indianapolis, IN	Fused aluminum oxide (high-purity).
Saint-Gobain/Norton Industrial Ceramics Corp.	Huntsville, AL	Fused aluminum oxide (high-purity) and aluminum-zirconium oxide.
Do.	Worcester, MA	General abrasive processing.
Do.	Chippawa, Ontario, Canada	Fused aluminum oxide (regular and high-purity) and aluminum-zirconium oxide.
Do.	Shawinigan, Quebec, Canada	Silicon carbide.
Superior Graphite Co.	Hopkinsville, KY	Do.
Washington Mills Electro Minerals (Canada) Corp.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).
Washington Mills Electro Minerals (US) Corp.	Niagara Falls, NY	Fused aluminum oxide (high-purity).
Washington Mills Ltd.	Niagara Falls, Ontario, Canada	Fused aluminum oxide (regular).

TABLE 12
END USES OF CRUDE SILICON CARBIDE AND ALUMINUM OXIDE (ABRASIVE GRADE) IN THE UNITED STATES AND CANADA, AS REPORTED BY PRODUCERS

Use	1992 Quantity (metric tons)	1992 Value (thousands)	1992 Yearend stocks	1993 Quantity (metric tons)	1993 Value (thousands)	1993 Yearend stocks
SILICON CARBIDE						
Abrasives	44,673	$23,954	2,956	38,296	$20,647	1,448
Metallurgical	39,611	19,510	5,258	36,650	19,284	3,092
Refractories and other	W	W	—	W	W	—
Total[1]	84,283	43,464	8,214	74,945	39,931	4,540
ALUMINUM OXIDE						
Regular: Abrasives and refractories	142,545	56,284	6,388	132,403	48,482	14,392
High purity	24,231	14,388	1,134	21,276	13,220	1,256
Total[1]	166,777	70,672	7,522	153,680	61,700	15,648

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

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

TABLE 13
U.S. PRODUCERS OF METALLIC ABRASIVES IN 1993[1]

Company	Location	Product (shot and/or grit)
Alco Tech Wire Co.	Traverse City, MI	Cut wire.
Abrasive Materials, Inc.	Hillsdale, MI	Cut wire, steel.
Barnsteel Abrasives	Butler, PA	Annealed iron and steel.
Chesapeake Specialty Products	Baltimore, MD	Steel.
Durasteel Abrasive Co.	Pittsburgh, PA	Do.
Ervin Industries, Inc.	Adrian, MI	Do.
Do.	Butler, PA	Do.
Metaltec Steel Abrasives Co.	Canton, MI	Do.
National Metal Abrasive Co.	Wadsworth, OH	Do.
Pellets, Inc.	Tonawanda, NY	Cut wire.
The Platt Brothers, Inc.	Waterbury, CT	Other types.
Premier Shot Co.	Cleveland, OH	Cut wire shot.
The Wheelabrator Co.	Bedford, VA	Steel.

[1] Excludes reclaimed materials.

TABLE 14
ANNUAL PRODUCTION, SHIPMENTS, AND PLANT CAPACITIES FOR METALLIC ABRASIVES IN THE UNITED STATES, BY PRODUCT[1]

Product	Production		Shipments		Capacity[2]
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	(metric tons)
1992:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	202,325	$81,330	205,623	$85,700	235,705
Other[3]	11,477	8,270	12,089	8,725	XX
Total[4]	213,802	89,601	217,712	94,424	XX
1993:					
Chilled iron shot and grit	W	W	W	W	W
Annealed iron shot and grit	W	W	W	W	W
Steel shot and grit	197,547	76,832	202,925	79,216	247,440
Other[3]	15,389	7,746	15,855	8,672	XX
Total	212,936	84,578	218,780	87,888	XX

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

[1] Excludes secondary (recycle) producers.

[2] Total quantity of the various types of metallic abrasives that a plant could have produced during the year, working three 8-hour shifts per day, 7 days per week, allowing for usual interruptions, and assuming adequate fuel, labor, and transportation.

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

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

ALUMINUM, BAUXITE, AND ALUMINA

By Patricia A. Plunkert and Errol D. Sehnke

Ms. Plunkert, a physical scientist with 25 years of U.S. Bureau of Mines experience, has been the commodity specialist for aluminum since 1987. Domestic survey data for aluminum were prepared by Shonta E. Osborne, lead statistical assistant; and the international data table was prepared by Harold D. Willis, international data coordinator.

Mr. Sehnke is a physical scientist with 20 years of minerals industry and U.S. Bureau of Mines experience. Domestic survey data for bauxite and alumina were prepared by Shonta E. Osborne, lead statistical assistant; and international data tables were prepared by Harold D. Willis, international data coordinator.

Aluminum is the second most abundant metal element in the Earth's crust after silicon, yet it is a comparatively new industrial metal that has been produced in commercial quantities for just over 100 years. It weighs about one-third as much as steel or copper; is malleable, ductile, and easily machined and cast; and has excellent corrosion resistance and durability. Measured either in quantity or value, aluminum's use exceeds that of any other metal except iron, and it is important in virtually all segments of the world economy.

Domestic primary aluminum production decreased significantly in 1993 to its lowest level in 6 years. Thirteen companies operated twenty-two primary aluminum reduction plants and 1 plant remained temporarily closed. Montana, Oregon, and Washington accounted for 34% of the production; Kentucky, North Carolina, South Carolina, and Tennessee, 22%; and other States, 44%. The value of primary metal produced domestically in 1993 was estimated at $4.3 billion. In response to rising world inventories and depressed prices, more than one-half of the domestic primary aluminum smelters announced temporary shutdowns in production capacity during the year.

Aluminum recovered from purchased scrap, however, increased to more than 2.9 million metric tons. Forty-five percent of this recovered metal came from new (manufacturing) scrap and 55% from old scrap (discarded aluminum products). The recycling rate for aluminum used beverage can (UBC) scrap decreased slightly compared with that of the previous year, but remained above the 60% level for the fifth consecutive year.

Aluminum consumption, by an estimated 25,000 firms, was centered in the East Central United States. Packaging accounted for an estimated 30% of domestic consumption; transportation, 26%; building, 17%; electrical, 9%; consumer durables, 8%; and other uses, 10%.

U.S. imports for consumption increased dramatically in 1993 and reached an alltime high. Although there were increased imports from several different countries, one of the most significant increases was the rise in the level of imported ingot from the former U.S.S.R. Total exports, however, decreased to their lowest level since 1987.

The price of primary aluminum ingot trended downward during 1993 on the domestic and world markets. Prices in the aluminum scrap markets paralleled the general trend of primary ingot prices.

World inventories of metal continued to rise during the year. By yearend, inventories on the London Metal Exchange (LME) reached record levels, approaching 2.5 million tons. Inventories held by producers, as reported by the International Primary Aluminium Institute (IPAI), exceeded 2 million tons.

Primary aluminum was produced in 44 countries in 1993. The United States was the largest producer with 19% of the world total, followed by Russia with 15% and Canada with 12%. World metal production remained relatively unchanged compared with that of the previous year. Announced production cutbacks, particularly in the United States and Europe, were counterbalanced by increased smelter capacity that started production during the year. The flow of metal from the former U.S.S.R. to Western markets continued. In late 1993, the Government of Russia invited representatives from several major aluminum-producing countries to Moscow to prepare the framework for informal multilateral meetings to discuss the crisis in the world aluminum market.

U.S. mine production of bauxite increased in 1993; however, imports continued to dominate the domestic market. U.S. bauxite mine production amounted to less than 1% of total world production. Three companies operated surface mines in Alabama and Georgia. Virtually all of the domestic ore was consumed in the production of nonmetallurgical products such as abrasives, chemicals, proppants, and refractories. The United States remained totally dependent on foreign sources of metallurgical-grade bauxite, and approximately 92% of the total bauxite consumed in the United States during 1993 was utilized for the production of alumina.

World production of bauxite and alumina, feedstocks for the aluminum industry, increased by modest amounts in 1993. Mine production of bauxite was reported from 26 countries, and alumina was produced in 29 countries.

Identified world bauxite resources (reserves plus subeconomic and undiscovered deposits) at yearend 1993 were estimated by the U.S. Geological Survey to be 55 to 75 billion tons, in South America (33%), Africa (27%), Asia (17%), Oceania (13), and elsewhere (10%). The world reserve base was estimated by the U.S. Bureau of Mines at 28 billion tons and world reserves at 23 billion tons.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for aluminum, bauxite, and alumina are developed by the U.S. Bureau of Mines from five separate, voluntary surveys of U.S. operations. Typical of these monthly, quarterly, and annual surveys is the "Aluminum" survey. Of the 13 companies canvassed by this form, all responded, representing 100% of the total domestic primary aluminum production.

ANNUAL REVIEW—ALUMINUM

Production

Primary.—Domestic primary aluminum production, totaling 3,694,752 tons, decreased compared with 1992 production levels. At the beginning of 1993, one smelter was temporarily closed and the other 22 smelters were operating at or near full capacity levels. During the year, several companies announced temporary reductions in primary metal capacity levels. In their company annual reports and press releases, the companies stated that these reductions were in response to shortages of available electricity and/or depressed metal prices. By the end of the year, domestic primary aluminum production capacity had been reduced by a total of 790,000 tons, 20% of engineered capacity levels. *(See tables 1 and 2.)*

Secondary.—According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, 59.5 billion aluminum UBC's were recycled in 1993, equivalent to a recycling rate of 63.1%. This was the fifth consecutive year that the recycling rate of aluminum UBC's has exceeded 60%. *(See tables 3, 4, and 5.)*

Consumption and Uses

The container and packaging industry remained the largest domestic consumer of aluminum products, representing about 30% of the domestic shipments of aluminum products. The Can Manufacturers Institute reported that 95.1 billion aluminum beverage cans were shipped in 1993, representing more than 97% of the total metal beverage can shipments.

The transportation industry accounted for about 26% of domestic aluminum shipments. According to a factsheet, "Aluminum Applications in the Automotive Industry," published by the Aluminum Association in October 1993, the use of aluminum by the auto industry has more than doubled from an average of 35 kilograms (77 pounds) per car in 1971 to 87 kilograms (191 pounds) in 1991. Aluminum is used to make hundreds of parts in the automotive industry. The report provided the following examples of aluminum's widespread use. Approximately 30% of all wheels are aluminum, and some forecasts call for that number to increase to 50% by 1995. Almost all passenger car heat exchanger systems produced in the United States are aluminum. Virtually all passenger car transmission cases are now produced in aluminum, as well as some differential carriers. *(See tables 6, 7, and 8.)*

Stocks

Inventories of aluminum ingot, mill products, and scrap at reduction and other processing plants, as reported by the U.S. Department of Commerce, increased from 1.875 million tons at yearend 1992 to 2.046 million tons at yearend 1993.

The LME reported that its U.S. warehouses held a total of 167,600 tons of primary aluminum metal ingot at yearend 1993, a decrease from the 213,525 tons of metal reportedly held in these warehouses at yearend 1992. The LME also reported that aluminum alloy ingot held at its U.S. warehouses at yearend 1993 decreased to 980 tons, a mere fraction of the 10,120 tons of alloy held at yearend 1992. Increased demand by the domestic automotive diecasting industry reportedly contributed to this major decrease in LME alloy inventories.

There were no releases of aluminum metal from the National Defense Stockpile (NDS) during the year, and the inventory level remained at 57,010 tons.

Markets and Prices

The monthly average U.S. market price of primary aluminum metal, as reported by Platt's Metals Week, fluctuated throughout the year but with a general downward trend. The monthly average price began the year at a high of 56.132 cents per pound and posted a low of 49.950 cents per pound in November. The average price for the year was 53.326 cents per pound, slightly more than 4 cents per pound lower than the 1992 average annual price of 57.519 cents per pound. The LME cash price for high-grade primary aluminum ingot followed the same general trend as the U.S. market price. The 1993 average annual LME cash price was 51.667 cents per pound.

Purchase prices for aluminum scrap, as quoted by American Metal Market (AMM), fluctuated during the year and closed the year at lower levels than those at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 39.5 to 40.5 cents per pound; old sheet and cast, 34.5 to 35.5 cents per pound; and clean, dry aluminum turnings, 34 to 35 cents per pound. Prices for UBC's trended downward for most of the year and closed about 6 cents per pound lower than prices at the beginning of the year. Aluminum producers' buying price range for processed and delivered UBC's, as quoted by AMM, began the year at 40 to

42 cents per pound. The price range at the end of the year widened and decreased to 33 to 37 cents per pound.

In mid-July, AMM discontinued the publication of secondary aluminum ingot prices and substituted an indicator price series. The yearend 1993 indicator price for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 61.96 cents per pound; alloy 360 (0.6% copper content), 67 cents per pound; alloy 413 (0.6% copper content), 67.09 cents per pound; and alloy 319, 64.52 cents per pound.

The LME began cash trading of a secondary aluminum contract in January. The 1993 annual average price, based on 11 months of prices, was 45.13 cents per pound. Metals Week published an annual average U.S. price of 55.46 cents per pound for A-380 alloy (3% zinc content), the alloy comparable to that traded on the LME.

Foreign Trade

Exports of all forms of aluminum from the United States decreased from those of 1992 and reached their lowest level since 1987. Most of the decrease occurred in the crude metal and alloys category.

Imports for consumption, however, increased dramatically to a record high. As with exports, the major change in shipments occurred in the crude metal and alloy category. Shipments from most countries increased from those of the previous year. Canada remained the major shipping country to the United States, accounting for two-thirds of the ingot imports in 1993. The most dramatic increase, however, was in the level of imports from Russia, which became the second largest shipping country of aluminum ingot into the United States. Combined imports from Russia and Tajikistan approached 440,000 tons compared with slightly more than 16,000 tons of ingot imports from countries in the former U.S.S.R. in 1992. *(See tables 9, 10, 11, and 12.)*

World Review

World production of primary aluminum metal was relatively unchanged in 1993 compared with that of the previous year. Increased smelter capacity that started production during the year was offset by cuts in production in Europe and the United States. The continued slowdown in world economic activity outside of the United States, and the buildup of inventory levels, especially those inventories held by the LME, kept world metal prices at a depressed level. Russian metal exports continued to flow onto the world market. Estimates of the quantity of metal exported from the former U.S.S.R. ranged from 1.6 million tons to more than 2 million tons.

Primary aluminum inventories held by members of the IPAI, which represent the bulk of stocks held outside the former centrally planned economy countries and the LME, increased from 1.717 million tons at yearend 1992 to 2.007 million tons at yearend 1993. IPAI reported that total metal inventories, including secondary aluminum, increased from 3.283 million tons at yearend 1992 to 3.532 million tons at yearend 1993.

Inventories of primary aluminum metal held by the LME reached record levels in 1993. LME inventories increased by almost 1 million tons during the year. At the beginning of the year, LME inventories totaled 1.527 million tons. By yearend, the total had climbed to 2.486 million tons.

In August, the European Commission announced the introduction of a 60,000-ton limit on aluminum imports from the former U.S.S.R. effective until the end of November. The limit was subsequently extended to allow another 45,000 tons of imports through the end of February 1994. The import quotas were imposed on all aluminum metal, whether it arrived directly from states in the former U.S.S.R. or through a third country. The imposition of the import quotas was seen as a temporary measure while negotiations for an agreed-upon level of imports continued.

In October, the Russian Government invited several world aluminum-producing countries to Moscow to prepare the framework for informal multilateral meetings to address the crisis in the world aluminum market. Representatives from Australia, Canada, the European Community (EC), Norway, Russia, and the United States met to discuss the oversupply situation that resulted from the downturn in the major Western economies and the introduction of the former U.S.S.R. as a major exporter of aluminum. The 2-day meeting ended with a commitment by all participants to meet again in Washington, DC, in December.

The second round of meetings held in Washington, DC, brought together the same group of producing nations along with their industry representatives, who were invited to give presentations outlining their analyses of the crisis in the aluminum market. Industry participation was limited to a general session on the first day of the meetings and included most of the presidents and chief executive officers of the world's major aluminum-producing companies, as well as representatives from the IPAI. Industry estimated that between 1.5 and 2 million tons of aluminum had to be taken out of production to return the market to balance by 1996. Although no solution was reached by the government representatives at the meeting, the framework for future meetings was outlined. *(See table 13.)*

Current Research

Bench-scale tests by the U.S. Bureau of Mines have shown that magnesium and zinc can be readily distilled from common aluminum alloys. The results showed that temperature and pressure strongly influenced distillation rates. Changes in the alloy composition, however, did not have a noticeable effect on the distillation rates. Even though the distillation rates were high, they were less than predicted by distillation equations, and possible explanations were explored. A conceptual apparatus for integrating distillation into a secondary aluminum smelter was discussed.[1]

OUTLOOK—ALUMINUM

The world demand for aluminum metal

showed signs of improvement during the first half of 1994. Demand for aluminum remained strong in the United States, and other areas of the world appeared to be edging out of the recent economic downturn. Aluminum metal prices had improved, and inventories, both LME and IPAI, began to slowly decrease. Exports of aluminum metal continued to flow out of Russia but were beginning to be absorbed by slowly expanding aluminum markets. If these positive economic signs persist, the excess metal inventory supply overhanging the market should begin to fade away and eventually return to a more economically acceptable level. Thereafter, the long-term growth rate for aluminum metal should average about 2% per year.

ANNUAL REVIEW—BAUXITE AND ALUMINA

World production of bauxite and alumina increased only modestly during 1993; bauxite production rose by 4% and alumina output was up 3% over the previous year's total. Mine production of bauxite was reported from 26 countries. Domestic consumption of bauxite in 1993 rose over 1992 consumption levels, but remained below a previous recent high reached in 1991. Within the specialty products area, consumption of abrasive-grade bauxite fell below 1992 usage, but bauxite consumption by the chemical and refractory industries increased in 1993. Demand for alumina was sluggish throughout the year, mainly in response to reduced primary aluminum smelter operating levels. U.S. production of smelter-grade alumina increased by 2% in 1993, while shipments declined by a very slight amount, less than 1%. U.S. alumina consumption moderated slightly from 1992 levels and a continued softening of the alumina market developed throughout 1993 as a buildup occurred in alumina stocks. Alumina reportedly was produced in 29 countries around the world. *(See table 14.)*

Legislation and Government Programs

There were no additions of bauxite to the NDS in 1993; however, 508,000 tons of Jamaican-type metallurgical-grade bauxite was released from the NDS as part of two individual, 5-year sales arrangements begun in fiscal 1993 by the Defense Logistics Agency (DLA). Reynolds Metals Co. bought 245,000 tons of this material at $8.29 per ton and Kaiser Aluminum and Chemical Corp. bought a similar amount at $6.40 per ton. Under terms of the separate agreements, the purchase price accepted in fiscal 1993 will be indexed in future years to average quarterly LME primary aluminum prices. Additionally, at the close of the 1993 fiscal year, 49,000 tons of calcined refractory-grade bauxite was sold from the NDS.

Under the new Department of Defense Annual Materials Plan (AMP) for fiscal year 1994, released in mid-1993, DLA was authorized to dispose of a further 914,000 tons of metallurgical-grade bauxite—approximately 610,000 tons of Jamaica type and 305,000 tons of Suriname type. In fact, on December 16th, under this new authority, the DLA agreed with Kaiser and Reynolds on terms of sale for the fiscal year 1994 quotas in their separate long-term contracts to purchase metallurgical-grade bauxite from the NDS. Kaiser was awarded 305,000 tons of Jamaican-type bauxite at $8.53 per ton, while Reynolds was awarded 305,000 tons at $6.59 per ton. In addition, as a part of the 1994 AMP, DLA expects to release 51,000 tons of calcined refractory-grade bauxite in fiscal year 1994. This is the maximum amount recommended for disposal during the fiscal year, and the actual level of sales will depend upon prevailing market conditions.

At yearend 1993, NDS holdings for metallurgical-grade bauxite were 11.6 million tons of Jamaica type and 5 million tons of Suriname type with both of these amounts authorized for total disposal. The NDS calcined refractory-grade bauxite inventory was listed as 231,000 tons, with 161,000 tons authorized for disposal.

Production

The total U.S. bauxite production during 1993 was 29% greater than that reported for 1992. The only currently active bauxite mines remaining in the United States are the surface operations in Alabama and Georgia that produce bauxitic materials, a natural mixture of bauxitic clay and bauxite with a very low iron oxide content, primarily used for the production of alumina calcines. Demand for these domestic ores increased by a moderate amount during 1993. Within this market sector, the Harbison-Walker Refractories Div. of INDRESCO Inc. shipped bauxite from mines in Alabama to its local calcining plant and to Carbo Ceramic Co.'s proppant plant at Eufaula, AL. Throughout the year, C-E Minerals continued to operate and maintain its mines in Alabama and Georgia, with the raw ore shipped to its Andersonville, GA, facility for the production of refractory products.

In 1993, Kaiser Aluminum and LaRoche Chemicals Inc. formed a worldwide joint venture to market alumina trihydrate. The marketing venture, Kaiser LaRoche Hydrate Partners, reportedly will focus its marketing efforts on companies that produce flame retardants, catalysts, zeolites, aluminum sulfate, and other specialty chemicals. *(See tables 15 and 16.)*

Consumption and Uses

Weak demand for smelter-grade alumina lowered the consumption of crude and dried metallurgical-grade bauxite to a level below that of 1992. Consumption of bauxite by the abrasive industry decreased by nearly 10% in 1993, while consumption within the chemical and refractory industries increased by moderate amounts for the year. Approximately 92% of the bauxite consumed in the United States during 1993 was refined to alumina, and an estimated average of 2.08 tons of dried bauxite was required to produce 1 ton of calcined alumina. Twenty-two primary aluminum smelters reported a consumption of 7.42 million tons of calcined alumina in 1993, a 9% decrease from the consumption level reported for 1992. This lower rate of consumption, coupled with a lower level of U.S. alumina imports, resulted in the development of a reduced supply of smelter-grade alumina for the domestic alumina market. An estimated 91% of the alumina shipped by U.S. refineries went to domestic primary smelters for metal production. Consumption in various forms by the abrasives, chemicals, refractories, and specialties industries accounted for the balance of the alumina usage. *(See tables 17, 18, 19, and 20.)*

Markets and Prices

Contract terms for the purchase of metallurgical-grade bauxite and smelter-grade alumina in world markets are not normally made public, and, consequently, prices for these commodities are not published by trade journals. Price quotes are generally limited to certain specialty forms of bauxite and alumina for nonmetallurgical uses.

In 1993, the U.S. Bureau of Mines estimated the average value of domestic crude bauxite shipments, f.o.b. mine or plant, to be $21 per ton. The average value of calcined domestic bauxite was estimated to be $195 to $200 per ton. Base prices quoted by Industrial Minerals magazine and independent sources for imported calcined refractory-grade bauxite were as follows: Chinese, typical 85% alumina (Al_2O_3), f.o.b. barge, Burnside, LA, $85 to $120 per ton; and Guyanese, f.o.b. rail car, Baltimore, MD, or f.o.b. barge, Gulf Coast, $175 ton. Abrasive-grade bauxite, minimum 86% Al_2O_3, c.i.f. main European ports, was priced at $95 to $108 per ton. Base prices were subject to adjustment for various grain-size specifications, size of order, and fuel cost factors.

A growing alumina surplus on world markets led to prices easing from the very high levels established during the previous 2 years. The average value of domestic calcined alumina shipments was estimated to be $192 per ton. Trade data released by the Bureau of the Census indicated the average value of imported calcined alumina was $182 per ton, f.a.s. port of shipment, and $194 per ton, c.i.f. U.S. ports. Beyond these current prices, medium-term projections support a reasonably resilient market outlook for alumina toward the mid-1990's.

For 1993, the International Bauxite Association (IBA) once again recommended that its members set their minimum c.i.f. price for metallurgical-grade bauxite at between 2% and 2.5% of the composite reference price for primary aluminum ingot and for metallurgical-grade alumina between 14.5% and 16.5% of the composite reference price for primary aluminum ingot. In 1993, IBA member countries produced 38% of the world's bauxite and 16% of its alumina.

A second United Nations Conference on Trade and Development (UNCTAD) ad hoc review meeting on bauxite was held April 29-30, 1993, in Geneva, Switzerland, to provide the world's bauxite-producing countries with a forum in which to discuss the need for a producer-consumer dialogue. The meeting focused on the need for improved market transparency, especially improved statistical data, and particularly, information regarding the republics of the former U.S.S.R. *(See table 21.)*

Foreign Trade

Dried bauxite exports from the United States totaled 85,000 tons in 1993, a major increase over the 1992 total of 54,400 tons; Canada received 98% of the 1993 exports. U.S. exports of calcined refractory-grade bauxite totaled 2,800 tons for 1993; Mexico received 57% and Canada 43%. Exports of all other grades of calcined bauxite (chiefly abrasive grade) amounted to 2,000 tons for the year. Specialty aluminum compounds exported included 6,800 tons of aluminum sulfate, 7,800 tons of aluminum chloride, 10,700 tons of aluminum oxide abrasives, and 26,900 tons of various fluoride-based compounds of aluminum, including synthetic cryolite and aluminum fluoride.

Imports for consumption of crude and dried bauxite increased by 6% from the level of 1992 receipts, and the four principal suppliers, Jamaica, Guinea, Brazil, and Guyana, in order of shipments, provided 93% of the total. As in previous years, China and Guyana remained the dominant suppliers of calcined bauxite to the United States. Australia continued to be the primary source of U.S. alumina imports, accounting for approximately 70% of the total receipts for the year. *(See table 22, 23, 24, and 25.)*

World Review

World production of bauxite and alumina increased in spite of a continued sluggishness in demand for primary aluminum metal and a protracted surge of aluminum from the former U.S.S.R. Twenty-six countries reportedly mined bauxite in 1993, and the total world production of bauxite increased to 105.6 million tons, an increase of 4% over 1992 production. Australia, Guinea, Jamaica, and Brazil, in order of volume, accounted for slightly more than 70% of the total bauxite mined during the year. The corresponding world output of alumina increased to 43 million tons, which was 3% above the 1992 production level. The four principal producing countries, Australia, United States, Russia, and Jamaica, in order of volume, supplied approximately 60% of the total world production.

Capacity.—The 1993 world annual rated capacity of plants producing alumina remained essentially unchanged from the 1992 level. At the same time, apparent worldwide refinery capacity utilization for 1993 was estimated at approximately 89% and represented a increase of about 2% from the previous year. As has been the case in recent years, further increases in smelter-grade alumina production capacity are primarily expected to develop from incremental expansions of existing plants and only in very special situations from new greenfield refineries, which normally demand a 4- to 5-year design, engineering, and construction period, plus very significant levels of capital investment.

Australia.—In 1993, production levels rose in this, the world's largest bauxite- and alumina-producing country. Bauxite output was up by about 5% and alumina increased by nearly 7%.

As a result of the decision by Australia's High Court on the Mabo native claims case in mid-1992, several Mabo-style land claims were filed by Aboriginal groups in 1993, including those that challenged Comalco Ltd.'s bauxite mining leases at Weipa, on the Cape York Peninsula in the far north of Queensland. However, the Native Title Act 1993, which was passed into law by Australia's Federal Government in late 1993, validated all mining leases granted before 1975 and thereby ensured that Comalco's bauxite operations in Queensland were not subject to native title claims.

Alcoa of Australia Ltd. announced plans to increase production capacity at its Wagerup alumina plant in Western Australia by a further 200,000 tons per year to an annual capacity of approximately 1.7 million tons, with this new capacity expected to come on-stream in mid-1994.

In an effort to strengthen its presence in the Pacific Basin market area, Alusuisse-Lonza announced that the majority of its bauxite, alumina, and alumina trihydrate trading activities would be moved from Zurich, Switzerland, to Sydney, Australia. This marketing activity will be managed by a newly incorporated group, Alusuisse Australasia Pacific Pty. Ltd.

Brazil.—Mineraçao Rio do Norte (MRN), operator of Brazil's large Trombetas bauxite mining operation in the Amazon Basin, reportedly signed an agreement to supply alumina plants in Ukraine and Kazakhstan with 500,000 tons of bauxite in 1993. The price of the bauxite was expected to be between $22.50 and $23 per ton, f.o.b. Trombetas.

Plans reportedly were undertaken to resume construction work on a limited scale at the long-delayed 1.1-million-ton-per-year Alunorte alumina plant near Belém in northern Brazil. State-controlled Companhia Vale do Rio Doce (CVRD) indicated that it would finance construction using its own resources, Government funds, and capital from two recent joint ventures.

Canada.—Alcan Aluminium Ltd. of Canada announced the development of a new variant of the Bayer process designed to exploit the different dissolution temperatures of alumina minerals in the recovery of alumina from bauxite. The new process, designated as counter-current digestion, reportedly provides energy savings of 7% to 10%.

Ghana.—Ghana reportedly was once again seeking foreign investors for the development of an alumina plant to fully exploit its bauxite resources at Nyinahin and Kibi.

Greece.—It was announced that Russia and Greece are to resume the construction of the stalled 700,000-ton-per-year alumina plant near Thísvi in central Greece. Russia now plans to acquire a 51% share in the Hellenic Alumina Industries S.A. (Elva) joint-venture project by providing $178 million in direct financial investment. Alumina produced by the facility would be supplied to Russia under long-term contracts, with Russia providing natural gas as payment for the material.

Hungary.—The Hungarian aluminum producer, Hungalu, secured alumina-aluminum barter agreements with Russian partners covering approximately 400,000 tons of its alumina exports in exchange for 60,000 tons of Russian metal imports in 1993. These trade contracts are expected to provide short-term relief to Hungary's struggling bauxite and alumina industries.

India.—Alcoa signed a joint-venture agreement with India's Associated Cement Companies Ltd. (ACC) to manufacture and market raw materials for the Indian refractories and ceramic industries. The new business partners plan to build a facility at Falta, in West Bengal, capable of producing 10,000 tons of tabular alumina and magnesium aluminate spinel aggregates when it becomes operable in the second quarter of 1994.

India's privately owned Indian Aluminium Co. (Indal) and Tata Industries have joined with Norsk Hydro of Norway to set up an export-oriented company that will build an alumina plant with an annual installed capacity of 1 million tons per year in India's eastern State of Orissa. The facility, which will be based on Alcan and Alusuisse technology, is expected to cost 24,000 million Rupees (US$774.2 million) and projected to come on-stream in 1998.

Indonesia.—Another country interested in joining the alumina-producing countries of the world is Indonesia. The Indonesian Government entered into a joint-venture project to study the feasibility of establishing a 900,000-ton-per-year alumina plant on Bintan Island in the Riau Archipelago. This is a reactivation of a project initiated in the early 1980's.

Jamaica.—In Jamaica, alumina output at Jamalco was increased to 700,000 tons per year and was scheduled to be expanded to 1 million tons per year by 1994. Jamalco is a joint venture of Alcoa and the Jamaican Government.

Russian Federation.—A Russian-registered joint stock company, Boksit Timana, was reportedly awarded the tender to develop the Middle Timan bauxite deposits of the Komi Republic. The development costs for this project have been estimated at several billions of dollars.

Saudi Arabia.—Saudi Arabia reported the identification of additional bauxite reserves near Az Zabirah in the northern part of the country. Bauxite occurrences in this area were evaluated in the late

1970's to early 1980's.

In a related matter, the Gulf Organization for Industrial Consulting (GOIC) attempted to attract financial interests in Saudi Arabia and the United Arab Emirates to invest in developing the region's first alumina plant. Presently, the majority of the region's alumina requirements are supplied by Australia.

South Africa, Republic of.—Royal Dutch/Shell indicated it had entered discussions with South Africa's Gencor Ltd. for the purchase of the major portion of the metal assets owned by companies within the Royal Dutch/Shell Group. Gencor reportedly has expressed a specific interest in the aluminum industry assets that Royal Dutch/Shell holds in Australia, Brazil, and Suriname. They comprise various joint-venture holdings in bauxite and alumina operations.

Suriname.—Suriname Aluminium Co. (Suralco) declared a force majeure on alumina shipments in early February due to an unexpected labor action at its Paranam operations. The union and company management were able to reach agreement in about 2 weeks, and the force majeure was lifted following settlement of the strike.

In 1993, Billiton Maatschappij Suriname commenced mining operations at the Accaribo bauxite deposit near Paranam.

Venezuela.—By midyear, various reports indicated that Venezuela's CVG intended to merge its aluminum industry holdings—Bauxiven, Interalumina, and Venalum—into one single operating company.

ICF Kaiser Engineers announced that it was awarded a 9-month, $1 million contract to conduct a feasibility study for expanding CVG Interalumina's alumina plant at Puerto Ordaz, Venezuela, to an annual capacity of 3 million tons per year. The study is being funded by the U.S. Trade and Development Agency. *(See tables 26 and 27.)*

OUTLOOK—BAUXITE AND ALUMINA

Known world bauxite reserves are sufficient to meet cumulative world demand well into the 21st century. Considering the high probability of discovering additional bauxite deposits, plus the added possibility of employing lower grade bauxite deposits and other alternative sources of alumina, world resources of aluminum remain adequate to satisfy demand for the foreseeable future.

The continued and extended economic restructuring of Eastern Europe and the newly independent republics of the former U.S.S.R. appears to provide substantially increased market opportunities for the established bauxite- and alumina-producing countries of the world. The quality and quantity of bauxite resources within the former Eastern bloc nations are believed to be incapable of sustaining an economically viable market-based aluminum industry. To become truly competitive in the "new global economy," major amounts of imported bauxite and alumina feedstocks will be required to supply the primary aluminum production facilities of the former U.S.S.R. The most crucial element in the development of this trade pattern will be the implementation of adequate and reliable payment or tolling mechanisms for the continued timely transfer of these vital raw materials to the aluminum industry of the former U.S.S.R.

In the short term, the outlook for the metallurgical markets of bauxite and alumina seem rather bleak owing to the oversupply of primary aluminum metal that has been provoked by substantial exports from the former U.S.S.R. and excess primary metal production capacity in the Western World. On a more positive note, nonmetallurgical consumers of bauxite and alumina are expected to provide the fastest growing markets in the 1990's. In these specialty product areas it is envisioned that bauxite and alumina will lose some market share within the refractory and abrasive materials sectors, but gain very substantially in the ceramics and plastics markets.

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[1] Murphy, J. E., and J. J. Lukasko. Vacuum Distillation of Magnesium and Zinc From Aluminum Scrap. Paper in Light Metals 1993, ed. by S. K. Das (122nd TMS Annu. Meeting, Denver, CO, Feb. 21-25, 1993). TMS-AIME, Warrendale, PA, 1993, pp. 1061-1065.

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Metal Bulletin.
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  Aluminium 1992, 5th ed.
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TABLE 1
SALIENT ALUMINUM STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Primary production	4,030	4,048	4,121	4,042	3,695
Value	$7,801,086	$6,604,398	$5,402,627	$5,125,612	$4,343,667
Price: (average cents per pound)					
U.S. market (spot)	87.8	74.0	59.5	57.5	53.3
Secondary recovery	2,054	2,393	2,286	[r]2,756	2,944
Exports (crude and semicrude)	1,615	1,659	1,762	1,453	1,207
Imports for consumption (crude and semicrude)	1,470	1,514	1,490	1,725	2,545
Aluminum industry shipments[1]	[r]6,751	[r]6,592	[r]6,395	[r]6,809	7,231
Consumption, apparent	4,957	5,264	5,043	5,725	6,540
World: Production	[r]19,010	[r]19,299	[r]19,575	[r]19,467	[e]19,816

[e]Estimated. [r]Revised.

[1]Shipped to domestic industry.

TABLE 2
PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons)		1993 ownership (percent)
	1992	1993	
Alcan Aluminum Corp.:			
Sebree, KY	180	180	Alcan Aluminium Ltd., 100%.
Alumax Inc.:			
Ferndale, WA (Intalco)	275	275	AMAX Inc., 75%; Mitsui & Co., 11%; Toyo Sash, 7%; Yoshida Kogya K.K., 7%.
Frederick, MD (Eastalco)	170	170	Do.
Mount Holly, SC	184	184	AMAX, 73%; Clarendon Ltd., 27%.
Total	629	629	
Aluminum Co. of America:[1]			
Alcoa, TN	210	210	Aluminum Co. of America, 100%.
Badin, NC	115	115	Do.
Evansville, IN (Warrick)	300	300	Do.
Massena, NY	125	125	Do.
Rockdale, TX	315	315	Do.
Wenatchee, WA	220	220	Do.
Total	1,285	1,285	
Columbia Aluminum Corp.:			
Goldendale, WA	168	168	Columbia Aluminum Corp., 70%; employees, 30%.
Columbia Falls Aluminum Co.:			
Columbia Falls, MT	168	168	Montana Aluminum Investors Corp., 100%.
Kaiser Aluminum & Chemical Corp.:			
Mead, WA (Spokane)	200	200	MAXXAM Inc., 100%.
Tacoma, WA	73	73	Do.
Total	273	273	

See footnotes at end of table.

TABLE 2—Continued

PRIMARY ANNUAL ALUMINUM PRODUCTION CAPACITY IN THE UNITED STATES, BY COMPANY

Company	Yearend capacity (thousand metric tons) 1992	Yearend capacity (thousand metric tons) 1993	1993 ownership (percent)
NSA:			
Hawesville, KY	186	186	Southwire Co., 100%.
Noranda Aluminum Inc.:			
New Madrid, MO	215	215	Noranda Mines Ltd., 100%.
Northwest Aluminum Corp.:[2]			
The Dalles, OR	82	82	Martin Marietta Corp., 87.2%; private interests, 12.8%.
Ormet Corp.:			
Hannibal, OH	245	245	Ohio River Associates Inc., 100%.
Ravenswood Aluminum Corp.:			
Ravenswood, WV	168	168	Stanwich Partners Inc., 100%.
Reynolds Metals Co.:			
Longview, WA	204	204	Reynolds Metals Co., 100%.
Massena, NY	123	123	Do.
Troutdale, OR	121	121	Do.
Total	448	448	
Vanalco Inc.:			
Vancouver, WA	116	116	Vanalco Inc., 100%.
Grand total	4,163	4,163	

[1] Individual plant capacities are U.S. Bureau of Mines estimates based on company reported total.

[2] Northwest Aluminum Corp. signed a lease-purchase agreement for The Dalles smelter with Martin Marietta Corp. in 1986.

TABLE 3

U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,[1] BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1992			
Secondary smelters	945,627	760,064	815,548
Intergrated aluminum companies	1,365,751	1,139,971	1,215,115
Independent mill fabricators	553,318	473,818	505,679
Foundries	85,529	70,298	75,555
Other consumers	[r]9,899	[r]9,899	[r]9,899
Total	[r]2,960,124	[r] [2]2,454,049	[r]2,621,796
Estimated full industry coverage[3]	[r]3,112,000	2,580,000	[r]2,756,000
1993			
Secondary smelters	1,134,840	881,726	946,036
Intergrated aluminum companies	1,344,522	1,120,756	1,194,230
Independent mill fabricators	607,569	523,833	559,077
Foundries	89,925	74,256	79,881
Other consumers	9,558	9,558	9,558
Total	3,186,414	2,610,129	2,788,782
Estimated full industry coverage[3]	3,365,000	2,754,000	2,944,000

[r] Revised.

[1] Excludes recovery from other than aluminum-base scrap.

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

[3] Rounded.

TABLE 4
U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1993

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	[r]4,779	96,359	96,886	4,252
Borings and turnings	[r]4,321	114,277	114,632	3,966
Dross and skimmings	[r]2,580	131,131	128,507	5,204
Other[3]	[r]1,035	127,935	122,852	6,118
Total	[r]12,715	469,702	462,877	19,540
Old scrap:				
Castings, sheet, clippings	[r]13,358	516,789	515,192	14,955
Aluminum-copper radiators	[r]946	8,263	8,110	1,099
Aluminum cans[4]	[r]1,149	101,079	100,812	1,416
Other[5]	[r]453	46,039	46,238	254
Total	[r]15,906	672,170	670,352	17,724
Sweated pig	229	1,680	1,611	298
Total secondary smelters	[r]28,850	1,143,552	1,134,840	37,562
Integrated aluminum companies, foundries, independent mill fabricators, other consumers:				
New scrap:				
Solids	[r]11,182	669,430	667,650	12,962
Borings and turnings	385	32,960	33,054	291
Dross and skimmings	39	11,486	11,511	14
Other[3]	[r]7,094	232,592	228,402	11,284
Total	[r]18,700	946,468	940,617	24,551
Old scrap:				
Castings, sheet, clippings	[r]8,337	314,535	315,384	7,488
Aluminum-copper radiators	[r]358	2,089	2,284	163
Aluminum cans	[r]23,714	757,104	770,148	10,670
Other[5]	[r]226	12,372	11,860	738
Total	[r]32,635	1,086,100	1,099,676	19,059
Sweated pig	268	11,348	11,281	335
Total intergrated aluminum companies, etc.	[r]51,603	2,043,916	2,051,574	43,945
All scrap consumed:				
New scrap:				
Solids	[r]15,961	765,789	764,536	17,214
Borings and turnings	[r]4,706	147,237	147,686	4,257
Dross and skimmings	[r]2,619	142,617	140,018	5,218
Other[3]	[r]8,129	360,527	351,254	17,402
Total new scrap	[r]31,415	1,416,170	1,403,494	44,091
Old scrap:				
Castings, sheet, clippings	[r]21,695	831,324	830,576	22,443
Aluminum-copper radiators	[r]1,304	10,352	10,394	1,262
Aluminum cans	[r]24,863	858,183	870,960	12,086
Other[5]	[r]679	58,411	58,098	992
Total old scrap	[r]48,541	1,758,270	1,770,028	36,783
Sweated pig	497	13,028	12,892	633
Total of all scrap consumed	[r]80,453	3,187,468	3,186,414	81,507

[r] Revised.

[1] Includes imported scrap. According to reporting companies, 8.41% of total receipts of aluminum-base scrap, or 265,305 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 5

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1992		1993	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	41,921	[r]44,703	45,539	44,724
380 and variations	[r]465,503	[r]465,009	517,948	516,863
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	78,089	67,146	85,064	84,406
No. 12 and variations	W	W	W	W
No. 319 and variations	[r]52,852	[r]52,931	67,373	65,654
F-132 alloy and variations	52,652	51,483	24,025	25,844
Al-Mg alloys	645	644	639	641
Al-Zn alloys	3,086	2,881	3,218	3,468
Al-Si alloys (0.6% to 2.0% Cu)	10,680	10,705	10,840	11,018
Al-Cu alloys (1.5% Si, maximum)	1,664	1,588	1,738	1,726
Al-Si-Cu-Ni alloys	1,352	1,326	1,360	1,395
Other	[r]2,707	[r]2,771	3,792	3,812
Wrought alloys: Extrusion billets	[r]71,486	[r]65,861	80,914	84,880
Miscellaneous:				
Steel deoxidation	3,345	3,413	—	—
Pure (97.0% Al)	59	69	—	—
Aluminum-base hardeners	93	97	93	93
Other[2]	34,262	33,433	34,244	35,233
Total	[r]820,396	[r] [3]804,063	876,787	879,757
Less consumption of materials other than scrap:				
Primary aluminum	65,351	—	79,643	—
Primary silicon	35,573	—	39,192	—
Other	3,620	—	4,601	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[4]	[r]715,852	XX	753,351	XX

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

[4] No allowance made for melt-loss of primary aluminum and alloying ingredients.

TABLE 6
U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1989	1990	1991	1992	1993
Primary production	4,030	4,048	4,121	4,042	3,695
Change in stocks:[1]					
Aluminum industry	+61	+2	+45	-100	-171
LME stocks in U.S. warehouses	—	—	-168	-46	+46
National Defense Stockpile	—	—	—	-55	—
Imports	1,470	1,514	1,490	1,725	2,545
Secondary recovery:[2]					
New scrap	1,043	1,034	969	[r]1,144	1,312
Old scrap	1,011	1,359	1,317	1,612	1,632
Total supply	7,615	7,957	7,774	[r]8,322	9,059
Less total exports	1,615	1,659	1,762	1,453	1,207
Apparent aluminum supply available for domestic manufacturing	6,000	6,298	6,012	[r]6,869	7,852
Apparent consumption[3]	4,957	5,264	5,043	5,725	6,540

[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).

TABLE 7
DISTRIBUTION OF END-USE SHIPMENTS OF ALUMINUM PRODUCTS IN THE UNITED STATES, BY INDUSTRY

Industry	1991		1992		1993	
	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	2,210	[r]28.5	2,259	[r]28.1	2,181	26.2
Building and construction	1,052	13.6	1,144	[r]14.2	1,237	14.9
Transportation	[r]1,414	[r]18.2	[r]1,591	[r]19.8	1,904	22.9
Electrical	579	7.5	587	7.3	609	7.3
Consumer durables	472	6.1	523	6.5	563	6.8
Machinery and equipment	426	5.5	448	5.6	477	5.7
Other markets	241	3.1	256	3.2	259	3.1
Total to domestic users[1]	[r]6,395	[r]82.5	[r]6,809	84.6	7,231	86.9
Exports	1,357	[r]17.5	[r]1,236	15.4	1,092	13.1
Grand total[1]	[r]7,752	100.0	[r]8,045	100.0	8,324	100.0

[r] Revised.

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

Source: The Aluminum Association Inc.

TABLE 8
U.S. NET SHIPMENTS[1] OF ALUMINUM WROUGHT AND CAST PRODUCTS, BY PRODUCERS

(Metric tons)

	1992	1993[p]
Wrought products:		
Sheet, plate, foil	4,097,009	4,030,039
Rod, bar, pipe, tube, and shapes	1,185,893	1,293,910
Rod, wire, cable	303,475	296,935
Forgings (including impacts)	61,705	126,865
Powder, flake, paste	43,035	58,796
Total	5,691,117	5,806,545
Castings:		
Sand	98,761	NA
Permanent and semipermanent mold	197,848	NA
Die	594,531	NA
Other	26,703	NA
Total	917,843	NA
Grand total	6,608,960	NA

[p] Preliminary. NA Not available.

[1] Net shipments derived by subtracting the sum of producers' domestic receipts of each mill shape from the domestic industry's gross shipments of that shape.

Source: U.S. Department of Commerce.

TABLE 9
U.S. EXPORTS OF ALUMINUM, BY CLASS

Class	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	603,818	$843,261	400,435	$540,502
Scrap	295,239	299,598	211,609	211,390
Plates, sheets, bars, strip, etc.	533,905	1,416,160	570,859	1,345,845
Castings and forgings	5,348	54,904	6,064	55,778
Semifabricated forms, n.e.c.	14,383	66,279	17,573	75,229
Total[1]	1,452,695	2,680,202	1,206,539	2,228,744
Manufactures:				
Foil and leaf	41,751	128,389	53,244	153,165
Powders and flakes	4,246	16,406	5,082	18,379
Wire and cable	28,758	86,395	40,184	98,655
Total[1]	74,755	231,190	98,510	270,200
Grand total	1,527,450	2,911,392	1,305,049	2,498,944

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

Source: Bureau of the Census.

TABLE 10

U.S. EXPORTS OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc.[1]		Scrap		Total[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Brazil	96	$230	5,293	$17,203	966	$1,243	6,355	$18,676
Canada	78,651	120,799	288,983	671,018	45,615	50,867	413,249	842,684
France	5,396	7,885	3,359	19,312	1,975	2,111	10,730	29,308
Germany	316	1,264	10,511	32,028	411	657	11,238	33,950
Hong Kong	7,685	10,248	4,906	17,505	8,845	6,471	21,436	34,224
Italy	60	337	2,481	19,624	533	533	3,073	20,495
Japan	416,122	547,661	24,673	86,404	139,835	144,919	580,630	778,984
Korea, Republic of	18,828	25,877	16,332	47,509	17,138	18,714	52,298	92,100
Mexico	30,112	60,338	73,552	232,295	26,010	28,409	129,675	321,041
Netherlands	1,249	2,199	2,493	15,236	524	598	4,266	18,033
Philippines	3,034	4,129	187	941	126	144	3,348	5,215
Saudi Arabia	163	413	20,557	48,114	125	179	20,846	48,706
Singapore	167	384	3,016	8,534	386	262	3,569	9,180
Taiwan	21,289	29,865	12,545	40,341	30,855	23,663	64,689	93,869
Thailand	10,965	14,407	4,360	9,045	1,992	1,590	17,317	25,042
U.S.S.R.[3]	409	242	85	489	—	—	495	730
United Kingdom	3,866	6,151	10,946	50,812	2,035	2,185	16,847	59,148
Venezuela	16	63	23,629	61,429	557	547	24,203	62,039
Other	5,393	10,770	45,727	159,505	17,312	16,505	68,431	186,779
Total[2]	603,818	843,261	553,637	1,537,343	295,239	299,598	1,452,695	2,680,202
1993:								
Belarus	—	—	18	9	—	—	18	9
Brazil	61	158	8,405	24,477	707	779	9,172	25,414
Canada	80,705	114,139	320,466	690,407	46,496	47,292	447,667	851,838
France	922	1,572	5,354	12,147	582	785	6,858	14,504
Germany	209	485	10,844	20,690	85	217	11,138	21,391
Hong Kong	5,093	6,299	3,490	13,040	7,965	5,615	16,547	24,954
Italy	75	281	1,941	6,928	55	56	2,071	7,265
Japan	220,174	280,359	15,868	71,721	92,280	94,831	328,322	446,911
Korea, Republic of	20,738	26,747	11,175	34,597	8,162	9,809	40,075	71,153
Mexico	33,847	56,492	66,950	201,887	18,306	19,982	119,103	278,361
Netherlands	203	445	3,586	8,847	272	305	4,062	9,597
Philippines	3,045	3,935	186	795	135	129	3,365	4,859
Russia	—	—	184	1,755	—	—	184	1,755
Saudi Arabia	19	40	20,121	43,935	—	—	20,139	43,975
Singapore	69	244	3,842	12,233	718	900	4,629	13,378
Taiwan	22,901	26,730	15,836	40,252	16,298	11,628	55,035	78,610
Thailand	7,028	8,824	5,297	11,374	1,028	1,125	13,354	21,323
United Kingdom	512	2,313	17,581	47,002	229	424	18,322	49,739
Venezuela	85	349	16,360	38,672	8	55	16,453	39,076
Other	4,747	11,089	66,996	196,084	18,282	17,457	90,026	224,630
Total[2]	400,435	540,502	594,495	1,476,853	211,609	211,390	1,206,539	2,228,744

[1] Includes castings, forgings, and unclassified semifabricated forms.

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

[3] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY CLASS

Class	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Crude and semicrude:				
Metals and alloys, crude	1,155,515	$1,500,777	1,836,406	$2,146,848
Plates, sheets, strip, etc., n.e.c.[1]	283,960	622,865	343,770	712,358
Pipes, tubes, etc.	4,538	30,683	5,336	28,962
Rods and bars	15,305	40,375	50,900	96,274
Scrap	265,306	267,372	308,542	276,082
Total[2]	1,724,624	2,462,070	2,544,954	3,260,523
Manufactures:				
Foil and leaf[3]	28,136	111,349	35,852	128,020
Flakes and powders	1,885	3,985	1,657	4,308
Wire	17,183	32,232	18,468	30,631
Total	47,204	147,566	55,977	162,959
Grand total[2]	1,771,827	2,609,636	2,600,931	3,423,483

[1] Includes plates, sheets, circles, and disks.
[2] Data may not add to totals shown because of independent rounding.
[3] Excludes etched capacitor foil.

Source: Bureau of the Census.

TABLE 12
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM, BY COUNTRY

Country	Metals and alloys, crude		Plates, sheets, bars, etc.[1]		Scrap		Total[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Argentina	5,301	$6,832	216	$573	—	—	5,517	$7,405
Australia	487	660	1,322	2,454	19	$12	1,829	3,126
Bahrain	—	—	5,925	11,618	—	—	5,925	11,618
Belgium	63	76	6,705	15,420	678	606	7,445	16,101
Brazil	10,369	13,474	2,631	5,313	330	368	13,330	19,155
Canada	1,056,011	1,372,463	168,939	312,046	168,792	183,677	1,393,742	1,868,186
France	222	1,691	9,835	34,498	3,252	2,386	13,310	38,575
Germany	640	3,644	17,213	69,694	4,816	5,554	22,669	78,892
Italy	22	1,326	2,100	5,600	—	—	2,122	6,926
Japan	61	122	17,273	68,061	85	372	17,419	68,554
Korea, Republic of	50	189	119	862	(3)	8	169	1,059
Mexico	160	399	3,864	10,653	43,632	37,997	47,656	49,049
Netherlands	—	—	4,728	14,456	2,243	2,821	6,970	17,277
Norway	126	904	891	1,719	69	87	1,086	2,710
South Africa, Republic of	199	672	6,216	11,226	20	7	6,435	11,905
Spain	—	—	6,873	12,441	63	174	6,936	12,615
U.S.S.R.[4]	16,384	16,684	391	518	5,919	4,808	22,694	22,010
United Arab Emirates	2,110	2,870	—	—	—	—	2,110	2,870
United Kingdom	7,081	10,429	8,674	30,479	1,639	1,737	17,395	42,645
Venezuela	55,554	67,663	15,223	23,537	20,721	16,464	91,499	107,664
Yugoslavia[5]	80	120	7,676	14,382	10	10	7,767	14,512
Other	595	558	16,987	48,373	13,017	10,284	30,600	59,215
Total[2]	1,155,515	1,500,777	303,802	693,922	265,306	267,372	1,724,624	2,462,070

See footnotes at end of table.

TABLE 12—Continued

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

Country	Metals and alloys, crude		Plates, sheets, bars, etc.[1]		Scrap		Total[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1993:								
Argentina	—	—	45	$106	—	—	45	$106
Australia	1	$2	1,153	2,068	300	$196	1,454	2,266
Bahrain	—	—	7,892	14,693	—	—	7,892	14,693
Belgium	275	399	7,170	15,497	372	515	7,817	16,410
Brazil	52,315	65,573	4,371	8,978	4	14	56,690	74,565
Canada	1,222,898	1,487,929	244,125	452,110	178,710	165,967	1,645,732	2,106,006
Croatia	—	—	2,179	4,354	—	—	2,179	4,354
France	2,433	4,914	10,499	31,566	2,006	1,468	14,938	37,948
Germany	2,368	5,997	18,613	68,921	9,185	9,772	30,166	84,690
Italy	29	1,710	2,174	4,644	—	—	2,203	6,354
Japan	542	954	15,405	53,667	250	499	16,197	55,120
Korea, Republic of	64	231	94	607	10	8	167	846
Macedonia	—	—	284	449	—	—	284	449
Mexico	63	134	2,630	7,435	46,547	38,009	49,240	45,577
Netherlands	4,230	4,298	4,307	12,722	4,928	6,116	13,465	23,135
Norway	184	1,342	1,902	2,946	—	—	2,086	4,289
Russia	421,270	446,061	9,620	13,619	18,629	18,180	449,520	477,859
Slovenia	—	—	5,180	11,543	—	—	5,180	11,543
South Africa, Republic of	247	667	3,351	6,057	21	4	3,618	6,727
Spain	3,115	2,991	18,048	28,108	390	408	21,553	31,507
Tajikistan	18,091	17,436	—	—	—	—	18,091	17,436
Ukraine	—	—	—	—	110	698	110	698
United Arab Emirates	2,989	3,961	—	—	—	—	2,989	3,961
United Kingdom	4,415	6,116	6,463	23,152	4,725	4,615	15,604	33,883
Venezuela	63,693	70,195	15,679	25,101	25,739	16,899	105,111	112,195
Other	37,186	25,940	18,823	49,251	16,617	12,715	72,626	87,905
Total[2]	1,836,406	2,146,848	400,006	837,593	308,542	276,082	2,544,954	3,260,523

[1] Includes circles, disks, rods, pipes, tubes, etc.

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

[3] Less than 1/2 unit.

[4] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[5] Dissolved in Apr. 1992; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 13
ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Argentina[e]	162	[2]166	165	165	165
Australia	1,244	1,234	[r]1,228	[r]1,236	[2]1,345
Austria	93	89	80	[r]33	—
Azerbaijan	—	—	—	[e]25	20
Bahrain	187	213	227	[r]292	450
Bosnia and Herzegovina[3]	—	—	—	[r][e]30	15
Brazil	890	931	1,140	[e]1,200	1,200
Cameroon	92	93	83	[e]82	82
Canada	1,555	1,567	1,822	[r]1,972	[2]2,308
China[e]	[r]750	850	[r]963	[r]1,100	1,220
Croatia[3]	—	—	—	[r][e]20	20
Czechoslovakia[e] [4] [5] [6]	69	70	68	68	—
Egypt	180	179	178	[r]178	177
France	335	326	286	[r]418	458
Germany:					
Eastern states	54	20	—	—	—
Western states	[r]742	[r]720	—	—	—
Total	[r]796	[r]740	690	[r]603	[2]552
Ghana	169	174	175	[r]180	[2]175
Greece	145	150	152	153	145
Hungary	75	75	63	[r]27	28
Iceland[7]	88	87	89	89	91
India[6]	423	433	[e]504	[r][e]490	435
Indonesia[6]	197	186	187	[r]173	180
Iran[e]	54	60	80	[r]92	100
Italy	219	232	206	[r]161	170
Japan[8]	35	34	32	[r]19	[2]18
Korea, North[e]	10	—	—	—	—
Korea, Republic of[5]	18	2	[r]—	[r]—	—
Mexico[6]	72	68	51	[r]25	[2]26
Netherlands	274	270	264	235	229
New Zealand	[r]257	260	[r]258	[r]243	[2]268
Norway	863	845	833	813	[2]814
Poland[9]	48	46	46	[r]44	[2]47
Romania[10]	269	168	[r]113	[r]112	112
Russia	—	—	—	2,700	2,900
Serbia and Montenegro[3]	—	—	—	[r]76	70
Slovakia[5] [6] [11]	—	—	—	—	60
Slovenia[3]	—	—	—	[r]85	80
South Africa, Republic of	166	159	[r]169	[r]173	175
Spain	352	[r]353	355	[r]359	355
Suriname	28	32	29	[r]32	30
Sweden	97	96	97	[r]77	77
Switzerland	71	72	66	[r]52	45
Tajikistan	—	—	—	[r][e]400	300
Turkey	62	61	56	59	59
U.S.S.R.[12]	[e]3,300	3,523	3,251	—	—
Ukraine	—	—	—	[e]90	90

See footnotes at end of table.

TABLE 13—Continued

ALUMINUM, PRIMARY: WORLD PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
United Arab Emirates: Dubai	168	174	239	[e]240	225
United Kingdom	297	[r]294	294	[r]244	235
United States	4,030	4,048	4,121	4,042	[2]3,695
Venezuela	540	590	601	[r]561	570
Yugoslavia[6] [13]	331	349	315	—	—
Total[14]	[r]19,010	[r]19,299	[r]19,575	[r]19,467	19,816

[e]Estimated. [r]Revised.

[1] The U.S. Bureau of Mines defines primary aluminum as "The weight of liquid aluminum as tapped from pots, excluding the weight of any alloying materials as well as that of any metal produced from either returned scrap or remelted materials." International reporting practices vary from country to country, some nations conforming to the foregoing definition and others using different definitions. For those countries for which a different definition is given specifically in the source publication, that definition is provided in this table by footnote. Table includes data available through June 16, 1994.

[2] Reported figure.

[3] Primary ingot plus secondary ingot.

[4] Dissolved Dec. 31, 1992.

[5] All production in Czechoslovakia from 1989-92 came from Slovakia.

[6] Primary ingot.

[7] Ingot and rolling billet production.

[8] Excludes high-purity aluminum containing 99.995% or more as follows, in metric tons: 1989—15,696; 1990—16,292; 1991—19,652; 1992—19,605 (revised); and 1993—20,258.

[9] Primary unalloyed ingot plus secondary unalloyed ingot.

[10] Primary unalloyed metal plus primary alloyed metal, thus including weight of alloying material.

[11] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[12] Dissolved in Dec. 1991.

[13] Dissolved in Apr. 1992.

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

TABLE 14

SALIENT BAUXITE STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Production: Crude ore (dry equivalent)	W	W	W	W	W
Value	W	W	W	W	W
Exports (as shipped)	44	[r]74	51	[r]63	90
Imports for consumption[1]	10,893	12,144	11,871	10,939	11,621
Consumption (dry equivalent)	11,810	12,042	12,204	[r]11,873	11,917
World: Production	[r]103,722	[r]109,042	[r]107,916	[r]101,145	[e]105,550

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

[1] Excludes calcined bauxite. Includes bauxite imported to the U.S. Virgin Islands.

TABLE 15
PRODUCTION AND SHIPMENTS OF ALUMINA IN THE UNITED STATES

(Thousand metric tons)

Year	Calcined alumina	Other alumina[2]	Total[1]	
			As produced or shipped[3]	Calcined equivalent
Production:[e]				
1989	4,580	605	5,180	5,000
1990	4,775	655	5,430	5,230
1991	4,805	610	5,415	5,230
1992	4,740	640	5,380	5,185
1993	4,835	655	5,490	5,290
Shipments:[e]				
1989	4,665	605	5,270	5,090
1990	4,750	575	5,325	5,150
1991	4,865	630	5,500	5,305
1992	4,805	650	5,455	5,260
1993	4,775	660	5,435	5,230

[e] Estimated.

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

[2] Trihydrate, activated, tabular, and other aluminas. Excludes calcium and sodium aluminates.

[3] Includes only the end product if one type of alumina was produced and used to make another type of alumina.

TABLE 16
CAPACITIES OF DOMESTIC ALUMINA PLANTS,[1] DECEMBER 31

(Thousand metric tons per year)

Company and plant	1991	1992	1993
Aluminum Co. of America: Point Comfort, TX	1,735	1,735	1,735
Kaiser Aluminum & Chemical Corp.: Gramercy, LA	1,000	1,000	1,000
Ormet Corp.: Burnside, LA	545	600	600
Reynolds Metals Co.: Corpus Christi, TX	1,700	1,700	1,700
Virgin Islands Alumina: St. Croix, VI	635	635	635
Total	5,615	5,670	5,670

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

TABLE 17
U.S. CONSUMPTION OF BAUXITE, BY INDUSTRY

(Thousand metric tons, dry equivalent)

Industry	1991	1992	1993
Alumina	11,383	11,066	11,002
Abrasive[1]	204	223	203
Chemical	218	190	225
Refractory	328	[r]334	429
Other	71	60	58
Total	12,204	[r]11,873	11,917

[r] Revised.

[1] Includes consumption by Canadian abrasive industry.

TABLE 18
PRODUCTION AND SHIPMENTS OF SELECTED ALUMINUM SALTS IN THE UNITED STATES IN 1992

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)	73	950	921	$108,739
Iron-free (17% Al_2O_3)	21	194	194	20,161
Aluminum chloride:				
Liquid and crystal	6	21	W	W
Anhydrous (100% $AlCl_3$)	4	18	18	15,292
Aluminum fluoride, technical	4	W	W	W
Aluminum hydroxide, trihydrate [100% $Al(OH)_3$]	10	768	770	174,512
Aluminates	18	114	108	32,353
Other aluminum compounds[1]	XX	XX	XX	163,617

W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[1] Includes light aluminum hydroxide, cryolite, etc.

Source: Data are based on Bureau of the Census 1992 Current Industrial Reports, Series MA-28A, "Inorganic Chemicals."

TABLE 19
STOCKS OF BAUXITE IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, dry equivalent)

Sector	1992	1993
Producers, processors, and consumers	2,319	1,045
Government	17,805	16,938
Total	20,124	17,983

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

TABLE 20
STOCKS OF ALUMINA IN THE UNITED STATES,[1] DECEMBER 31

(Thousand metric tons, calcined equivalent)

Sector	1992	1993
Producers	492	529
Primary aluminum plants	[r]1,224	1,211
Total	[r]1,716	1,740

[r] Revised.

[1] Excludes consumers' stocks other than those at primary aluminum plants.

TABLE 21
AVERAGE VALUE OF U.S. IMPORTS OF CRUDE AND DRIED BAUXITE[1]

(Per metric ton)

Country	1992		1993	
	Port of shipment (f.a.s.)	Delivered to U.S. ports (c.i.f.)	Port of shipment (f.a.s.)	Delivered to U.S. ports (c.i.f.)
Australia	$17.55	$30.55	$12.41	$20.81
Brazil	29.40	40.51	28.67	36.18
Guinea	28.65	35.88	25.43	32.68
Guyana	30.13	40.38	32.06	42.00
Jamaica	28.13	33.63	28.95	34.46
Weighted average	28.58	36.25	27.84	34.84

[1] Computed from quantity and value data reported to U.S. Customs Service and compiled by the Bureau of the Census, U.S. Department of Commerce. Not adjusted for moisture content of bauxite or differences in methods used by importers to determine value of individual shipments.

TABLE 22
U.S. EXPORTS OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	1	837	1	726	(2)	914
Belgium	2	3,562	6	8,079	4	4,891
Brazil	[r]170	[r]34,593	215	36,794	247	39,203
Canada	753	[r]205,811	729	155,863	814	169,761
Finland	77	17,615	43	8,314	25	4,050
France	1	2,526	1	6,595	1	5,307
Germany	1	[r]8,461	3	5,592	1	5,652
Ghana	98	22,298	41	7,820	7	1,403
Japan	22	[r]13,301	18	11,429	3	7,638
Mexico	125	47,388	37	22,503	38	21,266
Netherlands	13	[r]7,818	20	7,717	20	5,500
Norway	—	—	—	—	20	3,367
Sweden	12	[r]2,934	(2)	241	14	2,347
U.S.S.R.[3]	35	10,181	(2)	776	—	—
United Kingdom	2	4,723	5	8,613	5	7,722
Venezuela	4	3,865	2	2,066	2	2,101
Other	19	22,460	22	23,385	36	24,707
Total	[r]1,335	[r] [4]408,375	1,143	306,513	1,237	305,829

[r] Revised.

[1] Includes exports of aluminum hydroxide (calcined equivalent) as follows: 1991—35,105 tons; 1992—31,287 tons; and 1993—34,431 tons.

[2] Less than 1/2 unit.

[3] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

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

Source: Bureau of the Census.

TABLE 23
U.S. IMPORTS FOR CONSUMPTION OF BAUXITE, CRUDE AND DRIED,[1] BY COUNTRY

(Thousand metric tons)

Country	1991	1992	1993
Australia	408	179	148
Brazil	1,905	1,617	1,864
China	93	75	120
Guinea	3,609	3,223	3,777
Guyana	1,184	1,500	1,293
India	105	—	—
Indonesia	135	88	387
Jamaica[2]	4,261	4,128	3,917
Malaysia	94	91	11
Other	75	37	104
Total[3]	11,871	10,939	11,621

[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: 1991—11,174,990 tons; 1992—11,111,732 tons; and 1993—11,638,115 tons.

Sources: Bureau of the Census and the Jamaica Bauxite Institute.

TABLE 24
U.S. IMPORTS FOR CONSUMPTION OF CALCINED BAUXITE, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992				1993			
	Refractory grade		Other grade		Refractory grade		Other grade	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Australia	—	—	8	607	—	—	12	985
Brazil	—	—	—	—	16	1,120	—	—
China	174	9,903	88	4,616	66	3,599	86	4,283
Guyana	54	6,485	—	—	53	6,747	—	—
Malaysia	—	—	—	—	—	—	—	—
Other	9	997	13	681	—	—	4	264
Total[2]	238	17,385	108	5,904	135	11,466	102	5,532

[1] Value at foreign port of shipment as reported to U.S. Customs Service.
[2] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census; data adjusted by the U.S. Bureau of Mines.

TABLE 25
U.S. IMPORTS FOR CONSUMPTION OF ALUMINA,[1] BY COUNTRY

(Thousand metric tons, calcined equivalent, and thousand dollars)

Country	1991		1992		1993	
	Quantity	Value[2]	Quantity	Value[2]	Quantity	Value[2]
Australia	3,639	792,056	3,500	585,791	2,716	443,263
Brazil	92	20,520	51	12,394	33	9,740
Canada	74	39,790	82	43,660	84	46,428
France	7	15,537	6	18,031	10	17,522
Germany	20	36,752	20	34,025	22	37,811
Guinea	—	—	—	—	28	4,754
India	72	19,376	109	16,207	116	18,924
Israel	—	—	—	—	(3)	6
Italy	(3)	489	(3)	646	(3)	596
Jamaica	394	102,126	507	85,383	379	62,824
Japan	8	13,557	9	17,742	8	16,092
Suriname	242	47,784	242	38,626	313	48,992
Venezuela	(3)	41	150	24,273	85	17,155
Other	44	13,979	26	10,835	141	30,345
Total[4]	4,592	1,102,008	4,701	887,613	3,936	754,452

[1] Includes imports of aluminum hydroxide.
[2] Value at foreign port of shipment as reported to U.S. Customs Service.
[3] Less than 1/2 unit.
[4] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 26
BAUXITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Albania[e]	[r]25	26	[r]20	4	2
Australia	[r]38,584	41,391	40,503	[r]39,746	[2]41,900
Bosnia and Herzegovina	—	—	—	[r]200	100
Brazil	8,665	[r]9,678	10,414	[r] [e]9,366	9,357
China[e]	2,388	2,400	2,600	[r]2,700	2,900
Croatia	—	—	—	[r]—	—
Dominican Republic[3]	151	85	7	—	—
France	[r]550	490	9	—	—
Ghana	347	381	[r] [e]353	[r]338	[2]424
Greece	[r]2,550	[r]2,496	2,133	[r]2,042	1,700
Guinea[3]	[r]15,792	[r]15,772	[r]15,466	[e]13,773	14,100
Guyana[3]	1,321	1,424	2,204	[r]2,376	2,126
Hungary	2,644	2,559	2,037	[e]1,721	1,600
India	[r]4,471	4,852	[r]4,735	[r]4,898	[2]5,223
Indonesia	862	1,206	1,406	[e]804	1,320
Italy	12	(4)	[e]9	[r]98	97
Jamaica[3] [5]	9,601	10,921	11,552	[e]11,302	11,307
Kazakhstan	—	—	—	[e]500	500
Malaysia	355	398	376	[e]331	[2]69
Mozambique	6	7	8	[r]8	6
Pakistan	2	3	4	[r]3	5
Romania	313	[r]243	[e]200	[r] [e]175	185
Russia	—	—	—	[e]4,000	4,000
Serbia and Montenegro	—	—	—	[r]792	700
Sierra Leone	1,562	1,430	1,288	[e]1,246	[2]1,165
Spain	[r]1	[r]1	[r] [e]1	[r]—	—
Suriname	3,530	3,283	3,198	[e]3,250	3,400
Turkey[6]	[r]534	[r]773	489	[r]420	450
U.S.S.R.[e] [7]	5,500	5,500	5,000	—	—
United States	W	W	W	W	W
Venezuela	702	771	1,992	[e]1,052	2,914
Yugoslavia[8]	[r]3,253	2,952	[r]1,912	—	—
Total[9]	[r]103,722	[r]109,042	[r]107,916	[r]101,145	105,550

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

[1] Table includes data available through July 20, 1994.

[2] Reported figure.

[3] Dry bauxite equivalent of crude ore.

[4] Less than 1/2 unit.

[5] Bauxite processed for conversion to alumina in Jamaica plus kiln-dried ore prepared for export.

[6] Public-sector production only.

[7] Dissolved in Dec. 1991. In addition to the bauxite reported in the body of the table, Russia produces nepheline syenite concentrates and Azerbaijan produces alunite ore as sources of aluminum. Nepheline syenite concentrate, produced in Russia was as follows, in thousand metric tons: 1989—1,697; 1990—1,650 (estimated); 1991—1,500 (estimated); 1992—1,000 (estimated); 1993—800 (estimated). Estimated alunite ore produced in Azerbaijan was as follows, in thousand metric tons: 1989—600; 1990—550; 1991—500; 1992—300; and 1993—200. 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.

[8] Dissolved in Apr. 1992.

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

TABLE 27

ALUMINA: WORLD PRODUCTION,[1] BY COUNTRY[2]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Australia	[r]10,823	[r]11,197	[r]11,703	[r]11,803	12,600
Azerbaijan	—	—	—	300	200
Bosnia and Herzegovina	—	—	—	[r] [e]100	50
Brazil	1,632	1,655	[r]1,743	[r]1,833	1,833
Canada	1,048	1,087	1,131	1,104	1,100
China[e]	1,350	1,460	[r]1,520	[r]1,583	1,900
Czechoslovakia[e] [3] [4]	[5]205	175	150	150	—
France	[r]624	[r]606	538	508	500
Germany:					
Eastern states	69	27	—	—	—
Western states	964	922	—	—	—
Total	1,033	949	863	[r]857	800
Greece	521	587	625	[r]612	510
Guinea	619	631	[r]610	561	600
Hungary	882	826	[r]635	548	450
India	1,947	1,601	[e]1,700	[e]1,700	1,800
Ireland	[r]841	[e]885	981	1,007	950
Italy[6]	722	752	805	762	760
Jamaica	2,221	2,869	3,015	2,917	[5]2,989
Japan[7]	466	481	438	[r]316	[5]327
Kazakhstan	—	—	—	[r] [e]1,100	1,000
Romania	611	440	[r]413	[r]280	293
Russia	—	—	—	[r] [e]3,100	3,500
Serbia and Montenegro	—	—	—	[r]197	190
Slovakia[4] [8]	—	—	—	—	140
Slovenia	—	—	—	[r] [e]45	40
Spain[6]	949	1,002	[r] [e]1,003	[r]959	960
Suriname	1,567	1,532	1,510	1,576	1,500
Turkey	201	177	159	[r]156	[5]169
Ukraine	—	—	—	[r] [e]900	900
U.S.S.R.[e] [9]	5,700	5,900	[5]5,277	—	—
United Kingdom[e]	[5]116	[r]115	110	[r]100	100
United States[e]	5,000	5,230	5,230	5,185	5,290
Venezuela	1,212	1,293	1,295	1,308	1,500
Yugoslavia[10]	1,170	1,086	[e]900	—	—
Total[11]	[r]41,461	[r]42,535	[r]42,354	[r]41,567	42,951

[e] Estimated. [r] Revised.

[1] Figures represent calcined alumina or the total of calcined alumina plus the calcined equivalent of hydrate when available; exceptions, if known, are noted.

[2] Table includes data available through July 20, 1994.

[3] Dissolved Dec. 31, 1992.

[4] All production in Czechoslovakia from 1989-92 came from Slovakia.

[5] Reported figure.

[6] Hydrate.

[7] Data presented are for alumina used principally for specialty applications. Gross weight of aluminum hydrate for all uses was as follows, in thousand metric tons: 1989—863; 1990—890; 1991—864; 1992—714 (revised); and 1993—704.

[8] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[9] Dissolved in Dec. 1991.

[10] Dissolved in Apr. 1992.

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

ANTIMONY

By James F. Carlin, Jr.

Mr. Carlin, a physical scientist with more than 30 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for antimony since 1993. Domestic survey data were prepared by Joi Brown, statistical assistant; and international data were prepared by Ted Spittal, international data specialist.

Domestic consumption of primary antimony products increased substantially in 1993, as did production of primary antimony. Imports of antimony products declined slightly while exports declined substantially.

Primary antimony metal and oxide were produced by six companies operating six plants using both foreign and domestic feed material. Two plants were in Texas, and there was one each in Idaho, Montana, Nebraska, and New Jersey. A very small amount of antimony was recovered as a byproduct from the smelting of lead and silver-copper ores. Virtually all antimony metal (unalloyed) and oxides produced domestically originated from imports. The estimated value of primary antimony metal and oxides produced in 1993 was $62 million. The estimated distribution of primary antimony uses was as follows: flame retardants, 57%; transportation, including batteries, 22%; chemicals, 8%; ceramics and glass, 7%; and other, 6%.

Antimony produced from domestic source materials was derived mainly from recycled lead-acid batteries. Recycling plus U.S. mine output supplied less than one-half of the estimated domestic demand.

Antimony was mined as a principal product and produced as a byproduct of the smelting of base metal ores in 19 countries. China, the world's leading producer, accounted for 68% of the total world estimated mine production during 1993. China, together with the other three major producing countries, Bolivia, Russia, and the Republic of South Africa, accounted for about 87% of the total world estimated mine antimony production. *(See table 10.)*

Identified world antimony reserves at yearend 1993 were estimated to be 4.2 million metric tons.

DOMESTIC DATA COVERAGE

Domestic primary production data for antimony are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the six operations to which a survey request was sent, all responded, representing 100% of the primary smelter production shown in table 1. *(See table 1).*

ANNUAL REVIEW

Strategic Considerations

Public Laws 99-661 and 102-484 provided authorization for additional antimony monthly sales through 1994 or until the 3,507 short tons authorized for fiscal year 1993 is disposed. Sales of antimony from the National Defense Stockpile took place for the first time since 1988. Sales were conducted on a sealed bid basis, commencing on June 27 and were held the third Thursday of each month. Each month a maximum of 500 short tons of antimony, either Grade A or Grade B, was offered, usually in the form of ingots or cakes. In 1993, a total of 2,656 short tons was sold.

Antimony is stockpiled in Government warehouses in 13 locations, with the Somerville, NJ, depot holding the largest amount.

Domestic Production

Mine Production.—In the Coeur d' Alene district of Idaho, Sunshine Mining Co. produced antimony as a byproduct of the treatment of tetrahedrite, a complex silver-copper-antimony sulfide ore.

Smelter Production.—**Primary.**—The producers of primary antimony metal and oxide products were ASARCO Incorporated, Omaha, NE; Amspec Chemical Corp., Gloucester City, NJ; Anzon Inc., Laredo, TX; Laurel Industries Inc., La Porte, TX; Sunshine Mining Co., Kellogg, ID; and U.S. Antimony Corp., Thompson Falls, MT.

Secondary.—Old scrap, predominantly lead battery plates, was the source of essentially all of the secondary antimony output. New scrap, mostly in the form of drosses and residues from various sources, supplied the remainder. The antimony content of scrap was usually recovered and consumed as antimonial lead. *(See table 2.)*

Consumption and Uses

Domestic consumption of primary antimony increased substantially in 1993. The most significant increases occurred in the categories of antimonial lead, ceramics and glass, and plastics (especially as flame retardants). Lead-antimony alloys were used in starting-lighting-ignition batteries, ammunition, corrosion-resistant pumps and pipes, tank linings, roofing sheets, solder, cable sheaths, and antifriction bearings.

Antimony compounds were used in plastics as stabilizers and as flame retardants. Antimony trioxide in an organic solvent was used to make textiles, plastics, and other combustibles flame resistant. Antimony was used as a decolorizing and refining agent in some forms of glass, such as optical glass. The estimated distribution of antimony uses was flame retardants, 74%; transportation, including batteries, 11%; chemicals, 9%; ceramics and glass, 2%; and other, 4%. *(See tables 3, 4, and 5.)*

Markets and Prices

The New York dealer antimony metal price, published by Metals Week, averaged $0.77 per pound for the year, continuing the generally downward trend of recent years. The price range for high-tint antimony trioxide was $1.10 to $1.20 per pound at the beginning of the year and declined to a range of $1.00 to $1.10 per pound by the fourth quarter.

Foreign Trade

Total imports of antimony materials were about the same as those in 1992. China supplied about 60% of the total imported materials. Exports of antimony oxide were about 19% lower than those of the previous year. *(See tables 6, 7, 8, and 9.)*

OUTLOOK

Antimony demand rose to a new plateau in 1993, but it is not clear whether it can maintain that level or continue increasing. Some of that increased demand was probably due to continued lower antimony prices during the year. Most of the increased demand was registered in the category of flame retardants, and it is anticipated that field should grow, although tin and other metals are gaining as acceptable substitutes with commendable qualities of their own.

It is anticipated that China's dominance as a supplier of antimony will continue for the foreseeable future.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Antimony. Ch. in Mineral Commodity Summaries, annual.
Antimony. Ch. in Mineral Facts & Problems, 1985 ed.

Other Sources

Chemical Abstracts.
Engineering and Mining Journal.
Metal Bulletin (London).

TABLE 1

SALIENT ANTIMONY STATISTICS

(Metric tons of antimony content unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Production:					
Primary:					
Mine (recoverable antimony)	W	W	W	W	W
Smelter	[r]18,720	[r]19,438	16,032	[r]17,854	21,723
Secondary	19,501	20,351	19,294	[r]19,925	17,245
Exports of metal, alloys, waste and scrap	293	588	694	947	315
Exports of antimony oxide	1,850	7,142	3,752	[e]4,817	[e]3,896
Imports for consumption	25,165	29,403	28,833	31,204	30,944
Reported industrial consumption, primary antimony	13,424	12,766	11,864	[r]12,225	17,047
Stocks: Primary antimony, all classes, Dec. 31	6,270	8,175	10,170	[r]8,741	9,452
Price: Average, cents per pound[1]	94.3	81.8	82.0	79.0	76.9
World: Mine production	[r]105,239	[r]94,407	[r]92,448	[r]75,011	[e]73,288

[e]Estimated. [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

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

(Metric tons of antimony content unless otherwise specified)

	1992	1993
KIND OF SCRAP		
New scrap: Lead- and tin-base	[r]1,260	1,213
Old scrap: Lead- and tin-base	[r]18,665	16,032
Total	[r]19,925	17,245
FORM OF RECOVERY		
In antimonial lead	19,477	16,977
In other lead- and tin-base alloys	448	268
Total	19,925	17,245
Value millions	$41	NA

[r]Revised. NA Not available.

TABLE 3

REPORTED INDUSTRIAL CONSUMPTION OF PRIMARY ANTIMONY IN THE UNITED STATES

(Metric tons of antimony content)

Year	Class of material consumed				Total
	Metal	Oxide	Sulfide	Residues	
1989	2,523	10,640	27	234	12,067
1990	2,148	9,961	25	632	13,424
1991	2,542	9,296	26	W	11,864
1992	2,451	[r]9,745	29	W	[r]12,225
1993	2,474	13,475	(1)	(1)	17,047

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

TABLE 4

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

(Metric tons of antimony content)

Product	1989	1990	1991	1992	1993
Metal products:					
Ammunition	521	602	W	W	W
Antimonial lead	1,901	1,985	1,698	1,642	2,659
Bearing metal and bearings	129	90	77	36	45
Cable covering	W	W	W	W	W
Castings	8	8	8	9	14
Sheet and pipe	157	123	W	W	W
Solder	245	208	223	248	242
Type metal	4	3	W	W	W
Other	80	106	915	1,362	1,525
Total	3,045	3,125	2,921	3,297	4,485
Nonmetal products:					
Ammunition primers	20	23	23	25	24
Ceramics and glass	1,050	991	872	[r]928	1,191
Fireworks	5	3	2	3	3
Pigments	196	246	207	314	W
Plastics	1,137	1,171	1,112	717	1,035
Rubber products	71	29	W	W	W
Other	159	151	101	115	508
Total	2,638	2,614	2,317	[r]2,102	2,761
Flame-retardants:					
Adhesives	219	189	200	300	280
Paper	W	W	W	W	W
Pigments	926	502	W	W	W
Plastics	5,851	5,678	4,982	[r]5,113	8,050
Rubber	166	181	250	241	298
Textiles	558	460	513	444	424
Other	21	17	681	728	749
Total	7,741	7,027	6,626	[r]6,826	9,801
Grand total	13,424	12,766	11,864	[r]12,225	17,047

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

TABLE 5
INDUSTRY STOCKS OF PRIMARY ANTIMONY IN THE UNITED STATES, DECEMBER 31

(Metric tons of antimony content)

Stocks	1989	1990	1991	1992	1993
Metal	1,873	2,934	3,598	2,450	2,819
Ore and concentrate	W	W	([1])	([1])	([1])
Oxide	4,079	4,380	3,338	[r]2,952	3,663
Residues	302	844	([1])	([1])	([1])
Sulfide	16	17	([1])	20	20
Total	6,270	8,175	10,170	[r]8,741	9,452

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

[1]Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 6
U.S. EXPORTS OF ANTIMONY METAL, ALLOYS, WASTE AND SCRAP, BY COUNTRY

Country	1992		1993	
	Gross weight (metric tons)	Value (thousands)	Gross weight (metric tons)	Value (thousands)
Belgium	267	$396	32	$39
Brazil	—	—	35	59
Canada	71	188	94	232
Chile	14	33	—	—
Colombia	35	79	15	28
Dominican Republic	8	33	—	—
El Salvador	5	9	5	9
Japan	17	20	1	10
Mexico	409	505	46	95
Panama	2	4	9	19
Thailand	—	—	9	19
United Kingdom	13	50	([1])	21
Venezuela	97	211	43	95
Other	[r]9	[r]88	8	89
Total[2]	947	1,619	315	871

[r]Revised.

[1]Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 7
U.S. EXPORTS OF ANTIMONY OXIDE, BY COUNTRY

Country	1992 Gross weight (metric tons)	1992 Antimony content[1] (metric tons)	1992 Value (thousands)	1993 Gross weight (metric tons)	1993 Antimony content[1] (metric tons)	1993 Value (thousands)
Belgium	65	54	$178	76	63	$228
Brazil	33	27	123	27	22	102
Canada	584	485	1,595	816	677	2,073
Colombia	175	145	452	34	28	147
France	25	21	65	57	47	138
Germany	180	149	481	122	101	372
Indonesia	—	—	—	10	8	36
Israel	90	75	217	72	60	169
Italy	45	37	62	362	300	362
Japan	356	295	1,017	540	448	1,232
Korea, Republic of	—	—	—	28	23	28
Mexico	3,244	2,693	3,743	1,405	1,166	1,621
Netherlands	18	15	19	26	22	26
Singapore	551	457	1,051	748	621	1,385
Spain	36	30	85	—	—	—
Sweden	5	4	5	11	9	11
Taiwan	167	139	673	17	14	62
Turkey	53	44	180	46	38	154
United Kingdom	47	39	117	127	105	328
Venezuela	10	8	32	12	10	39
Other	121	99	349	157	131	374
Total[2]	5,804	4,817	10,443	4,694	3,896	8,889

[1] Estimated by the U.S. Bureau of Mines.

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

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY, BY CLASS AND COUNTRY

Country	1992			1993		
	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Antimony content[1] (metric tons)	Value (thousands)
Antimony ore and concentrate:						
Bolivia	267	91	$505	—	—	—
Canada	893	243	478	1,497	374	$775
Chile	69	67	94	—	—	—
China	1,079	1,015	1,572	97	83	136
France	103	49	328	29	14	92
Guatemala	—	—	—	48	29	31
Hong Kong	147	123	188	—	—	—
Mexico	388	277	388	48	43	31
Other	83	59	157	—	—	—
Total[2]	3,029	1,923	3,710	1,720	543	1,066
Antimony oxide:						
Belgium	704	584	1,973	867	720	2,430
Bolivia	4,025	3,341	5,775	3,354	2,784	5,016
China	5,925	4,918	7,454	7,018	5,825	9,179
France	242	201	557	241	200	521
Germany	118	98	1,272	331	275	1,779
Guatemala	42	35	78	18	15	32
Hong Kong	384	319	585	201	167	349
Kyrgyzstan	124	103	157	661	549	835
Mexico	3,306	2,744	3,149	3,064	2,543	2,539
Netherlands	28	23	87	68	56	202
Russia	163	136	190	198	164	236
South Africa, Republic of	1,794	1,489	647	3,027	2,513	906
Switzerland	57	47	63	—	—	—
United Kingdom	122	101	361	67	55	284
Other	52	43	271	208	174	539
Total[2]	17,085	14,181	22,619	19,322	16,037	24,847

[1] Antimony ore and concentrate content reported by Bureau of the Census. Antimony oxide content estimated by the U.S. Bureau of Mines.

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

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF ANTIMONY METAL, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Bolivia	113	$156	174	$230
Chile	36	50	40	54
China	13,066	20,875	12,332	20,366
Hong Kong	1,424	2,400	396	652
Japan	137	1,825	72	1,902
Mexico	171	79	366	184
Russia	41	72	—	—
Taiwan	8	87	11	92
Thailand	40	63	160	224
Other	64	469	812	1,892
Total[1]	15,100	26,077	14,364	25,594

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

Source: Bureau of the Census.

TABLE 10
ANTIMONY: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Australia[2]	1,360	1,420	[e]1,500	[r]1,701	1,700
Austria (content of concentrate)	350	352	—	—	—
Bolivia	9,189	8,454	7,287	[r]6,022	4,500
Canada[3]	2,821	658	469	[r]948	741
China[e]	61,000	[r]54,800	[r]58,300	45,000	50,000
Czech Republic[4]	—	—	—	—	250
Czechoslovakia[e] [5]	600	1,270	1,000	1,000	—
Guatemala	[r]1,335	[r]1,068	609	[r]582	600
Honduras[e]	10	—	—	—	—
Kyrgyzstan	—	—	—	[r] [e]2,000	1,600
Macedonia	—	—	—	[r]—	—
Mexico[6]	1,906	[r]1,672	[r]1,469	[r] [e]1,200	[7]1,469
Morocco (content of concentrate)	142	192	90	[e]90	90
Namibia (content of sodium antimonate)	34	2	10	[r]6	8
Pakistan[e]	8	9	11	12	—
Peru (recoverable)	[r]304	[r]307	[r]278	[r]339	340
Russia[e] (recoverable)	—	—	—	10,000	6,000
Serbia and Montenegro	—	—	—	[r]—	—
Slovakia[5]	—	—	—	—	450
South Africa, Republic of (content of concentrate)	5,201	4,815	4,485	[r]3,779	3,500
Spain[e]	5	—	—	—	—
Tajikistan	—	—	—	[r] [e]1,500	1,200
Thailand (content of ore and concentrate)	495	326	60	[r]269	270
Turkey	1,471	[r]552	[r] [e]370	[r] [e]309	310
U.S.S.R.[e] [8]	18,000	18,000	16,000	—	—
United States	W	W	W	W	W
Yugoslavia[9]	798	409	[e]350	—	—
Zimbabwe (content of concentrate)	210	101	160	[r]254	260
Total	[r]105,239	[r]94,407	[r]92,448	[r]75,011	73,288

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

[1] Antimony content of ore unless otherwise indicated. Table includes data available through June 20, 1994.

[2] Antimony content of antimony ore and concentrate, lead concentrates, and lead-zinc concentrates.

[3] Antimony content of antimonial lead alloys, flue dust, and doré slag estimated on the basis of reported gross production.

[4] Formerly part of Czechoslovakia.

[5] Dissolved on Dec. 31, 1992.

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

[7] Reported figure.

[8] Dissolved in Dec. 1991.

[9] Dissolved in Apr. 1992.

BARITE

By James P. Searls

Mr. Searls, a physical scientist and economist with 17 years of institute, government, and U.S. Bureau of Mines experience, is the commodity specialist for barite. Domestic survey data were prepared by Maria Rosa Arguelles, statistical assistant; and international data were prepared by Virginia Woodson, international data coordinator.

Domestic sales of barite as reported decreased 3% to 315,000 metric tons. Apparent consumption, as reported, increased 67% to about 1.1 million tons. A different measure of domestic consumption, which is referred to as "shipments from crushers and grinders" of both domestically produced and imported barite, indicated a much smaller trend. These operations reported an increase in sales of 4% to 1.0 million tons. Exports were 18,000 tons while imports rose strongly to 766,000 tons.

DOMESTIC DATA COVERAGE

Domestic production data for barite are developed by the U.S. Bureau of Mines (USBM) from a voluntary survey of U.S. operations. Of the 37 operations to which a survey request was sent, 4 had closed, 5 were idle, 11 were estimated, and 17 reported data. Reported data represented 51% of "sold or used by producers" and 48% of "crushed and ground (sold or used by processors)" shown in table 1. *(See table 1.)*

BACKGROUND

Definitions and Specifications

The term "primary barite," as used in this report, refers to the first marketable product and includes crude barite, flotation concentrate, and other beneficiated material such as washer, jig, heavy media, table, or magnetic separation concentrate. Most primary barite requires fine grinding before it is used for drilling muds, the principal end use. This grinding may or may not be done at the mine site.

Barite is the mineralogical name for barium sulfate and was derived from the Greek word "barus," meaning heavy. In commerce, the mineral is sometimes referred to as "heavy spar" or "barytes." "Spar" means almost any transparent or translucent, readily cleavable, crystalline mineral having a vitreous luster.[1] One domestic barite producer has commenced naming its white, technical-grade barite as "baryte" to separate it from the American Petroleum Institute (API) barite. API barite can be blue, black, brown, or gray depending on the ore body. Few mines in the United States produce a "spar-grade" barite.

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

Products for Trade and Industry

The principal use for barite, as a weighing material in well-drilling muds, accounted for 90% of total U.S. consumption in 1993 using "Crushed and ground (sold or used by processors)" data. Drilling muds have five main functions: (1) transport drill cuttings to the surface; (2) control formation pressures; (3) maintain bore hole stability; (4) protect producing zones; and (5) cool and lubricate the bit and drill string. Barite's lack of hardness (Mohs scale 2 to 3.5) is a plus in this application. The principal function of the barite constituent is as a weighing agent to suppress high formation pressures and prevent blowouts. The deeper the hole, the more barite is needed as a percentage of the total mud mix because hydrocarbon pressures rise strongly with increasing depth after about 2,130 meters (7,000 ft) of depth. The added weight of the barite in the column of mud in the drill string is used to counteract the dangerous pressures when deep reservoirs of hydrocarbons are encountered. High pressure hydrocarbons, if uncontrolled, can cause extremely dangerous pressure releases and/or fires at the drilling rig.

The use of barite as a filler or extender and other uses accounted for about 10% of total U.S. consumption in 1993. Barite has a high specific gravity, low oil absorption, easy wettability by oils, and good sanding qualities. Unbleached barite may be substituted for bleached barite when brightness is not a factor. In painting automobiles, barite is used as a filler for the primer coat where the barite contributes to the gloss of the topcoat and inertness to chemical attack. When the primers are applied by the electrodeposition process, the body structure is dipped into a tank containing water and paint primer. The method eliminates one of the primary coats, thus reducing the quantity of barite used.

Barite also is used as a filler or extender in some plastic and rubber products. Processors of polyurethane foam use barite in manufacturing such products as floormats and carpet-backings to add weight and improve processing qualities. Barite is used in white sidewalls for tires; sidewalls consist mainly of rubber, zinc oxide, and a small quantity of barite.

Other industries use small quantities of barite fillers. In the paper industry, the white and dense barite coatings serve as a base for the sensitized layers in photographic prints. In the printing industry, barite is used in inks.

In glassmaking, barite is added to the glass melt to reduce the heat-insulating froth that forms on the melt surface, thus saving fuel, and to act as an oxidizer and decolorizer, making the glass more workable and increasing its brilliance. Glass manufacturers usually require a minimum of 95% $BaSO_4$ with a maximum of 2.5% silicon dioxide (SiO_2) and 0.15% Fe_2O_3. The particle-size range generally preferred is -30 to +140 mesh. Finely ground barite can be substituted when crushed material is not available. In glass manufacture, barite reduces seeds and annealing time and increases toughness and brilliancy.

Minor uses include ballast for ships, heavy concrete aggregate for radiation shielding and pipeline-weighing in swampy or aquatic areas, friction products, and applications in foundries.

Barite is also a raw material for barium chemical manufacturing. Barite is the leading commercial source of barium and barium compounds in the United States. About 200 tons of witherite ($BaCO_3$) was imported from Canada, China, and Japan in 1993 and may be a starting point for barium chemical end uses. The major barium chemicals are the manufactured carbonate, chloride, hydroxide, nitrate, oxide, 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 (the barium combines with the sulfate to form the insoluble barium sulfate) and to diminish porosity and prevent discoloration in brick. Other uses are in television picture tubes as a radiation barrier, optical glass, ceramic glazes, porcelain enamel, ferrites, and miscellaneous ceramic products. Barium-base glass (using barium carbonate) is considered to be more brilliant than lime glass and more durable than lead glass. Barium carbonate is replacing lead oxide in television tube faceplates to stop X-ray radiation. The same amount of strontium carbonate will be used with the barium as was used with the lead. The X-rays occur when the high voltage electrons from the "gun" that excite the phosphors have been stopped quickly at the faceplate.

Blanc fixe, chemically precipitated barium sulfate, is used as a white filler in paints, rubber, inks, and other material where a degree of purity higher than natural barite is required. Barium chloride is used in case-hardening and heat-treating baths, in leather and cloth, in making magnesium metal, in water treatment, and as a laboratory reagent. Fused barium chloride may be electrolyzed to produce barium metal.

Barium metal also is produced by reduction of barium oxide. The metal is used as a "getter" to remove traces of gas from vacuum tubes, or in alloys for spark plugs and electronic emission elements in electronic tubes.

Barium nitrate is used in green signal flares, tracer bullets, primers and detonators, and enamels. Barium oxide is used in electric furnace ferrous metallurgy to increase the life of acid furnace linings, to give a quieter and steadier arc, to reduce the sulfur content of the iron, and to lower the slag viscosity.

Barium hydroxide us used to prevent scumming in ceramics, to make soap for lubricating oils and greases, and to recover sugar from molasses by the barium saccharate process. Barium titanate finds use in miniature electronic and communication equipment.

Industry Structure

Currently, much of the barite that is supplied to the drilling mud industry is supplied by barite from China and India. The domestic industry is undergoing changes with downsizing in the United States and movement toward Asia and countries in and around the former U.S.S.R. Several U.S. firms import barite and grind the barite to size in plants along the gulf coast instead of producing from U.S. mines owing to the lower cost of the imported barite delivered at the grinding plant. A Nevada mine reopened during 1992 owing to transportation cost reductions. Seven mining firms, operating 10 mines, continue to compete in the industry. One U.S. mine is owned by a Canadian company and one mine is owned by a French company. Only one barium chemical firm competes in the barium chemical industry using its domestically mined barite from another division, mixed with imported barite, as feedstock.

Geology

Pure barite has a specific gravity of 4.5. Barite varies considerably in appearance depending on source and treatment. It is a moderately soft crystalline material with a Mohs hardness between 3 and 3.5. In residual deposits, it ranges in size from large boulders to fines. Shades of white to dark gray and black, depending on impurities and surficial coating, are common in commercial deposits.

Vein and cavity-filling deposits are those in which barite occurs along faults, joints, bedding planes, and other solution channels or sink structures. These deposits are found most often in limestone. Most of the vein deposits are believed to be of hydrothermal origin.

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

Residual barite deposits are formed by weathering of preexisting deposits. The principal residual deposits are found in southeastern Missouri; the Appalachian region; Sweetwater, TN; Cartersville, GA; and in the Rio Grande area of Texas. A concentration of at least 60 to 180 kilograms of barite per cubic meter is required in a commercial deposit. In Washington County, MO, the residuum is 3 to 4.6 meters thick, while in Cartersville, GA, the ore is 45 meters thick in some areas. This form of deposit has been of considerable economic significance.

The most important commercial deposits are of bedded barite. These are principally in Arkansas, California, and Nevada. The barite in these areas is generally dark gray to black and has a characteristic fetid odor when struck with a hammer. The beds, which vary in thickness from 5 centimeters to more than 15 meters, occur interbedded with dark chert and siliceous siltstone and shale. In most of the deposits, the barite is laminated. In some areas, barite nodules and rosettes make up a large part of the beds. Many of the beds contain 50% to 95% barite. Originally, it was thought that these deposits were the result of the replacement of carbonate rocks; however, current thought is that the deposits are of sedimentary origin. The actual environment of deposition has not been established, but theories range from submarine volcanic emissions to hydrothermal solutions to recycling of barite from preexisting rocks.

ANNUAL REVIEW

Legislation and Government Programs

The antidumping duty on barium carbonate from Germany continued for another year. The proposed exemption of barium sulfate from reporting requirements of the category "barium compounds" of the list of toxic chemicals under section 313 of the Emergency Planning Act of 1986 (EPCRA) was announced for comment but not completed in 1993.

Producers

Dresser Industries Inc., an equipment manufacurer (through M.W. Kellog) for refineries, petrochemicals, and liquefied natural gas production, announced its intention to buy Baroid Corp. in September. The purchase was not completed by the end of the year due to the Justice Department's concerns for: (1) Dresser's partial (64%) ownership of M-I Drilling Fluids, and (2) Baroid's diamond drill bit subsidiary DBS. Dresser was expected to sell its portion of M-I Drilling Fluids. Halliburton maintained its ownership of the 36% of M-I Drilling Fluids. Milpark Drilling Fluids became part of Baker Hughes Inteq, a drilling equipment company, in March 1993. It would appear that the oil-well drilling fluids companies went through a consolidation phase in the early 1980's as consumption dropped and recently have been drawn into vertically integrated companies that have drilling equipment, drill bits, drilling fluids, other equipment, and services.

Of the 37 operations that were surveyed, 23 were mills (processing or beneficiating plants, and crushing and grinding operations) and 14 were mines. Seventeen mills were operating, two mills were idle during the year, and four mills had closed. Eleven mines were operating and three mines were idle. Only one mine reported run-of-mine ore sales, therefore run-of-mine ore was not included in table 1. The recently reopened mine was not surveyed and did not verbally report until after the USBM data entry window had closed and therefore was estimated.

Sales

For 1993, beneficiated product was 100% of reported sales because the small amount of run-of-mine ore sales was withheld. *(See table 1.)* For 1993, "Sold or used by producers" is incorrect and should be 100,000 to 125,000 tons more, which would also increase apparent consumption figure by the same amount. *(See tables 2 and 3.)*

Consumption and Uses

The consumption of crushed and ground barite, as reported in table 1, increased about 4% from 1 million tons in 1992. Apparent consumption, as calculated by "Sold or used by producers" minus exports plus imports, rose by 67% as reported in the table. The oil- and gas-well-drilling industry was estimated to have completed more than 24,900 wells and drilled nearly 42.3 million meters (139 million feet) of hole.[2] This is 4% above 1992's revised number of holes and more than 9% above 1992's revised total distance. From a table reporting oil, gas, and dry well completions, total oil wells for 1993 were estimated to be 8,274, a more than 7% drop from 8,943 wells in 1992 and much less than the 11,916 wells in 1991. Gas wells in 1993 rose more than 16% from the 1992 total gas wells. The first three quarters of 1992 averaged 1,762 gas well completions per quarter, the last quarter of 1992 and the first quarter of 1993 averaged 3,087 gas wells per quarter, and the final three quarters of 1993 were estimated to have averaged 2,187 gas wells per quarters. This would seem to support the renewed interest in natural gas production in the United States that caused some increase in barite consumption. *(See table 4.)* For end of year 1993 (week ending December 24), the week-average-oil-futures price for light sweet crude oil had fallen by 27.5% from $19.92 in the same week of 1992 while the natural gas price had fallen by about 1.1% on the same basis.[3] The future price for light sweet crude in the week ending July 9, 1993, was $18 per barrel, so the decrease in oil futures price occurred later in the year.

At the beginning of the year, the Baker Hughes' monthly average active U.S. rig count reported that there were 922 drilling rigs with 368 directed toward oil prospects or developments and 527 rigs directed toward gas prospects or developments. At midyear, there were 353 oil rigs and 346 gas rigs. At the end of the year, there were 385 oil rigs and 423 gas rigs for a total of 814 rigs, down 12% from 922 rigs at the beginning of the year.

Prices

Price quotation in Industrial Minerals Magazine for API grade on the U.S. gulf coast was $85 per ton through March when the series switched to prices paid by grinders for Chinese and Indian lump barite.

The reported average value per ton of domestic barite, based on reported value of direct-ship, beneficiated, and floated material, increased slightly, f.o.b. plant, from $60.22 to $61.16. The average value of crushed or ground barite, sold or used by processors, was $74.16, a 12% decline from $84.49 per ton reported in 1992. Within this group, the average value of barite for well-drilling end use was $64.26, down 14% from $75.55 per ton, while the average value for barium chemicals, filler and extender, and glass was essentially unchanged at $163.10 per ton. The average c.i.f. value of imported crude barite was $37.72 per ton, while the c.i.f. value of imported ground barite was $139.78 per ton.

Foreign Trade

Exports of natural barium sulfate or barite rose by 50% to 18,500 tons but was still well under the 1991 figure of 43,000 tons. Export data provided by the Bureau of the Census did not indicate the grades of barite traded; however, based only on the per-ton value of individual shipments, which varies from about $40 to nearly $2,000 per ton, drilling-, filler-, glass-, chemical-, and pharmaceutical-grade were all exported. *(See table 5.)*

Imports for consumption of crude barite rose sharply (137%) from 1992 to nearly 766,000 tons. The principal source countries, in descending order, were China, India, and Mexico. The shipment listed from Switzerland was probably from India, according to its price. The higher priced material was chiefly crude filler and extender-quality barite. Most of the crude barite entered through customs districts along the gulf coast for delivery to grinding plants in the area. *(See tables 6 and 7.)*

World Review

Little change in overall barite production occurred around the world because production has moved closer to the areas of petroleum drilling. The former U.S.S.R. and Asia are the areas of present and future petroleum exploration and development. It is less likely that barite will be hauled long distances to these areas, given barite's worldwide distribution. Some areas, such as Turkey and Kazakhstan, will produce more barite in the near future for drilling in nearby countries, and some countries, probably including the United States, will produce less barite as drilling profits decline. The forecast for the United States is not perfectly clear as gas exploration may be profitable due to the environmental friendliness of gas consumption according to the new administration.

The Ballynoe Mine, owned by Magcobar (Ireland) Ltd., closed permanently in October. *(See table 8.)*

OUTLOOK

With several countries moving away from socialist beliefs and toward greater acceptance of international development of petroleum resources for expertise and financial backing, the petroleum exploration and development effort has moved away from North America and into the former U.S.S.R. and countries in the Pacific Basin. The large volumes of barite that will be needed for the exploration will be more likely to be supplied from mines and mills nearby to those regions and not from the United States. Drilling will continue in the United States, albeit at a slower pace, and for gas.

The domestic barite industry may change its production away from drilling mud barite, dominated by China and India, and toward higher valued products, planning to displace imports from several countries.

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[1] Thrush, P. W. (ed.) A Dictionary of Mining, Mineral, and Related Terms (Dep. of Interior), U.S. GPO, Washington, DC, 1968, p. 1049.

[2] American Petroleum Institute, Quarterly Completion Report, 4th Quarter. V. IX, No. 4, Jan. 1994, pp. 4,7.

[3] The Oil and Gas Journal. V. 91, No. 29, PennWell Publ., Tulsa, OK, July 19, 1993, p. 3.

TABLE 1

SALIENT BARITE AND BARIUM CHEMICAL STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Barite, primary:					
Sold or used by producers	290	430	448	326	[1]315
Value	$12,625	$16,000	$21,310	$19,633	[1]$19,265
Exports	10	9	43	12	18
Value	$1,622	$1,675	$3,304	$1,806	$2,608
Imports for consumption (crude)	987	988	841	323	766
Value	$39,768	$40,103	$35,883	$12,941	$28,894
Consumption (apparent)[2]	1,267	1,409	1,246	637	1,063
Crushed and ground (sold or used by processors)[3]	1,277	1,434	1,267	999	1,038
Value	$103,759	$99,562	$102,934	$84,404	$76,981
Barium chemicals (sold or used by processors)	[e]30	W	W	W	W
Value	[e]$17,000	W	W	W	W
World: Production	[r]5,740	[r]5,763	[r]5,712	[r]5,118	[e]4,890

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

[1] Data exclude run of mine.

[2] Sold or used plus imports minus exports.

[3] Includes imports.

TABLE 2

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

State	Number of operations	Run of mine		Beneficiated material[1]		Total	
		Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)	Quantity (thousand metric tons)	Value (thousands)
1992:							
Nevada	4	W	W	229	$8,120	[2]229	[2]$8,120
Other States	5	W	W	85	10,850	[2]85	[2]10,852
Total	9	12	$664	314	18,970	326	[3]19,633
1993:							
Nevada	4	W	W	242	9,100	[2]242	[2]9,100
Other States	5	—	—	73	10,165	[2]73	[2]10,165
Total	9	W	W	315	19,265	315	19,265

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

[1] Includes flotation concentrate.

[2] Data exclude run of mine.

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

TABLE 3

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

State	1992			1993		
	Number of plants	Quantity (thousand metric tons)	Value (thousands)	Number of plants	Quantity (thousand metric tons)	Value (thousands)
Louisiana	7	516	$39,618	7	534	$36,965
Nevada	3	180	12,427	4	163	7,125
Texas	4	185	13,684	4	W	W
Other[2]	12	118	18,675	9	341	32,891
Total	26	999	84,404	24	1,038	76,981

W Withheld to avoid disclosing company proprietary data.

[1] Includes imports.

[2] Includes California, Georgia, Illinois, Missouri, Oklahoma, Texas (1993), and Utah.

TABLE 4
CRUSHED AND GROUND BARITE[1] SOLD OR USED BY PROCESSORS IN THE UNITED STATES, BY USE

(Thousand metric tons and thousand dollars)

Use	1992		1993	
	Quantity	Value	Quantity	Value
Barium chemicals, filler and/or extender, glass	112	18,281	104	16,962
Well drilling	887	66,123	934	60,019
Total	999	84,404	1,038	76,981

[1] Includes imports.

TABLE 5
U.S. EXPORTS OF NATURAL BARIUM SULFATE (BARITE), BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Angola	103	$12	—	—
Argentina	7	5	—	—
Australia	20	5	—	—
Canada	7,025	912	9,118	$1,183
China	5	6	—	—
Cote d'Ivoire	6	12	—	—
Equatorial Guinea	1,688	200	—	—
Honduras	—	—	3	3
Italy	1	10	14	3
Japan	207	162	118	604
Korea, Republic of	—	—	6	13
Mexico	305	78	1,042	262
Panama	—	—	150	20
Spain	—	—	20	65
Trinidad and Tobago	—	—	9	4
Tunisia	—	—	3	35
United Kingdom	—	—	2	4
Venezuela	3,102	402	8,001	412
Total	12,469	[1]1,806	18,486	2,608

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

Source: Bureau of the Census.

TABLE 6

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

Country	1992 Quantity (metric tons)	1992 Value[1] (thousands)	1993 Quantity (metric tons)	1993 Value[1] (thousands)
Crude barite:				
Canada	5,901	$224	144	$24
China	216,826	9,450	419,484	17,129
India	100,031	3,252	270,917	8,915
Japan	1	2	—	—
Mexico	20	6	36,006	1,371
Netherlands	18	7	—	—
Switzerland	—	—	39,398	1,454
Total[2]	322,797	12,941	765,949	28,894
Ground barite:				
Canada	10,994	2,819	10,239	2,725
Germany	162	76	147	69
Japan	36	37	8	21
Mexico	19,649	1,437	27,394	2,456
Netherlands	27	14	24	12
Total[2]	30,868	4,383	37,817	5,286

[1] C.i.f. value.

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

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF BARIUM CHEMICALS

Year	Blanc fixe (precipitated barium sulfate) Quantity (metric tons)	Blanc fixe (precipitated barium sulfate) Value[1] (thousands)	Barium choride Quantity (metric tons)	Barium choride Value[1] (thousands)	Barium oxide, hydroxide, and peroxide Quantity (metric tons)	Barium oxide, hydroxide, and peroxide Value[1] (thousands)
1989	10,638	$8,945	1,477	$702	4,644	$5,335
1990	10,354	8,675	1,510	783	4,186	5,275
1991	9,707	8,384	584	354	4,597	5,812
1992	—	—	550	277	4,730	5,076
1993	—	—	487	275	4,585	5,017
	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)
1989	1,477	$1,012	14,401	$8,047	—	—
1990	1,178	1,394	11,201	6,038	—	—
1991	2,180	1,912	12,314	6,089	—	—
1992	2,413	2,326	12,891	6,608	11,589	$10,035
1993	2,172	2,149	10,859	6,369	12,244	10,710

[1] C.i.f. value.

Source: Bureau of the Census.

TABLE 8

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Afghanistan[e] [3]	2,000	2,000	2,000	2,000	2,000
Algeria	49,000	53,078	44,361	[r]45,000	45,000
Argentina	57,558	[r]36,597	[r]61,094	[r]44,170	44,000
Australia[e]	11,000	11,000	11,000	11,000	11,000
Belgium[e]	40,000	35,000	35,000	30,000	30,000
Bolivia	—	300	1,277	[r]368	—
Bosnia and Herzegovina[4] [5]	—	—	—	[r] [e]3,000	2,000
Brazil (beneficiated)	51,407	55,576	46,784	[r]54,490	47,000
Burma[6]	11,278	9,468	[e]9,000	[e]10,000	10,000
Canada	[r]47,000	[r]41,000	50,000	[r]37,000	59,000
Chile	59,873	3,038	[r]3,183	[r]2,434	1,800
China[e]	1,750,000	1,750,000	1,800,000	1,800,000	1,900,000
Colombia	5,460	5,380	[r]9,288	[r]9,380	9,400
Croatia[5]	—	—	—	[e]1,500	1,500
Czechoslovakia[7]	[r]52,600	[r]88,000	[r] [e]86,000	[r]31,313	—
Egypt	7,295	6,197	5,943	[e]5,900	5,900
Finland	1,614	—	—	—	—
France	111,800	92,500	[e]90,000	[r]96,200	96,000
Georgia[8]	—	—	—	[e]40,000	30,000
Germany:					
Eastern states	89,400	[r]61,433	—	—	—
Western states	144,106	[r]147,836	—	—	—
Total	233,506	[r]209,269	163,691	[r]157,014	155,000
Greece (crude ore)	1,247	1,617	1,309	[e]1,000	1,000
Guatemala	3,995	[r]421	--	[r]1,723	1,500
India	548,103	633,000	615,000	[e]620,000	400,000
Iran[3]	59,660	77,423	191,238	[r]181,174	200,000
Ireland	82,000	101,000	[r]94,300	[r]70,600	55,000
Italy	60,331	44,345	88,486	[r]74,884	75,000
Kazakhstan[8]	—	—	—	[e]200,000	200,000
Kenya	210	105	[e]100	[e]100	100
Korea, Republic of	3,735	2,923	1,014	[r]40	50
Malaysia	36,526	48,291	16,600	[r]10,525	14,000
Mexico	324,739	[r]305,716	[r]191,962	[r]187,730	[9]193,000
Morocco	370,000	363,580	433,325	[r]401,000	[9]325,200
Pakistan	29,718	23,329	28,751	[r]32,432	15,000
Peru	[e]150,000	[r] [e]130,000	150,200	[r]16,579	16,600
Philippines[e]	[9]348	500	500	500	500
Poland	57,900	25,316	[r]18,300	[r]15,700	16,000
Portugal[e]	[9]1,729	1,220	1,400	1,200	1,200
Romania	25,250	[r] [e]65,000	[r] [e]70,000	[r]118,100	115,000
Slovakia[10]	—	—	—	—	30,000
South Africa, Republic of	8,570	2,490	4,790	3,570	1,200
Spain	6,745	11,285	[e]9,000	[r] [e]10,000	10,000
Thailand	[r]87,052	107,707	[e]100,000	[r]46,328	50,000
Tunisia	33,104	30,885	22,366	[r]30,179	30,000
Turkey (run-of-mine)	425,519	[r]366,995	[r]250,579	[r]311,335	300,000
U.S.S.R.[e] [11]	540,000	500,000	450,000	[r]—	—

See footnotes at end of table.

TABLE 8—Continued

BARITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
United Kingdom	70,026	67,551	85,505	[r]76,723	75,000
United States[12]	290,000	[r]430,000	448,000	[r]326,000	[9]315,000
Yugoslavia[4, 5, 13]	30,509	23,601	[e]20,000	—	—
Zimbabwe	1,900	320	866	[r]232	300
Total	[r]5,740,307	[r]5,763,023	[r]5,712,212	[r]5,118,423	4,890,250

[e]Estimated. [r]Revised.

[1] Table includes data available through June 21, 1994.

[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] All production in Yugoslavia from 1989-91 came from Bosnia and Herzegovina.

[5] Barite concentrates.

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

[7] Dissolved on Dec. 31, 1992. Production in Czechoslovakia from 1989-91 came from the Czech Republic and Slovakia; all production for 1992 came from Slovakia.

[8] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[9] Reported figure.

[10] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[11] Dissolved in Dec. 1991.

[12] Sold or used by producers.

[13] Dissolved in Apr. 1992.

BORON

By Phyllis A. Lyday

Mrs. Lyday has covered boron for 15 years. Domestic survey data were prepared by Pam Shorter, statistical assistant; and international data were prepared by Harold Willis, international data coordinator.

U.S. production and sales of boron minerals and chemicals increased during the year. Domestically, glass fiber insulation was the largest use for borates, followed by sales to borosilicate glass, textile-grade glass fibers, and agriculture.

California was the only domestic source of boron minerals. The United States continued to provide essentially all of its own supply while maintaining a strong position as a source of sodium borate products and boric acid exported to foreign markets.

Supplementary U.S. imports of Turkish calcium borate and calcium-sodium borate ores, borax, and boric acid, primarily for various glass uses, continued.

DOMESTIC DATA COVERAGE

Domestic data for boron are developed by the U.S. Bureau of Mines from two separate, voluntary surveys of U.S. operations. Of the three operations to which a sold and used survey request was sent, two responded, representing 99% of the total boron sold or used shown in tables 1 and 8. A U.S. Bureau of Mines canvass of the three U.S. producers also collected data on domestic consumption of boron minerals and compounds shown in tables 3 and 4. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Few of the many minerals that contain boron are commercially valuable. Only colemanite and ulexite minerals, primarily imported from Turkey, are marketed in the United States. The boron oxide content of both minerals is usually marketed at about 40%. *(See table 2.)*

Tincal and kernite ore and brines are the U.S. source of refined borate chemical compounds. The most common refined borates, borax pentahydrate and its derivative anhydrous borax, are marketed in technical and agricultural grades. Lesser quantities of borax decahydrate are produced in technical, United States Pharmacopeia, and special quality grades.

Boric acid is a white, odorless, crystalline solid sold in technical national formulary and special quality grades as granules or powder. Boron oxide is a hard, brittle, colorless solid resembling glass that is ground and marketed most often under the name anhydrous boric acid.

Elemental boron is a dark brown powder in the amorphous form and a yellowish-brown, hard, brittle solid in the monoclinic crystalline form. Boron is marketed in grades from 90% to 99% purity.

Ferroboron is a name given to a variety of boron-iron alloys containing 0.2% to 24% boron used primarily to introduce small quantities of boron into specialty steels.

In the boron hydride series are diborane, a gas; pentaborane, a liquid; and decaborane, a solid. These compounds range from 31,220 British thermal units (Btu) per pound for diborane to 27,850 Btu per pound for decaborane.

Boron nitride, a soft, white, highly refractory solid resembling graphite, can withstand significant oxidation to temperatures up to 650°C. Boron nitride produced in fibrous form equals glass fibers in strength and modules of elasticity, but is lighter in weight and more resistant to high temperature. When subjected to extremely high pressure and temperature, boron nitride forms cubic crystals that rival the hardness of diamond. Boron carbide, produced by reacting carbon and boric acid at 2,300° C, is a highly refractory material and one of the hardest substances known. Most commonly used for both abrasive and abrasion-resistant applications as well as nuclear shielding, boron carbide is marketed in technical and high-purity grades.

Geology

At the Kramer borate deposit of the Boron open pit mine, tincal consists of more than 80% of high-grade beds, with claystone only between the crystals. In low-grade beds, tincal is less than 50% of the beds and is disseminated in a claystone matrix. The lower portions of the beds consist of kernite, a secondary mineral formed by the dehydration and recrystallization of borax resulting from high temperature and pressure. Probertite is found radiating prismatic crystals, or rosettes, commonly within claystone and exclusively where kernite is the dominant sodium borate. The sodium borate facies is enveloped by ulexite, colemanite, and barren claystone facies. The barren facies contain calcareous nodules but are barren of borates.[1]

Searles Lake in southeastern California is a closed structural basin filled with alluvian and lacustrine evaporites. The flat area of about 100 square kilometers overlies two separate salt structures. The evaporite beds were formed during periods of high evaporation and low rainfall. Mud beds were formed during full lake conditions. The upper salt structure is 21 to 27 meters thick and the lower one is 8 to 12 meters thick. The brines in these salt structures are high in sodium carbonate and low in sodium chloride. The important chemical ions are bicarbonate, carbonate, borate, chloride, potassium, and sulfate as halite, hanksite, trona, nahcolite, burkeite, borax, and thenardite. An impervious mud parting layer 4 meters thick divides the upper and lower salt layers. The upper brine contains 1.63% borax and is rich in potash. The lower brine contains 1.97% borax and more carbonate.[2]

The Fort Cady colemanite deposit is in the Mojave Desert near Barstow, CA. The known deposit extends over 154 hectares at an average depth of 411 meters from the surface. The deposit is encapsulated in clay beds, which make it an ideal setting for in situ mining technology. Ground water in the ore body is brackish with a total dissolved solids figure in the 20,000-milligram-per milliliter range.[3]

Technology

Problems with the discovery, processing, and transporting of boron minerals and compounds from remote and hostile locations became a part of the history of the borax industry. The location of the ore and the methods of production remained a guarded secret for many centuries. It was not until the end of the 17th century when Amsterdam had replaced Venice as the center of borax production that the mineral source and methods of process were commonly known. Producers of boric acid from the steam vents of Tuscany, Italy, prospered because of a lack of competition in the world market. Large reserves of borates were found in Turkey in 1865 and in the Western United States in 1856. With the discovery of new minerals, new processes were developed. The history of boron production and processing has continued for thousands of years because of the benefits derived from using the product. The use and processing have varied little over the past 100 years. Modern changes in processing are a result of improved equipment and processing controls.

Byproducts and Coproducts

More than four-fifths of the U.S. production comes from mineral deposits mined only for their boron content. The remainder is produced from lake brines, which also supply sodium carbonate, sodium sulfate, potassium sulfate, and potassium chloride. Turkish colemanite, ulexite, and tincal ores are worked only for their boron content. Most Soviet borates also are 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. Domestic producers now use cogeneration facilities to reduce the cost of energy for processing and supplying excess electricity for sale.

Depletion Provisions.—The domestic and foreign depletion allowances for boron are 14% of gross income and may not exceed 50% of net income without the depletion deduction.

Operating Factors

Occupational Safety and Health Administration's (OSHA) Hazard Communication Standard went into effect November 1985 and May 1986. It is OSHA's most comprehensive worker protection regulation. It provides for information and training for workers encountering chemical exposures in the workplace. The standard requires the use of labels and material safety data sheets for all regulated chemicals. Part of the standard includes the Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienist. TLV's refer to airborne concentrations of substances and represent conditions under which nearly all workers might be repeatedly exposed day after day without adverse effect. The only hazard listed for boron chemicals produced at the mine site was a Time Weighted Average for borax decahydrate, listed as 5 milligrams per cubic meter per 8-hour workday, 40-hour workweek, to which nearly all workers may be repeatedly exposed without adverse effect. Sodium borates, boric acid, and boron oxide are not present to any significant degree in air and are placed in the same hazard category as general dust.[4]

Small quantities of boron are essential for all plant life. Boron is added in trace levels to fertilizers; however, quantities well below concentrations affecting humans and animals are so extremely toxic to vegetation that boron compounds also are used commercially as herbicides. Concentrated boric acid is used to control certain insects and in dilute solutions as a preservative to control the growth of bacteria.

Owens-Corning detailed the results of four new studies on fiberglass and human health, which were completed. One of the four studies was an extensive animal inhalation study. The studies, in conjunction with epidemiology, provided strong evidence that working with fiberglass does not pose a significant human health risk. These studies were consistent with the results of animal inhalation studies. Direct injection of fibers into test animals has produced tumors, but the relevance has been challenged most recently by the World Health Organization.[5]

ANNUAL REVIEW

Legislation and Government Programs

The Senate Energy Committee approved a bill October 5 for the California Desert Protection Act. Under the proposed bill, 1.8 million hectares (4.3 million acres) of public land would be designated wilderness. In addition to the wilderness designation, the bill would add 0.5 million hectares (1.3 million acres) of Federal lands to the existing Death Valley National Monument and 83,000 hectares (200,000 acres) to the Joshua Tree National Monument. The land under discussion contains numerous mineral deposits, including most known boron reserves. At yearend, H.R. 2929 had passed the House and was sent to the Senate for further consideration. The U.S. Bureau of Mines published OFR 62-92 (NTIS:PB 92-238237/AS) in May 1992 that presents nine case histories to highlight the diversity of deposits, commodities, and markets represented in the California Desert Conservation Area.

The Department of the Interior, Bureau of Land Management, published in the December 23, 1993, Federal Register the availability of Final Environmental Impact Report/Environmental Impact Statement (EIR/EIS) for the Fort Cady Minerals Corp. borate solution mining project. The decisions generated from the EIR/EIS will be consistent with the California Desert Conservation Plan as Amended.

The Environmental Protection Agency published a proposed rule on Boric Acid and its Salts, Borax (Sodium Borate Decahydrate), Disodium Octaborate Tetrahydrate, Boric Oxide (Boric Anhydride), Sodium Borate and Sodium Metaborate; Tolerance Exemptions in the Federal Register on June 30. The document proposes an exemption from the requirements of a tolerance to be established in or on raw agricultural commodities when used as an active ingredient in insecticides, herbicides, or fungicides preharvest or postharvest in accordance with good agricultural practices.

The Department of Health and Human Services ordered a review of research that concludes fiberglass insulation is a possible carcinogen. Scientists believe that fiberglass insulation may cause cancer in humans. The health threat is to construction workers who install the insulation, not to occupants of the dwelling.

Congress continued to debate the fate of the Mining Law of 1872 as amended and its affect on the hard-rock mineral industry. Boron is leasable as sodium borate. Other colemanite and probertite minerals are locatable because they also contain calcium and are deposited as placer deposits. Changes in the mining law will probably affect royalty rates for minerals, including these locatable industrial minerals in addition to the commonly thought of hard-rock minerals such as gold and copper.

Production

The majority of boron production continued to be from Kern County, with the balance from San Bernardino and Inyo Counties, CA.

American Borate Co. (ABC), a wholly owned subsidiary of Owens-Corning, was sold in December 1990 to a private firm. ABC renewed its mine permits and began to mine small amounts of colemanite and ulexite from the Billie Mine. Colemanite was processed at Lathrop Well, NV. Storage and grinding facilities were at Dunn, CA.

North American Chemical Co. operated the Trona and Westend plants at Searles Lake, in San Bernardino County, to produce refined sodium borate compounds and boric acid from the mineral-rich lake brines. North American is owned by the Harris Chemical Group, with corporate headquarters in New York City and operating headquarters in Overland Park, KS. At the Trona plant, a differential evaporative process produced borax with potash as a byproduct. Boric acid was produced by solvent extraction. The Westend plant used two lines to supply brines to the plant. The first line fed lake brine to the Argus plant where sodium carbonate was produced. The effluent borax-rich brine then is pumped to the Westend plant where it supplied about two-thirds of the brine feed. The effluent was blended with fresh lake brine from a second feed line that supplied about one-third of the brine feed. The blended brine was then cooled to 18° C to precipitate decahydrate borax. The effluent was cooled to 8° C, and the precipitated Glauber's salt was used to produce sodium sulfate. North American was in the process of evaluating technical changes in it production operation that were to be implemented during 1993.

U.S. Borax, Inc. (Borax), a part of Borax Consolidated Ltd. of the RTZ Corp. PLC of London, United Kingdom, continued to be the primary world supplier of sodium borates. RTZ is traded on the New York Stock Exchange. Borax combined its corporate headquarters and Research Center and moved to Valencia, CA, in March 1993.

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 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 Borax's storage in Wilmington, CA. Products made at Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate.

Consumption and Uses

U.S. consumption of borates increased. Glass accounts for three major borate applications as follows: glass fiber insulation, textile glass fiber, and borosilicate glass.

The use of borates in glass fiber thermal insulation, primarily used in new construction, was the largest area of demand for borates and the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, its purpose is to trap and hold air. Typically between 4% and 5% boron oxide is incorporated in the formulation to aid melting, inhibit devitrification, and improve the aqueous durability of the finished product. Cellulosic insulation, the ninth largest area of demand, increased.

The fifth major market for borates, manufacturing high-tensile-strength glass fiber materials for use in a range of products, showed a decrease in demand. The process of producing glass fiber uses a borosilicate E-glass formulation that is continuously drawn through platinum alloy bushings into continuous filaments of between 9 to 20 microns in diameter. The plastic industry uses roving or chopped strand fibers and the textile industry uses yarn fibers.[6] E-Glass, or textile fiber glass, typically contains between 6% and 8% boron oxide.

Originally these glasses were used for electrical purposes, and low sodium levels were important. Now their major applications are reinforcements for plastics, but the low sodium tolerance still applies. The nonconductive and low dielectric properties of high-strength glass-reinforced materials make them transparent to radar and thus valuable for "stealth" applications. Carbon-fiber-reinforced resins can be stronger than metals and, with higher modules, more stable. Although composites can be 10 times more expensive than typical aerospace-grade aluminum, the flexibility they offer in design and consolidation of parts allows large, complex structures to be fabricated to exacting specifications. In addition, their light weight and ability to withstand high temperatures have made them the material of choice for a variety of aerospace applications.

Annual production of fiber glass was reported to be 2 million metric tons per year at a value of $2.3 billion. This represented 18% of the total energy used to produce glass products. Typical glass industry cost for an 80-ton-per-day-capacity fiberglass plant was estimated at $45 million for a product that sells for $750 per ton.[7]

Owens-Corning planned to reopen its Jackson, TN, glass fiber plant that closed in 1987. Capital investment was between $30 and $40 million to install new equipments. When the plant reopens in 1994, it will employ about 80 people and produce wet-process mat glass fiber for use in making roofing shingles.[8]

Consumption of borates in borosilicate glasses remained the third major end use, and demand decreased. Boron added in amounts of between 10% and 13% to glass reduced the viscosity of the melt, assisted with fiber formation during processing, allowed for improved specific optical properties, increased resistance to aqueous or chemical attack, enhanced certain mechanical properties, and reduced the thermal expansion coefficient and thermal shock resistance of the product. Scientific glassware products are usually fabricated in Pyrex borosilicate glass. This type of glass is resistant to heat up to 400° C and to chemical corrosion from liquids and gases.[9]

Construction of the Nation's first facility to produce a borosilicate glass from solid nuclear waste was completed at Savannah River Site, Aiken, SC. High-level nuclear waste that has accumulated during 35 years will be reprocessed and stored in stainless steel canisters for temporary storage before interment in a geologic repository. Boron and lithium are added to the sludge to improve the viscosity of the glass. The viscosity of the borosilicate glass is a function of temperature. Viscosity determines the rate of melting of the raw feed, the rate of glass bubble release (foaming and fining), the rate of homogenization, and therefore, the quality of the final glass product. If the viscosity is too low, excessive convection currents can occur, increasing corrosion and erosion. After vitrification at 1150° C, the glass is pored into the stainless steel canisters for interim storage.[10]

Glazes and enamels are the thin, glassy coatings fused onto ceramics and metals, respectively. Examples include wall and floor tiles, tableware, earthenware, bone china and porcelain, cookers, washing machines, pots and pans, and architectural panelling. The surface decoration of glass articles can now be made with lead-free enamels. A glass enamel composition has a low softening point glass frit and inorganic pigment in a ratio of approximately 9:1. Traditional frits are composed of boric acid, lead, and silica. Traditional lead-bearing frits fired between 540° C to 740° C allow the glass enamel manufacturer to meet requirements of the hand-blown and bent glass industries. Metal in various forms give different colors, such as cobalt silicate for a deep blue; zinc and alumina for lighter shades of blue; chrome oxide for green; and iron, zinc, chrome, and aluminum oxides for brown. Durability can be improved by the addition of titanium dioxide or zirconium oxide. The most common lead-free decorating formulations in frits are zinc borosilicate and bismuth borosilicate, although some barium is being used as a lead replacement. The only difference in lead-bearing enamels is the inability to develop the cadmium sulfoselenide series of yellows, oranges, and reds. At firing, the frit softens and approaches a molten state and wets the pigment and the surface of the article being decorated, thus permanently bonding the glass substrate. Low lead release frits fire at higher temperatures and have low levels of leachability of the lead pigments.[11]

Boron compounds continued to find application in the manufacture of biological growth control chemicals for use in water treatments, algicides, fertilizers, herbicides, and insecticides. Boron can be applied as a spray and incorporated in herbicides, fertilizers, and irrigation water. Sodium polyborate can be used in carpets to control fleas.[12] The Potash & Phosphate Institute of Atlanta, GA, recommended 0.9 kilogram (one-half pound) of boron for every ton of expected yield of alfalfa in the spring 1992 Agi-Briefs. The brief recommended that micronutrient levels in the soil be monitored by soil testing. The Tennessee Valley Authority published Commercial Fertilizer 1993 that list total boron compounds consumed as secondary and micronutrients by region in the United States for 1992 and 1993 as 14,666 and 16,350 metric tons, respectively.

A growing and important use of zinc borate, ammonium pentaborate, and boric oxide is as fire retardants in the cellulosic materials such as chipboard, cellulose insulation, and cotton mattresses. Zinc borate is of commercial importance in synthetic polymers.

Boron compounds also were 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.

Neodymium-iron-boron alloys used in magnets are produced commercially by melt spinning and sintering. In melt spinning, molten alloy is ejected onto a rotating disk where a ribbon 30 to 50 micrometers thick and 1 to 3 millimeters wide of solid material "spins" off the disk. The process is conducted in an inert atmosphere. In the sintered process, the alloy powder is oriented in a magnetic field, pressed, and sintered. The ingots of the alloy are crushed, milled, and pulverized to a powder of about 3 micrometers in diameter. The alloys of the nonmetal boron and the metals neodymium and iron produces the strongest magnetic material known. The magnets then are used in automotive direct-current motors, computer disk drives, portable power tools, and home appliances.[13]

Boron also is used as a bleaching agent in detergents and cleaning products, such as compact washing powders. Perborates carry active oxygen that forms hydrogen peroxide in solution. Perborate tetrahydrate has been displaced by perborate monohydrate, which is more soluble in cool laundry wash temperature conditions. In the United States, two companies now produce a low-temperature activate perborate bleach.

Recycling

Research attempts have been made at recycling fiber-reinforced plastics, but at present it is not economical. Canada's Enviromental Ministry funded in 1992 a recycling plant reportedly to be the first of its kind in North America. The facility will create new raw materials from old fiberglass boat hulls, bathtubs, and auto parts by separating the glass fibers from the resins.

Prices

Prices for Turkish colemanite and ulexite increase slightly. The price for high-purity boric acid decreased 52%. All other reported prices remained the same. *(See table 5.)*

Foreign Trade

The majority of material from the Borax facility in Boron was shipped to storage, loading, and shipping facilities at Wilmington, CA. A large part of the output was exported to Western Europe from Wilmington to Botlek, Netherlands.

Imports of Turkish colemanite ore totaled 81,650 tons, primarily destined for Owens-Corning Fiberglass, Toledo, OH, through a port in Moreheady City, NC. Carolina Shipping of Charleston, SC, also imported two shiploads through the port of Charleston.

Colemanite exports totaled 16,597 tons. American Borate, Virginia Beach, VA, shipped 8,487 tons of that amount to Keelung and Kaohsiung, China. A company named ITC Inc., Balitmore, MD, shipped 3,146 tons to the Republic of Korea and 887 tons to Hong Kong. American Borate also shipped 2,268 tons to Australia and 1,052 tons to the Republic of South Africa.

Imports of Turkish ulexite ore totaled 135,071 tons, primarily destined for Owens-Corning Fiberglass through the port at Morehead City, NC. A small amount of ulextie from Chile was imported by F & S Alloys & Minerals Corp., New York, NY, through the port of Houston, TX. *(See tables 6 and 7.)*

World Review

Argentina.—The Argentina Mining Plan was announced. The plan changed the collection of taxes to encourage foreign investment. FMC Corp. will begin development of a lithium and boron production facility at the Salar del Hombre Muerto in the northern region because of the new mining plan. FMC plans to utilize new extraction technologies for the brine that will be developed from the salar.

Boroquimica SA continued production of tincal from the Salar del Hombre Muerto and boric acid from Tincalayu in Salta Province. Tincal between 16% and 18% boron oxide is concentrated by washing and crystallizing to a 99.9% borax product. At Sijes in Salta Province, hydroboracite and colemanite are produced. Ulexite is produced by Boroquimica at Cauchari in Jujuy Province and at Diablillos in Salta Province.[14]

Bolivia.—During March 1992, Boron International Inc. entered into an agreement with Teck Corp. to finance an $8 million expansion at Capina for the production of 60,000 tons per year of calcium borate manufactured from ulexite. Current mining in the area of 30,000 tons annually resulted in 8,000 tons of ulexite (40% boron oxide), 4,000 tons of boric acid, and 1,500 tons per year of sodium octaborate.[15]

Compania Minera Tierra Ltd., a small company formed in 1988 for producing borates in an area of the Department of Potosi, has important concessions of ulexite and sulfur near the Chilean border in the southwestern tip of the country. About 120,000 tons per year of ulexite is exported to Brazil and other neighboring countries. In 1990, the company employed 120 persons. In 1993, a boric acid plant was operational and producing 10,000 tons per year.

The company has interest in ulexite mineral concessions that cover an area of 4,800 hectares, and reserves have been estimated by the company to exceed 13 million tons of raw ulexite with grades ranging from 20% to 37%. Ulexite is extracted and dried by plowing with a tractor. The dried ulexite is washed and roasted. The processed ulexite of about 42% borate content is bagged and exported by trucks and rail.

Various borate deposits are in the southwestern part of the Altiplano. Llipi Llipi, in the south of Salar de Uyuni, contains an estimated 12 million tons of ulexite. Copla Ltda. was mining ulexite for export. Production of ulexite in 1989 was 9,609 tons.[16]

The Salar de Uyuni is the largest salt flat in the Central Andes salt basin. The flat is composed of lithium, potassium, and boron salts in the form of brines. In 1988, the Ministry of Mines and Metallurgy and the Complejo Industrial de los Recursos Evaporiticos del Salar de Uyuni (Ciresu) began negotiation with Lithium Corp. of America (LITHCO), a subsidiary of FMC. FMC announced on January 15, 1993, to the Ministry that it was ending plans to explore and develop the brine of the Salar de Uyuni.[17]

Chile.—New legislation in 1992 allowed Corporación Nacional del Cobre de Chile (Codelco) to associate with private national and international firms for exploration and development. State-owned Empresa Nacional de Minería (ENAMI) will be given some smaller prospects at yearend.

Boratom Quimica Processes Ltda. had operated in Chile since 1986 by providing technology and sales support to producers. In 1986, Boratom shipped 3,000 tons of ulexite to the United States in connection with Borichem Inc. The ulexite mines are in the I and II Regions of Chile. Boratom operates a refining plant near Iquique. In March 1992, Boratom's assets and technology were sold to Boron International Inc. (Canada). In November, Boron entered into an agreement with Teck Corp. called Boron Chemicals Processes Chile S.A.[18]

Quimica & Industrial del Borax (Quiborax) was the main producer of boric acid and concentrated ulexite. The second stage of an expansion was completed in 1992. Included in the expansion were about 70,000 square meters of evaporation ponds, a ulexite washing plant, a water purification osmosis plant, and a boric acid plant. Quiborax operated a mine at Surire, Parindacta, with a crude annual output of 1,000,000 tons per year of ulexite. The ulexite is washed and upgraded from 30% to 40% boron oxide by centrifugal action and flotation prior to filtration. Calcium borate is produced by adding calcium hydroxide to the washed ulexite.[19] Beginning in 1993, the boric acid production was estimated to be 20,000 tons and calcium borate production was expected to be 20,000 tons. The plant facilities are at El Aguila, Arica.[20]

The National Boraxx Corp. (Cleveland, OH) packages and distributes boric acid in the United States for Quimica E Industrial del Borax Ltda. (Quiborax Ltda.).[21]

Compania Minera Salar de Atacama (Minsal) is a joint-venture project between AMAX Inc. of the United States, Molibdenos Y Metales (Molymet) of Chile, and Corporacian de Fomento de la Produccion (CORFO). CORFO established the joint venture as a result of an international public licitation in 1986, in which LITHCO was the only other bidder. The project was designed to produce lithium carbonate, potassium chloride, potassium sulfate, and boric acid from the Salar de Atacama in the II Region. Future production was expected to be 26,000 tons of boric acid per year. In February 1991, the project was placed on hold for a second year, under the terms of AMAX's original contract. Sociedad Quimica y Minera del Chile (SQM) acquired the 63.75% stake held by AMAX. Plans were to limit the production to about 300,000 tons per year of potassium chloride and possibly lithium. SQM indicated a target date of mid-1995 for production.[22]

China.—The borates in the salt lakes of China are mainly found on the Qinghai-Xizang (Tibet) Plateau. Boron is distributed in many saline lakes from the southern side of the Gilian Mountains to the north side of the Gangdisi-Tanggula Mountains.

In Liaoning Province, 700,000 tons of ore was mined in 1991. Other provinces where borax was reported were Beijing, Hebei, Heilongjiang, Jilin, Qinghai, Shaanxi, and Tianjin.[23]

France.—An agreement between Callery Chemical Co. and the French Sipsy division of Jouveinal was finalized to develop and produce chemical reagents. Callery is a producer of borane reagents.[24]

Iran.—At Deh-e-Shotoran near Sirjan, the region is of tourmaline-rich granites that have invaded metamorphosed sandstones. Ulexite is found in depressions. At Tonkar near Sabzevar, there are several sources of borates in consolidated sediments of thin beds of limestone, marl, and clays. Ulexite also occurs close to the village of Ashin near Anarak.[25]

Italy.—In 1992, EniChem, part of Ente Nazionale Idrocarburi SpA (ENI), the state-owned petroleum company, announced a plan that provides for the sale of nonstrategic operations in the core business of chemicals, oil, and gas. In 1992, negotiations began on the sale of Societa Chimica Larderello (SCL), Tuscany, a producer of ultrahigh-purity boric acid and other boron compounds. The sale was finalized in 1993 when SCL became part of the Harris European affiliates of the D. George Harris & Associates holding company. High-purity boric acid produced at Larderello was marketed in the United States by EniChem Americas Inc. SCL exported about 50% of production to more than 30 countries worldwide, primarily for use in ceramics, borosilicate glasses, for the production of fluoborates, and other boron compounds. The company was founded in 1818 and extracted boric acid from geothermal sources. These fumaroles now supply electrical energy and chemicals, such as carbon dioxide and ammonia, to the plant. The first chemical plant in Italy to produce boric acid from imported colemanite ores was built in 1963 with a capacity of 11,000 tons per year. A newer plant was built in 1981 with a capacity of 66,000 tons per year of refined boric acid and approximately 16,500 tons per year of high-purity sodium borate pentahydrate, decahydrate, and other boron specialties. In 1984, SCL developed Boric Acid NS 99.99% (nuclear grade), which is marketed to nuclear power companies because it exceeds PD Specifications 52205 AP Revision F. No. 79500 for use in powerplant applications.

Mexico.—The 1992 Mining Law eliminated the National Mining Reserves and released more than 3 million hectares into the public lands that are now concessionable by mining companies. Foreign companies can invest and participate in exploration and exploitation of governmental concessionable mineral deposits through investment trusts with 100% ownership. Without the investment trust, a foreign investor is limited to 49% ownership.

Metamin Enterprises Inc., with the support of Dauntless Developments, has terminated two claims, Carlos and Carlos Uno, in the Tubutama evaporite basin. The claims, covering beds of colemanite and gypsum, are about 31 kilometers south of the U.S. border in the State of Sonora. Work by the Government organization Consejo de Recursos Minerales identified a reserve of all classes of about 30 million tons grading 8.33% boron oxide. The 160-hectare area covered by the Carlos claims has a potential for an open pit colemanite deposit of up to 40 million tons. The mineralization occurs as beds of colemanite and possibly howlite, with clay and silt bands, and gypsum and celestite beds. Chemical analysis indicates very low values of arsenic between 2 and 7 parts per million. Mining costs were expected to be less than $5 per ton.[26]

U.S. Borax continued as a partner with Vitro Corp. for the Magdelena colemanite deposit. The processing development work had been halted because of high arsenic content in the ore that was difficult to remove. Vitro was in the process of selling U.S. Borax's ownership in the deposit.

U.S. Borax acquired claims to the Tubutama colemanite reserve, which surrounded the Carlos claims of Ainsworth Jenkins, when the Government eliminated the National Mining Reserves in 1992.[27]

Netherlands.—Morton International planned to transfer sodium hydride manufacturing operations from Beverley, MA, to Delfzijl where Morton now produces sodium borohydride. When the plant is completed in 1994, Morton planned to stop production in the United States and supply that market from the Delfzijl plant.[28]

The Silenka glass fiber factory in Hoogezand, northern Holland, was founded in 1961 as a joint venture between PPG and Akzo. The state-owned Development Co. for the Northern Netherlands assisted by purchasing a 30% share in 1977 when the company was struggling because of rising energy costs. PPG purchased the remaining shares in 1990 and renamed the site PPG Industries Fiber Glass bv. PPG is the second biggest fiberglass manufacturer in Western Europe.

Peru.—The quantity and number of minerals produced in Peru and the likelihood of significant deposits to be discovered attracted attention to the privatization plants. The Government continued its privatization program to reactivate the entire mining sector selling many properties at prices below comparable resources in the international market. Boron continued to be produced in Arequipa by Compania Minera Ubinas S.A. A total of 34 metric tons of sodium borate and sodium calcium borates was imported by Fertilizer Corp. of America into Miami, FL, and Wilmington, NC.

Russia.—Primorsky Industrial Amalagmation, in Dalnegorsk, produces boron minerals from datolite containing 20% boron oxide. Amalgamation is part of the Russian Agricultural Joint Stock Co. known as ROSAGROCHIM. ROSAGROCHIM coordinates the activities of about 100 companies.

Boron minerals also were reported to be produced in Kazakhstan, the second largest newly independent republic of the former U.S.S.R. The Government was actively pursuing foreign investment to increase production capacity by improving efficiency to increase exports.[29]

Turkey.—Turkey's boron operations are under the control of the Government corporation Etibank. Colemanite is mined at Bigadic, Emet, and Kestelek; tincal at Kirka; and ulexite at Bigadic. Etibank was reported to have an ore production capacity of 8,000 tons of colemanite, 500,000 tons of tincal, and 115,000 tons of ulexite. Etibank operates refining facilities to produce refined sodium borates and boric acid from tincal concentrates at Bandirma and Kirka. Boron minerals and compounds are shipped from the Port of Bandirma on the Sea of Marmara and Izmir on the Aegean Sea. Bandirma can produce 55,000 tons of borax, 35,000 tons of boric acid, and 20,000 tons of sodium perborate per year. Kirka can produce 50,000 tons of borax, 160,000 tons of pentahydrate borax, and 50,000 tons of anhydrous borax per year.[30]

The Government announced that Etibank would become two separate divisions as a prelude to privatization of the banking business. Sixty days after the July 13 announcement, the two divisions became affiliated companies and the process will begin for privatization of the banking division.

The Turkish Government now owns all boron and trona minerals, and private concessions of these minerals could not be sold to private investors. Boron is a profitable operation for Etibank and the privatization of this sector is unlikely.[31]

United Kingdom.—Borax Consolidated, a subsidiary of RTZ Corp., was building a 5,580-square-meter (60,000-square-foot) technical center at the University of Surrey Research Park, near Guildford. The move will involve a total of 120 people from the research, technical, and development functions and the technical marketing operations.[32]

Imperial Chemical Industires Plc planned to close the 38,000 tons per year Sodium perborate plant at Runconrn at yearend. The remaining sodium perborate capacity will be supplied by German producer Degussa A.G. and Netherlands producer Interox S.A. with 285,000 and 240,000 tons per year of capacity, respectively.[33]

Current Research

The use of oxygen-fuel firing of glass melting furnaces has been in use for several decades. Sixteen States have one oxy-fuel conversion and some States have several conversion plants. Twenty-one plants using borosilicate glass have converted to oxy-fuel—9 were fiberglass and 12 were lighting, tableware, and television conversions. Both types of conversions were designed to limit particulate matter. Advancements in technology and the need to reduce air emissions have been an added incentive to the conversions. Glass melting will be affected by titles I, II, and V of the Federal Clean Air Act Amendment of 1990 (CAAA). Oxy-fuel conversions are a way to decrease capital expenditures for post-treatment systems such as electrostatic precipitators or bag houses required under title I of the CAAA.[34]

A group of research chemists developed a triply bonding silicon using a borate anion that offers new synthesis routes for certain types of silicones. The silicon cation already has been used to catalyze the formation of silicones of commercial importance. A boron compound was chosen as the anion for the tricoordinate silicon because it is stable in toluene and does not react with silicon cations.[35]

A typical glass wool formation uses

5% boron oxide. Virtually any borate can be used for the boron oxide source, although refined pentahydrate borax is preferred. Studies reinforced the uniqueness of boron oxide in improving glass durability and assisting melting in fiberglass formation by reducing the viscosity-related temperature. Increasing the alumina content increased the aqueous durability of glass wool. Increasing sodium oxide greatly reduces the durability. Other alkali oxides have small positive or negative effects.[36]

A new automated instrument is able to decrease the time needed to separate sugars using a sodium cyanoborohydride solution. Previous separations took weeks or months using mass and nuclear magnetic resonance. The new instrument can have a "fingerprint" of the glycoproteins (proteins bonded to carbohydrates) in 48 hours that can be used in research on many biochemical functions such as cell interaction with hormones, antibodies, and other cells.[37]

Two independent research teams have verified superconductivity for the first time in quaternary intermetallic compounds. The new compounds have the potential for better superconducting wires than the niobium compounds now in use. Both mixtures consist of four elements that are both metals and nonmetals. The two new compounds are mixture of yttrium-nickel-boride carbide and yttrium-palladium-boride carbide.[38]

Adding boron to polymers can transform low-cost polymers to material that rival engineering plastics such as polycarbonate. Normally, polyolefins do not adhear to carbon and glass fibers. The addition of boron can yield polyolefins that cling without interferring with the production of the raw material or the processing of the polymer into finished products.[39]

Studies on the effect of boron content for the mass manufacture of rectangular pipes for the storage of spent nuclear fuel resulted in the manufacture of a 19%Cr-8%NI-0.6%B steel. Hot workability of steel decreases with increasing boron content after 0.76% mass percent but is improved by forging. The decrease in hot workability with increasing boron content is due to precipitates of iron and chrome borides.[40]

OUTLOOK

Production of boron minerals and compounds have decreased between 1983 and 1993. One reason is that production and imports reported in 1 year may be utilized over a period of years. In addition, environmental concerns may change the demand for boron significantly in a short period. The regulation of fire retardants in products has resulted in changes in boron usage as a fire retardant. More recent decreases in domestic consumption have been attributed to decreases in glass consumption because of less demand resulting from a recession. Moreover, one-half of domestic production is exported. Because of increases in production in other coutries, this amount has decreased significantly during the past few years.

Agriculture

Boron usage in agriculture increased significantly in 1993. The primary reason was attributed to the decline in the number of farms during the same time period. Farming exports are showing increased strength, and demand for boron usage in agriculture increased during 1993.

Ceramics and Glass

Reported consumption of boron minerals in glass and ceramic uses was 211,656 tons of boron oxide content representing 60% of total demand consumed. This was down from the 214,411 tons representing 62% of total demand consumed in 1992. Ceramics and glass both have faced competition with polymers. The U.S. fiberglass industry was reported to be feeling the effects of recessionary pressures. The sagging economy produced a decline in demand for fiberglass reinforcements. Fiberglass is closely related to construction and transportation.

Coatings and Plating

Primarily used as a protective coating for steel products and as a glazing on ceramic tiles, boron usage increased 37% during the year.

Fabricated Metal Products

Boron usage decreased in metal products during the year. Many traditional metal products that require soldering now are produced from polymers as one piece. Usage in specialized metal was expected to increase.

Soaps and Detergents

This usage declined primarily as chlorine bleaches and cold water washes replace boron soap powders. Recent concern for environmental effects of chlorine has reversed the decline. Perborate bleaches have returned to name brand soap products. The usage of boron in soaps and bleaches was expected to increase by 4% per year during the next 5 years.

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TABLE 1

SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[1]	1,114	1,094	1,240	1,009	1,055
Boron oxide (B_2O_3) content	562	608	626	554	574
Value	$429,806	$436,175	$442,532	$338,700	$372,839
Exports:					
Boric acid:[2]					
Quantity	42	39	47	80	74
Value	$32,613	$31,679	$35,457	$53,652	$50,498
Sodium borates:					
Quantity	[3]646	[3]585	[4]554	[4]489	[4]481
Value	[e]$361,000	[e]$208,433	[e]$205,722	[4]$159,492	[4]$181,310
Imports for consumption:[4]					
Borax:					
Quantity	7	5	10	16	40
Value	$2,114	$1,570	$3,260	$5,328	$1,226
Boric acid:					
Quantity	3	6	5	6	17
Value	$2,197	$3,921	$3,784	$4,337	$11,910
Colemanite:					
Quantity	15	12	18	30	90
Value	$4,202	$3,310	$4,389	[r]$16,050	$48,600
Ulexite:					
Quantity	27	29	16	42	149
Value	$5,940	$7,360	$4,060	[r]$11,340	$40,677
Consumption: Boron oxide (B_2O_3) content	315	319	262	345	354
World: Production	[r]2,993	[r]2,886	[r]2,865	[r]2,660	[e]2,178

[e] Estimated. [r] Revised.

[1] Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

[2] Includes orthoboric and anhydrous boric acid.

[3] Source: The Journal of Commerce Port Import/Export Reporting Service.

[4] Source: Bureau of the Census.

TABLE 2

BORON MINERALS OF COMMERCIAL IMPORTANCE[1]

Mineral	Chemical composition	B_2O_3 weight percent
Boracite (stassfurite)	$Mg_6B_{14}O_{26}Cl_2$	62.2
Colemanite	$Ca_2B_6O_{11} \bullet 5H_2O$	50.8
Hydroboracite	$CaMgB_6O_{11} \bullet 6H_2O$	50.5
Kernite (rasortie)	$Na_2B_4O_7 \bullet 4H_2O$	51.0
Priceite (pandermite)	$CaB_{10}O_{19} \bullet 7H_2O$	49.8
Probertite (kramerite)	$NaCaB_3O_9 \bullet 5H_2O$	49.6
Sassolite (natural boric acid)	H_3BO_3	56.3
Szaibelyite (ascharite)	$MgBO_2(OH)$	41.4
Tincal (natural borax)	$Na_2B_4O_7 \bullet 10H_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O \bullet 5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9 \bullet 8H_2O$	43.0

[1] Parentheses include common names.

TABLE 3

U.S. CONSUMPTION OF BORON MINERALS AND COMPOUNDS, BY END USE

(Metric tons of boron oxide content)[1]

End use	1992	1993
Agriculture	9,186	16,261
Borosilicate glasses	29,288	38,488
Enamels, frits, glazes	8,230	11,302
Fire retardants:		
Cellulosic insulation	9,451	10,657
Other	1,394	1,421
Insulation-grade glass fibers	124,950	117,035
Metallurgy	2,624	2,058
Miscellaneous uses	23,130	35,951
Nuclear applications	455	9,775
Soaps and detergents	38,460	15,237
Sold to distributors, end use unknown	37,575	41,026
Textile-grade glass fibers	60,173	56,133
Total	344,916	355,344

[1] Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4
U.S. CONSUMPTION OF ORTHOBORIC ACID,[1] BY END USE

(Metric tons of boron oxide content)

End use	1992	1993
Agriculture	497	533
Borosilicate glasses	2,704	14,919
Enamels, frits, glazes	2,477	3,157
Fire retardants:		
Cellulosic insulation	1,506	1,944
Other	1,349	1,420
Insulation-grade glass fibers	2,758	—
Metallurgy	154	241
Miscellaneous uses	12,760	12,343
Nuclear applications	454	9,759
Soaps and detergents	79	1,718
Sold to distributors, end use unknown	13,133	15,071
Textile-grade glass fibers	18,625	8,258
Total	56,496	69,363

[1] Includes imports.

TABLE 5
YEAREND 1993 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON[1]

Product	Price, Dec. 31, 1992 (rounded dollars)[2]	Price, Dec. 31, 1993 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works[3]	626- 633	626- 633
Borax, technical, anhydrous, 99%, bags, carload, works[3]	689	689
Borax, technical, granular, decahydrate, 99%, bags, carload, works[3]	259- 367	259- 367
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works[3]	218	218
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works[3]	291- 346	291- 346
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works[3]	250	250
Boric acid, technical, granular, 99.9%, bags, carload, works[3]	664- 671	664- 671
Boric acid, technical, granular, 99.9%, bulk, carload, works[3]	623	623
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B_2O_3, 100-pound bags, carlots	2,345	1,125
Colemanite, Turkish, 42% B_2O_3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC[4]	535	540
Ulexite, Turkish, 38% B_2O_3, ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA[4]	270	273

[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] Figures revised to reflect metric tons.

[3] Chemical Marketing Reporter. V. 242, No. 26, Dec. 1992, p. 23; v. 245, No. 1, Dec. 1993, p. 24.

[4] American Borates Co.

TABLE 6

U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY

Country	1992			1993		
	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	1,110	$704	7,818	1,235	$997	7,153
Belgium	1,267	427	104	—	—	3,665
Brazil	251	178	896	2,013	784	509
Canada	5,295	3,277	29,199	5,504	3,616	33,182
China	34	32	864	34	23	896
Colombia	170	148	565	115	103	2,843
Costa Rica	32	16	688	63	31	88
Dominican Republic	26	12	2	—	—	9
Ecuador	—	—	1,172	—	—	864
Egypt	—	—	54	—	—	1
El Salvador	—	—	—	6	7	23
France	2,293	906	15	313	438	40
Germany	63	63	100	27	11	52
Guatemala	—	—	2,358	4	3	47
Honduras	—	—	10	9	9	20
Hong Kong	828	511	3,195	871	485	2,607
India	—	—	—	—	—	5,224
Indonesia	2,606	1,374	6,541	2,598	1,679	7,587
Israel	61	56	401	61	54	243
Jamaica	—	—	8	—	—	—
Japan	26,243	20,120	28,689	22,309	18,202	25,926
Korea, Republic of	8,571	4,778	13,971	9,701	6,148	14,734
Malaysia	2,837	1,396	7,319	1,993	972	4,920
Mexico	4,378	3,180	28,676	3,898	2,691	25,613
Netherlands	4,269	4,457	292,149	3,135	3,077	257,027
New Zealand	441	268	2,570	275	171	2,968
Pakistan	368	212	—	240	121	—
Panama	1	4	34	1	4	—
Papua New Guinea	—	—	16	—	—	32
Peru	—	—	—	—	—	259
Philippines	2,722	1,036	48	2,507	561	1,294
Saudi Arabia	9	14	1,216	—	—	—
Singapore	2,030	1,428	955	1,325	641	2,194
South Africa, Republic of	58	49	379	92	94	321
Spain	—	—	41,743	2,406	1,172	54,445
Taiwan	11,453	7,535	10,653	10,753	6,367	9,594
Thailand	1,444	974	4,005	1,764	1,251	5,043
United Kingdom	65	76	673	243	206	9,313
Uruguay	—	—	—	64	20	1
Venezuela	656	421	1,177	810	497	1,308
Zimbabwe	—	—	44	98	63	92
Other	—	—	816	—	—	787
Total	79,581	53,652	489,123	74,467	50,498	480,924

[1] HTS code No. 2440.11.0000.

[2] HTS code Nos. 2840.19.0000, 2840.30.0000, and 2840.20.0000.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Belgium	1	$3	—	—
Bolivia	—	—	318	$137
Canada	40	25	64	56
Chile	2,310	1,086	5,173	3,403
China	—	—	17	12
France	1	1	4	11
Germany	7	7	34	40
Italy	3,587	2,762	9,353	6,903
Japan	84	193	159	212
Netherlands	12	19	205	134
Norway	—	—	1	3
Russia	—	—	235	298
Switzerland	—	—	11	8
Taiwan	—	—	4	3
Turkey	300	158	1,000	473
United Kingdom	72	83	167	217
Total	6,414	4,337	16,745	11,910

[1] U.S. Customs declared values.

Source: Bureau of the Census.

TABLE 8
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Argentina	261	[r]123	[r]113	[r]143	143
Bolivia (ulexite)	10	3	14	[r]23	11
Chile (ulexite)	131	132	97	[r]203	100
China[e][2]	74	75	[r]93	[r]95	100
Germany (borax)[e]	4	4	3	2	2
Iran (borax)[3]	(4)	2	1	[r](4)	1
Kazakhstan	—	—	—	[e]100	90
Peru	25	20	26	[r]27	27
Turkey[5]	[r]1,175	1,253	[r]1,117	[r]1,059	650
U.S.S.R.[e][6]	200	180	160	[r]—	—
United States[7]	1,114	1,094	1,240	1,009	[8]1,055
Total[9]	[r]2,993	[r]2,886	[r]2,865	[r]2,660	2,178

[e] Estimated. [r] Revised.

[1] Table includes data available through May 25, 1994.

[2] B_2O_3 equivalent.

[3] Data are for years beginning Mar. 21 of that stated.

[4] Less than 1/2 unit.

[5] Concentrates from ore.

[6] Dissolved in Dec. 1991.

[7] Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

[8] Reported figure.

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

BROMINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for bromine for 15 years. Domestic survey data were prepared by Gail Mason, statistical assistant; and international data tables were prepared by Jeremy Tidwell, international data assistant.

Production of bromine worldwide in 1993 was as follows: United States, 45%; Israel, 34%; the United Kingdom, 7%; and other countries, 14%. The U.S. portion of world production has decreased steadily since 1973, when the United States produced 71% of the world supply. The decrease in world share has been a result of environmental constraints and the emergence of Israel as the world's second largest producer. Domestic capacity decreased 14% during the same period of time. The quantity of bromine sold or used in the United States was 177 million kilograms (kg) valued at $123 million. The value of bromine sold or used was 69 cents per kg. Primary uses of bromine compounds were in flame retardants (27%), agriculture (16%), water treatment and sanitizing (15%), petroleum additives (12%), well drilling fluids (10%), dyes and photographic (10%), pharmaceutical (6%), and other (4%).[1]

DOMESTIC DATA COVERAGE

Domestic production data for bromine were developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the six operations to which a survey request was sent, six responded, representing 100% of total elemental bromine sold or used. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

In the elemental form, bromine is a very dark, reddish-brown liquid. Bromine is the only nonmetallic element that is liquid at ordinary temperature and pressure. The natural form of bromine is a solution of sodium bromide in natural brines, saline deposits, salt lakes and seas, and oceans.

Elemental bromine is marketed in a "purified" grade with the following specifications: Specific gravity not less than 3.1 at 10° to 20° C; bromine, not less than 99.7%; iodine, none; and chlorine, not more than 0.1%.

Specifications for the various grades of bromine compounds include technical bromine, 99.5% pure, with the chief impurities consisting of chlorine, traces of moisture, and organic matter. Specifications of the United States Pharmacopoeia and the American Chemical Society Committee on Analytical Reagents allow 0.3% chlorine, 0.05% iodine, 0.0002% sulfur (0.006% as sulfate), and no more organic matter in 1 milliliter than will saturate 50 milliliters of 5% sodium hydroxide solution. The term "chemically pure" signifies a minimum of impurities.

Geology-Resources

Bromine is widely distributed in the Earth's crust, but in small quantities. By far the largest potential source of bromine in the world exists in the oceans. At a concentration of only 65 parts per million (ppm), large amounts of seawater are processed to obtain the bromine.

Arkansas brines contain about 5,000 ppm at depths of 2,591 meters (8,500 feet) in limestone of the Smackover Formation of Jurassic age. In Michigan, brines containing about 2,600 ppm of bromine occur in the Sylvania Sandstone Formation of the Detroit River Group of Devonian age.

In Israel, bromine is produced as a byproduct of salt, sodium chloride, and potash production from the Dead Sea. The waste brines contain 14,000 ppm bromine.

Technology

Processing.—The Arkansas Geological Commission reports three east-west bromine-rich brine fields. Wells are drilled down to the brine level, and a submersible pump is lowered to pump the liquid to the surface. Brine is separated by gravity from any residual gas at the surface and pumped to one of six processing facilities.

At the processing facility, bromine is separated from the brine by a steaming-out process. The brine is pumped into the top of a tower constructed of granite and filled with ceramic packing. As the brine falls through the packing material, it reacts with chlorine and steam that are injected at the bottom of the tower. One pound of chlorine yields 1 kg of bromine. About 95% of the bromine, or about 0.7 to 0.8 kg of bromine per barrel of brine, is recovered if the raw brine is first acidified to a pH of 3.5. The chlorine replaces the bromine in the brine, and the gaseous bromine rises with the steam out of the top of the tower; there it is condensed to a reddish-brown liquid. Bromine is separated from gases. The bromine liquid can be further purified or reacted with other materials to form bromine compounds. Bromine vapor, a little chlorine, and water vapor are captured at the top of the tower. Hot bromine-free liquor emerges from the bottom of the tower. After neutralizing with lime, the waste liquor is pumped through a heat exchanger to a waste pond. Brine from the pond is reinjected into the same producing zone to maintain hydrostatic pressure.

Seawater contains about 60 to 70 ppm of bromine as sodium bromide or magnesium bromide. Production of bromine from seawater uses the blowing-out process. Raw seawater is acidified by adding sulfuric acid and then chlorine. Air is drawn into the base of the tower and rises as the brine descends. Air containing bromine passes to the absorption tower. In the absorption tower, bromine reacts with sulfur dioxide to form a hydrogen bromide. The bromine is separated by adding acid to the solution and is distilled by steam. The gaseous bromine is condensed, separated, and purified.

Recycling.—Bromine containing waste from other processing is recycled into elemental bromine. The waste is reprocessed through the absorption towers to produce a high-quality elemental bromine. It was estimated that about 90 million kg of elemental bromine was produced by recycling during 1993.

The byproduct hydrogen bromide that arises from elemental brominations is not suitable for direct use as a feedstock when generated in streams that are too dilute or concentrated. Similar aqueous liquors can arise from the use of organic bromides as chemical building block intermediates, where the bromide is displaced by other functional groups.

These streams can generally be processed after essential cleanup for elemental bromine recovery in purpose-built units employing chlorine oxidation. Both Associated Octel Co. Ltd. in the United Kingdom and Great Lakes Chemical Corp. in the United States operate such bromide recovery units, serving local customers and their own internal demand.[2]

Byproducts and Coproducts

Some bromine-bearing brines contain hydrogen sulfide gas. This gas has a disagreeable odor, is highly toxic, and when burned, will oxidize to sulfur dioxide, an acid-producing gas. To prevent the emission of the gas to the atmosphere where sulfur dioxide may form, environmental regulations require the recovery of the sulfur. Hydrogen sulfide gas was chemically removed from the incoming brine and converted into elemental sulfur or other nontoxic sulfur-containing compounds. The cost of recovery was greater than the selling price of the sulfur, but recovery prevented emission of a gas that may contribute to the formation of acid rain. The hydrogen sulfide can be scrubbed with caustic soda to make sodium sulfite for low levels of hydrogen sulfide.

Aromatic bromination processes normally generate hydrogen bromide gas as a byproduct, which can often be used in the production of other derivatives. For instance, calcium bromide can be produced by adsorption of byproduct hydrogen bromide, primarily from flame retardant manufacture in aqueous slurries of lime.

The production of tetrabromobisphenol-A (TBBA) is produced by bromination of bisphenol A in aqueous methanol. The hydrogen bromide generated reacts in situ with methanol to provide methyl bromide as a byproduct, which can be used in agriculture.[3]

Substitutes

Various materials are used in flame retardants as replacements for bromine in engineering and high-performance thermoplastic polymers and blends, and polymeric composites. The distinguishing characteristic of engineering polymers is that they have properties that lend themselves to structural applications over a wide range of temperatures, high mechanical stress, and harsh chemical and physical environments. The high-performance polymers are also distinguished by their special properties such as extremely high-temperature tolerance and outstanding optical properties or conductivity, but they are not necessarily designed for structural integrity.[4]

The Federal Register for October 18, 1993, announced that the Halon Recycling Corp. is officially open for business after receiving a Business Review Clearance from the Department of Justice. The Defense Logistics Agency also is forming a reserve of ozone-depleting substances for mission-critical uses and is accepting recycled Halon 1301 from the public.

Three fluoride compounds were evaluated as candidates for Halon 1301 replacements. Perfluorobutane and perfluoropropane show significant promise for both new and retrofit applications. Small-scale cup burner tests have shown these compounds to be effective fire suppressants in the range of 6% to 8% volumetric concentrations. Technical data needed are the quantity and character of thermal decomposition products. Regulatory issues associated with these compounds include global warming potential.[5]

Economic Factors

Costs.—The cost of drilling and maintaining a bromine-producing well is estimated to be in excess of $1 million per well, with about 100 wells in operation. Chlorine, the largest manufacturing cost factor, represented about 30% of the manufacturing cost of bromine. Other cost factors include brine (22%), operating cost (15%), utilities (14%), overhead (12%), and other (7%).

Taxes.—During 1993, brines produced in Arkansas required the payment of $2 per 1,000 barrels in severance taxes, and capital equipment was subject to the payment of property taxes. Bromine produced in the United States was subject to Superfund taxes of $4.91 per metric ton ($4.45 per short ton). Bromine was manufactured using chlorine, which was subject to a Superfund tax of $2.98 per metric ton of chlorine ($2.70 per short ton).

Depletion Provisions.—Bromine producers (domestic and foreign) are granted a 5% depletion allowance under the Federal Income Tax Law on the value of bromine produced from brine wells.

The depletion allowance can be calculated by the actual cost method.

Operating Factors

Toxicity.—Bromine is highly toxic and corrosive and must not be allowed to escape into the atmosphere. Many bromine compounds are also poisonous or irritating and must be packaged in leakproof containers to avoid personal injury. If bromine spills on paper, rags, wood shaving, etc., it will generate considerable heat, which may lead to spontaneous combustion. Bromine reacts with living tissue and must be removed immediately to avoid serious injury.

Bromine vapors are hazardous to the eyes and lungs. Any concentration above 1 ppm in the air for an 8-hour exposure is considered a health hazard. Bromine can be detected by its odor even at this level. Exposure to concentrations of 500 to 1,000 ppm for as little as one-half hour is lethal. The Occupational Safety and Health Administration (OSHA) regulates the working conditions of bromine plants.

When handling bromine, a person should use safety goggles, a face shield, rubber gloves, rubber boots, and under some conditions, a self-contained breathing apparatus. Bromine spills are neutralized with a solution of sodium thiosulfate. Gaseous bromine is neutralized with controlled amounts of gaseous ammonia. All metal, such as electrical switches and connections, that may be exposed to bromine vapors should be made of corrosion-resistant materials and/or completely sealed from contact with the room air.

OSHA established a phase-in schedule that gives operators until 1996 to complete process-hazard analyses (OSHA 29 CFR 1910.119) for any operator who uses, stores, manufacturers, handles, or moves highly hazardous chemicals that include bromine, bromine chloride, bromine pentafluoride, bromine trifluoride, and propargyl bromide. The fines that apply to the new standard are the same as those specified by other OSHA safety regulations. A willful violation can result in a fine up to $70,000. A serious violation can result in a fine up to $7,000 per violation. A criminal violation can result in fines up to $250,000 to any responsible individuals and up to $500,000 against the corporation. Jail terms may be imposed for criminal violations.[6]

An Environmental Protection Agency (EPA) funded computer network began in May that would allow States to exchange technical and legal information about Superfund programs. Through a computer bulletin board, users would have access to four data bases: listing of more than 650 EPA policies and guidance documents; State Superfund program information; State settlement, including information on contaminants, technologies, costs, and timetables; and a record of State decisions.[7]

Employment.—During 1992 an estimated 1,600 employees were employed by the bromine industry in Arkansas. About 1,175 are employees of the companies and about 450 are contract workers.

Energy Requirements.—The manufacturing cost of bromine was heavily dependent on chlorine and brine cost. Of the total brine cost, 46% was power related and 53% was maintenance cost. Brine cost is dependent on well maintenance cost and energy cost associated with well pumping. Approximately 14% of the bromine manufacturing cost was energy related.

Transportation.—The Research and Special Programs Administration (RSPA), U.S. Department of Transportation, published rules for hazardous substances (49 CFR, parts 171 and 172). The action complies with a 1986 amendment (Public Law 99-499) to section 306(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (Public Law 96-510). The law mandates that RSPA regulate all EPA-designated hazardous substances. The amendment required shippers and carriers to identify CERCLA hazardous substances, to comply with the hazardous materials regulations (HMR), and to make the required notifications if a discharge of a hazardous substance occurs.

The Hazardous Material Transportation Act gives wide powers to the Department of Transportation (DOT). The DOT RSPA listed a final rule for performance-oriented packaging standards that included several bromine compounds under HMR (49 CFR, parts 173.193 and 228). The rule comprehensively revises the HMR with respect to hazard communication, classification, and packaging requirements. On January 1, 1991, the new DOT/United National Performance Oriented Packaging Standards (POPS) were phased into the current DOT HMR. On that date, compliance with domestic shipping was voluntary. However, shipping materials internationally or domestically by air or international waters must comply with the POPS regulations. POPS involves changes to every aspect of shipping activities, including selecting packages; preparing shipping documents; and labeling, marking, and placarding shipments of hazardous materials and waste.

The chemical and railroad industry reached a voluntary agreement through the Interindustry Rail Safety Task Force to transport 10 halogenated compounds, including ethylene dibromide (EDB), in sturdier tank cars. The Chemical Manufacturers Association, Association of American Railroads, and Railway Progress Institute agreed to the more stringent specifications. After the agreement was signed, the DOT proposed expanding the 10 substances to include the EPA's list of 100 toxic chemicals and making the tank car regulations more stringent, which would involve more costly construction than the voluntary agreement. The DOT will allow comments and study the proposal, and a decision whether to proceed with new standards for tank cars should be made by yearend 1995. Until DOT decides to proceed with new rulemaking, the Interindustry Rail Safety Task Force agreement will not be implemented because new standards may be promulgated by DOT that make the tank cars obsolete.[8]

ANNUAL REVIEW

Legislation and Government Programs

A notice of proposed rulemaking was published by the EPA in the Federal Register September 30, 1991, to conform its stratospheric ozone protection regulations (40 CFR, part 82) to the requirements of Title VI of the Clean Air Act Amendments of 1990 (Public Law 101-549). The notice proposes amended regulations implementing the 1992 and later requirements of section 604, as well as the related provisions of sections 603, 607, and 616, in a manner consistent with continuing U.S. obligations under the Montreal Protocol as amended.

The EPA proposed a Significant New Alternatives Policy (SNAP), which was required by the 1990 Clean Air Act Amendments. The list will have acceptable and unacceptable substitutes for ozone-depleting compounds. A range of factors, including ozone-depletion potential, air and water pollution issues, flammability, and worker and consumer safety, will be considered in determining acceptability as a substitute. Under SNAP, manufacturers or importers must notify EPA of the intent to sell, use, or distribute substitutes 90 days before introducing them into interstate commerce and provide EPA with health and safety studies. The list will be published in 1994.

On December 30, 1993, the EPA published in the Federal Register baseline production and consumption allowances for chemicals that were added to the list of class I ozone-depleting substances. These substances are methyl bromide and hydrobromofluorocarbons (HBFC's). EPA was establishing baseline production and consumption allowances for producers and importers of methyl bromide and HBFC's from data collected from companies that produced, imported, exported, and transformed or destroyed these substances in 1991. Baseline production allowances were as follows for methyl bromide: Great Lakes, 19,946 metric tons; and Ethyl Corp., 8,234 tons. Allowances for HBFC's was Great Lakes, 46 tons. Baseline consumption allowances for methyl bromide were as follows: Great Lakes, 15,515 tons; Ethyl, 6,380 tons, AmeriBrom Inc., 3,524 tons; and, TriCal Inc., 109 tons. Baseline consumption allowances for HBFC 22B1 was Great Lakes, 40 tons.[9]

A production freeze of methyl bromide at 1991 levels beginning on January 1, 1994, and usage as an agricultural fumigant for which no satisfactory substitute has been identified is to be phased out by 2000. The rule bans only production and importation of ozone-depleting chemicals, not their use.

The superior court in San Francisco refused to issue a temporary restraining order that would require a warning when crops are sprayed with methyl bromide. A State rule requiring a warning when houses are sprayed for termites took effect January 1, 1994.[10]

The United States asked the United Nations Environmental Program (UNEP) to exempt four uses of halons from the ban on the ozone-depleting chemicals' production that would be effective January 1, 1994. Under the Montreal Protocol on Substances that Deplete the Ozone Layer, countries may petition for the right to continue producing the fire suppressants for essential uses. Requests for exemption were forwarded from the nuclear power industry, the aerospace industry, and the oil companies for use in refinery control rooms and on older offshore drilling platforms.

Affirming a decision by the Ninth U.S. Circuit Court of Appeals, the Supreme Court ruled in February that Federal agencies must comply with a strict interpretation of the Delaney Clause's zero-risk standard. The EPA must change its policy on exemptions of cancer-causing pesticides, which included bromoxynil, a herbicide. Test have shown that the chemicals involved induce cancer in laboratory animals and are known to concentrate in processed food. The court said the Delaney amendment to the 1958 Food, Drug & Cosmetic Act gives EPA no discretion to allow pesticide residues in processed foods at levels greater than those allowed in raw food, if the pesticide has been found to induce cancer in animals.[11]

Production

Ethyl Corp. and Great Lakes Chemical Corp. produced and marketed bromine chemicals from plants in Arkansas. Small amounts of unpurified bromine were produced in Michigan as a byproduct in the extraction of magnesium from brine and reprocessed for consumption in Arkansas. The Arkansas plants accounted for 97% of U.S. elemental bromine capacity at yearend 1993 and 100% of bromine sold or used.

At yearend 1993, Ethyl Corp., of Richmond, VA, acting on the approval of a committee of outside directors, announced plans to form a publicly traded specialty chemicals segment with the Gottwald family, holders of 18% of Ethyl's stock, taking a major share in the new company. The new company will focus on the chemicals business and make it more competitive on the world market. An early retirement and work force reduction that affected 155 salaried employees, or about 10% of employees, at certain locations was a result of the formation of the new company. The employees were located at the Richmond headquarters and operations in Baton Rouge, LA.[12] Earlier, Ethyl completed the separation of First Colony Corp. in the form of a tax-free dividend stock.

Consumption and Uses

Methyl bromide is a broad spectrum pesticide that is widely used as fumigant in the control of insects, nematodes, weeds, pathogens, and rodentia. Worldwide it is primarily utilized for soil fumigation (80%), commodity and quarantine treatment (15%), and structural fumigation (5%).[13] Regulation requires that methyl bromide be used for fumigation of imported produce. About three-quarters of the 29,000 tons consumed domestically is for soil application. In colder climates, the onset of winter controls pests and diseases. But in California and Florida, where it is relatively warm year round, farmers fumigate the soil to kill insects, weeds, fungi, nematodes, and other organisms that attack roots of seedlings.

Fire retardants were primarily and

TBBA and decabromodiphenyl oxide (DBPO). Great Lakes expanded TBBA production capacity at its El Dorado, AR, facility to meet growing demand as a flame retardant for acrylonitrile-butadiene-styrene (ABS) polymers. The expansion increased Great Lakes' capacity by 25%. The U.S. International Trade Commission (USITC) publication entitled "Synthetic Organic Chemical, 1993" (SOC) listed Ethyl and Great Lakes as the only producers of TBBA.

TBBA is the largest volume brominated flame retardant. Its primary markets are epoxy circuit boards, ABS, and polycarbonates. DBPO is the second largest volume brominated flame retardant. Its primary markets are in television cabinets, video cassette recorder housings, wire, cable, and textile coatings. Tetrabromophthalic anhydride (TBPA) is used as a reactive flame retardant in unsaturated polyester resins. It also is used as an intermediate to make other flame retardants, which are used in polyolefin and polyvinyl chloride wire and cable coatings, rigid polyurethane foam insulation, and fabric and wood treatments. Brominated fire extinguishers are used to protect closed spaces, such as computer rooms, and in portable fire extinguishers. Ethyl and Great Lakes are primary suppliers to the domestic market.

Bromine combinations with antimony pentoxide were marketed with hydrobromic or hydrochloric acid to form volatile compounds that terminate combustion reactions and extinguish flames. Compounds with 32% bromine are used in textile coatings, spray-bonded nonwovens, adhesives, and fibers.[14]

The first commercial brominated aromatic phosphate ester flame retardant for use in polymers contained 60% bromine and 4% phosphorus. The flame retardants can be used in engineering thermoplastics, including polycarbonated, polybutylene terephthalate, and polyethylene terephthalate.[15]

USITC publication SOC listed Ethyl Corp. as the only producer of hexabromocyclododecane and Great Lakes as the only producer of hexabromocyclodecane. Sales of flame retardants account for one-half of the worldwide plastic additives market and are growing. Brominated hydrocarbons are the major materials used to make flame retardants. Demand for EDB is in gasoline additives as a scavenger for lead antiknock. The USITC's SOC listed Great Lakes and Ethyl as the only producers of EDB used in gasoline additives. Bromine was used in clear brine drilling fluids used in workover and completion fluids and other uses. Great Lakes's wholly owned subsidiary, OSCA, Inc., entered into a joint venture with M-I Drilling Fluids Co., a division of Dresser Industries. This venture provides access for marketing OSCA's completion fluids and ancillary services to the oil and gas industry in more than 40 countries.

Halogenated synthetic rubber consumption has grown. Exxon Chemical Co. is the only domestic manufacturer of bromobutly rubber. This rubber is more heat resistant than other types of rubber and is used primarily in truck tires. The International Institute of Synthetic Rubber Producers in Houston, TX, projected growth rates of 2.1% per year through 1996 for all synthetic rubber consumption, with the exception of polychoroprene.

Great Lakes continued to offer extraction of precious metals with bromine salts.

Prices

Prior to 1982, the price of bulk elemental bromine reported by U.S. producers, f.o.b. plant, was an average value of the quantity of bromine reported as sold. Statistical data published beginning in 1982 gave the total quantity and value of bromine sold and used. This total is equivalent to a weighted average of the value of bromine used by the producing company plus the value of bromine sold to other companies as reported prior to 1982.

Bromine was sold under contracts negotiated between buyer and seller. Price quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They were quoted in table 3 to serve only as a guide to yearend price levels.

Foreign Trade

Israel received duty-free treatment on its bromine products in all major world markets except the United States, where duties are paid on two significant bromine products, sodium bromide and potassium bromide. The duty on all bromine products will drop to zero in 1995. Following the removal of the 20% duty, imports can be expected to increase.

More than 117 nations approved the General Agreement of Tariffs and Trade (GATT) and brought the eighth round of multilateral trade negotiations to a close on December 15. The negotiators gave up their battle to guarantee U.S. entertainment companies access to the European Community's government-controlled television markets to close the talks. A bitter quarrel between the United States and France over reductions in subsidies for farm exports was settled. Major issues that affect the chemical industry will remain unresolved until next year. The President will submit the final agreement to the U.S. Congress for approval.

The North American Free Trade Agreement, commonly known as NAFTA, was signed into law.

The U.S. bromine chemical industry petitioned the Japanese Ministry for International Trade and Industry (MITI) for a temporary suspension of select Japanese duties. Imports from Israel currently receive duty-free treatment while imports from the United States receive no such preferential treatment. As a result, U.S. exports are losing markets. The U.S. Trade Representative stated that the best and most expeditious solution to the problem is temporary suspension through the Japanese Tariff Council Procedure, while efforts continue to seek full-multilateral resolution through the Uruguay Round. The Japanese market is almost totally served by imports of bromine chemicals. Japanese producers are not vocal opponents of liberalization of the tariffs because they already face competition from duty-free Generalized Systems of Preference imports and often purchase U.S. intermediate or finished products subject to duty.[16]

World Review

Methyl bromide emissions continued as a topic of world concern. The European Commission's proposals, which were sent to the European Council, were being examined. The proposals stipulate that hydrochlorofluorocarbons (HCFC's) be banned by 2015 and that methyl bromide use and pollution freeze start in 1996. Opposition is being voiced by France, Greece, Portugal, and Spain with minor reservations by Belgium. Worldwide, major production was divided as follows: United States, 30,000 tons; Israel, 20,000 tons; and France, 5,000 tons. Methyl bromide users have launched a $400,000 program to develop technology to prevent emissions of the gas, which is used mainly as a soil fumigant. In 1990, France's methyl bromide production was 5,000 tons. European consumption of 14,000 tons was met mainly by United States and Israeli imports. Worldwide methyl bromide production was 65,000 tons and growth was estimated at 5% per year.[17]

Producers of methyl bromide in Europe, Japan, and the three largest sellers in the United States, Great Lakes, Dead Sea Bromine's U.S. subsidiary Ameribrom, and Ethyl, banded together to form the Methyl Bromide Global Coalition. The group has provided $1.5 million to examine methyl bromide's effects on the environment.[18]

Canada.—Ethyl Corp. announced plans to close the Sarnia, Ontario, tetraethyl lead (TEL) plant on March 31, 1994. Bromine is a major component of leaded gasoline because it prevents the lead from depositing in the engine.

China.—Israel's Dead Sea Works expects to complete details on a potash project in China at yearend. Construction was planned to begin in 1994 and take 3 years to complete.

Joint ventures were sought in several bromine compounds plants in the Shouguang Province by Weifang Salt & Chemical Industry Group General Corp. The state-owned enterprise is the largest base for the production of salt and salt chemicals in China. Projects are to include technology and equipment. Project No. 7 is a 1,000-ton-per-year decabromodiphenol oxide project of the Shouguang Salt Industrial Co. that would consist of 6,000 tons per year of bromine from 2.26 million tons per year of salt. The products were intended for sale in China. Project No. 26 would produce lithium bromide at the Shouguang Salt Chemical Industrial Factory that presently produces sodium and ammonia bromide. Project No. 29 is with the Shouguang Chahe Saltworks and would produce 300 tons of lithium bromide as a byproduct; present production is 460,000 tons of salt, 1,500 tons of bromine, and 100 tons per year of bromate per year. The bromate has been sold on the international market. Project No. 32 is with Shouguang Chahe Saltworks and would produce hydrobromic acid as a byproduct of the present production of 460,000 tons of salt, 1,500 tons of bromine, and 100 tons of bromate per year.

Weifang City is situated in the middle of Shandong Province and Peninsula and has been qualified by the Government of the People's Republic of China as a "key" city with the capacity of conducting its own business with the world. The Jiaoji railway traverses the east and west and radiates in all directions. The leading industries are light-industry, textiles, electronics, machinery, chemical, and building materials. More than 400 projects introduced or run by foreign investment have been approved by the local government, with nearly 120 joint-venture, cooperative, and solely foreign-investment enterprises.[19]

European Union.—The entry into force of the Maastrich Treat on European Union on November 1, 1993, introduced some changes into terminology regarding the European Community (EC) and some of its institutions. The European Union is now the umbrella term encompassing the EC and the two new pillar Common Foreign and Security Policy and Justice and Home Affairs. The EC continues to exist as a legal entity within the broader framework of the Union.[20]

France.—Ethyl's French subsidiary Potasse et Produits Chimiques (PPC), formerly owned by Rhône-Poulenc, located at Thann, France, continued to process bromine derivatives and is the European center for sales. PPC was purchased by Ethyl in 1992.[21]

Great Lakes agreed to sell certain assets of the lubricant additives business of Great Lakes Chemical France, SA (GLCF) to Lubrizol. Headquartered near Paris, GLCF acquired Societe Francaise d'Organo Synthese from Rhône-Poulenc. GLCF will focus on its plastics additives business, but will continue to manufacture certain lubricant additives for Lubrizol under a long-term contract.[22]

Elf Atochem was Europe's only methyl bromide producer. Autochem, a joint venture at Port-de-Bouc 50% owned by Octel, operated a seawater bromine production facility.

Germany.—Bromine is produced from the waste bittern of potash production in Germany. German potash and salt producers Kali und Salz AG, based in Kassel, and Mitteldeutsche Kali AG, based in Sondershausen, planned to combine operations. The merger was seen as a means of achieving lower unit costs and increasing their competiveness by merging the entire German potash industry under one company. The exact form of the joint venture and the date at which it will come into operation are still under discussion. At yearend, the Bischofferode Mine, located in Thuringia, received a stay from closing. The 600,000-ton-per-year Mine planned to operate until the end of the year at a much reduced level of production and guaranteed employment for the workers until the end of 1995.[23]

The east German state of Thuringia has called for talks in east and west Germany to discuss dissatisfaction in terms between the potash producers and the Treuhandanstalt on a merger of BASF's subsidiary Kali und Salz and east German's potash holding Mitteldeutscher Kali.[24]

GLCF acquired Chemische Werke Lowi GmbH & Co. The acquisition will expand the Great Lakes worldwide plastics additives business with a technology base in antioxidants and ultraviolet (UV) absorbers to include hindered amides (HALS).[25]

Israel.—Bromine is produced as a byproduct from waste bitterns associated with potash production from the Dead Sea. After potash is removed in solar ponds, the waste bitterns are processed with chlorine to remove bromine. The bromine-free bitterns are then processed to remove magnesium.

Israeli Chemical Co. Ltd. (ICL) planned to split Dead Sea Bromine (DSB) from Dead Sea Works (DSW). Government approval was being sought to enable ICL to hold a direct stake of 89% in DSB; the balance will be held by the public. DSB has two production plants at Sodom and Ramat Hovav.[26] DSB announced plans to implement a $500 million expansion over the next 5 years that will increase bromine production to 200,000 tons per year. Part of the expansion effort involves construction of a salt refinery at Sodom that will use solar salt to produce electrolysis-grade salt.[27] Present salt production is used to produce chlorine, which is vital to the bromine process. Another $525 million project allocates $350 million magnesium plant and expansion of bromine compounds production. Part of the investment will include a 25,000-ton-per-year metallic magnesium plant in 30 months with another doubling of capacity by the late 1990's.[28]

DSB and Dead Sea Periclase Ltd. (DSP) will jointly build a plant to produce surface treated and untreated magnesium hydroxide flame retardants. The investment is expected to be about $12 million and should reach 6,000 tons per year. Technical support will be provided by DSB and its worldwide subsidiaries, already active in flame retardant technology. Sales are expected to reach $11 million per year. Both DSB and DSP are part of the integrated ICL. DSP produces magnesia products using the Aman process from brines supplied by DSW. DSW also supplies brine to DSB, which supplies byproduct caustic soda to DSP for the Aman process.[29]

DSW also has developed a flame retardant product that combines bromine and antimony under pressure to form granules, thus avoiding the use of a binder or carrier.[30]

The Government began efforts in 1985 to sell a share of ICL to offset an investment program. Much of the organic and inorganic chemical activity takes place within the framework of the massive ICL, which in 1986 was composed of 28 companies with a work force of 7,000. Formal bids were accepted in 1990, but a number of Government representatives favored a public sale rather than sale to a foreign investor. In 1991, privatization terms for ICL were approved, and ultimately 25% of ICL was sold by 1993. The Government was reportedly willing to reduce ownership to 49% at some point in time. The Knesset approved the Dead Sea Mineral Rights Law Interim Amendment November 10, 1993, clearing the way for DSW to proceed with expansion projects already under way. Unlike companies in the United States, all production is exported.[31]

Japan.—According to a study by DIA Research Institute Inc., Tokyo, organic brominated flame retardants for plastics experienced an annual growth rate of 27%, and aluminum hydroxide is showing the fastest growth in the inorganic flame retardants. Consumption of flame retardants for plastics has grown nearly 700% between 1976 and 1991.[32]

Russia.—Russia holds first place in the world for explored and potential reserves of rock salt and potash salts. The value of the deposits is markedly increased by the possibility of extracting lithium, bromine, and other useful constituents. The most important salt basins are confined to the Paleozoic sedimentary deposits filling intercontinental structures. The largest is the Upper Kama salt basin in the Perm region of European Russia. There the Permian sequences contain more than 60% of the total salt reserves of the former U.S.S.R.[33]

United Kingdom.—Great Lakes's affiliate, Associated Octel, was renovating and repacking a blowing out tower used for extracting bromine from seawater at the Anglesey site.[34] Octel signed a long-term agreement to supply Ethyl's requirement for lead antiknock compounds, effectively making Octel the world's only producer of TEL. Octel also signed an agreement to supply antiknock compound to E. I. du Pont de Nemours & Co. (Dupont) for the Mexico market. Octel's three facilities in Paimboeuf, France, Bussi, Italy, and Ellsmere Port, United Kingdom, will become the only significant sources of TEL in the world. In the United States, Dupont ended production at its Deepwater, NJ—based plant in 1991. Dupont closed its operation in Mexico in November 1992. PPG Industries Inc., Pittsburgh, PA, closed its Beaumont, TX, facility in 1983, and Nalco Chemical Co. closed its Freeport, TX, facility in 1985. Ethyl closed a plant in Baton Rouge, LA, in 1985 and another in Pasadena, TX, in 1980.[35]

Under the Montreal Protocol, production of halons ceases at the end of this year, except for those uses deemed essential by all parties to the protocol. The United Kingdom listed six uses on the list covering Halons 1211 and 1301 in aircraft, airport vehicles, offshore oil and gas installations, and certain trains' engine rooms. The essential uses must be agreed upon by the end of 1994.[36]

Current Research

The National Aeronautics & Space Administration (NASA) has been monitoring the stratosphere from space for 14 years. NASA and the National Oceanic & Atmospheric Administration (NOAA) have been measuring chlorofluorocarbons (CFC's) in the atmosphere since 1978. Halons are fluorocarbons that contain bromine. Research has confirmed that fully halogenated compounds are essentially inert in the troposphere, gradually floating unchanged into the stratosphere. Ozone is produced continually in the upper stratosphere where solar ultraviolet (UV) radiation dissociates molecular oxygen to form atomic oxygen. The intense concern regarding the fate of ozone in Earth's atmosphere stems from its ability to shield Earth's surface from potentially harmful solar UV radiation. Once halons rise above the bulk of the ozone layer, which is most dense between 15- and 30-kilometers altitude, depending on the altitude, they are photolyzed by UV light, producing halogen atoms.

Chlorine and bromine top the list of suspects causing the thinning of ozone in the Northern Hemisphere to accelerate. Although ozone researchers believe chlorine- and bromine-catalyzed destruction is responsible for the global ozone thinning, the process has not been quantified. The total amount of chlorine and bromine in the stratosphere is virtually uniform worldwide. Only in Antarctica do all elements take forms that attack ozone long enough to destroy massive amounts of ozone. Despite a growing perception that the problem of ozone depletion is solved, scientists are still struggling to understand its complexities.[37]

While in theory any halogen compound can function as a flame retardant, only chlorine and bromine compounds are actually used because of their molar effectiveness and the thermal stability of organohalogen compounds. Iodine, although the most effective, is never used because of cost and the instability of the organoiodine compounds. Aromatic bromine compounds are typically used with a synergist, such as antimony oxide, which promotes the formation of volatile bromine species. Aliphatic bromine compounds are commonly used without a synergist, but are limited to relatively low processing temperatures.[38]

Great Lakes' proprietary product, FM-200, received the Underwriters Laboratory listing mark. FM-200 matches Halon 1301's superior, people-safe fire fighting capabilities, yet poses no threat to the stratospheric ozone layer. FM-200 is under evaluation as a CFC replacement in testing in military applications.[39]

Bromine injected into an aquifer can help in understanding the spread of pollution under the site. The U.S. Geological Survey used an array of 10,000 test wells to sample ground water. Streamers of light mimic the path of pollutants.[40]

The selective oxidation of organics has been an important industrial reaction for intermediates in agrochemical, perfumery, pharmaceutical, polymers, and other areas. Solvay Interox developed two approaches to oxidation: one indirect and one direct. The indirect process involves reaction of the substrate with bromine generated in situ from hydrogen peroxide and hydrobromic acid. The actual product composition is determined by the reactivity of the substrate and the reaction conditions chosen. The direct oxidation method employs a cobalt (Co) catalyst in the presence of a promoter, such as the bromide ion, using peroxide to assist the oxidation of CoII or CoIII.[41]

Bromination of fullerene (C_{60}) yields a variety of materials. Surprisingly, the halogenation reaction is reversible. Heating a brominated fullerene regenerates C_{60}, supporting the idea that the fullerene cage remains intact during halogenation.[42]

Electrochemical technology can be used to produce sodium bromide and sodium bromate using electrodes and membrane material. The system operates on-site and can add sodium bromide or sodium bromate directly to the water system for use as a biocide. The use of selective anodes can minimize electrical consumption and avoid unwanted secondary reactions.[43]

Environmental concerns have pressured the pulp and paper industry to study new approaches for bleaching. Research and development facilities are investigating the suitability of bromine in aqueous solution as an on-site bleaching agent.[44]

OUTLOOK

Sales of bromine, primarily in compounds, have decreased about 25% since 1979. This represents an annual rate of decrease of about 2% per year. These decreases have been offset by increased use of bromine in fire retardants, sanitizers, and well-drilling fluids. Bromine is expected to increase in demand at the same 1.1% rate through the next 5 years. Demand as a fire retardant will offset any decreases in other uses. Bromine usage in well-drilling fluids was expected to increase.

Petroleum

Demand for bromine as a gasoline additive has declined each year since the EPA issued regulations in the 1970's to reduce the lead in gasoline. Bromine in the form of EDB is used as a "scavenger" for the lead to keep the lead from depositing in the engine. In 1979, the amount of bromine sold reached a peak of 225 million kg. The rapid decline to 141 million kg in 1986 was a direct result of the limits on lead in leaded gasoline. The EC continued discussions to reduce lead levels in gasoline.

Federal laws enacted to encourage alternative forms of power in automotive engines are likely to have a depressive effect on increases in petroleum demand. The Clean Air Act Amendments of 1990 has an amendment that will require mobile sources, such as cars and trucks, to use the most effective technology possible to control emission. Electric cars that do not require bromine gasoline additives are already on the market in California.

Sanitary Preparations

Bromine has found usage in swimming pools, hot tubs, and whirlpools. The sanitary preparation field is an area where bromine has been found to be safer than its substitutes because bromine has a higher biocidal activity level for the same amount of product. Applications in the pulp and paper industry and in cooling towers and Government-regulated food-washing applications are growth areas. The use of bromine will continue to grow in this area, closely following the gross national product in real growth.

Fire Retardants

Federal regulations covering flammability of private and public building materials and furnishings have required greater amounts of fire retardant chemicals to be used in these materials and furnishings. Fire retardants are expected to grow as organic materials replace metals in transportation, infrastructure, and packaging. Several State governments continue to support strong consumer laws that protect State residents from products with potential fire hazards produced in other States.

Other Uses

Usage of calcium bromide and zinc bromide in well-drilling fluids decreased during the 1980's as the domestic petroleum industry suffered a severe recession. Both the Baker Hughes and the Smith rig count published each week in the Oil & Gas Journal showed a decrease in activity at yearend 1993 when compared with that of 1992. The 1993 yearend workover rig count showed a 4% increase over that of yearend 1992. Oilfield chemicals used in drilling, completion and workover, and production operations have remained significantly more profitable internationally than in U.S. operations. The competition market included corrosion inhibitors, bactericides, viscosities and defoamers, as well as commodities such as calcium chloride and calcium bromide brines used to maintain well productivity.

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TABLE 1
SALIENT BROMINE AND BROMINE COMPOUND STATISTICS

(Thousand kilograms unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Bromine sold or used:[1]						
Quantity		175,000	177,000	170,000	171,000	177,000
Value	thousands	$139,000	$131,000	$124,000	$125,000	$123,000
Exports:						
Elemental bromine:						
Quantity		3,557	2,932	2,563	5,320	6,013
Value	thousands	$3,165	$4,008	$7,665	$5,542	$7,441
Bromine compounds:[2]						
Gross weight		35,914	17,094	17,123	19,996	15,754
Contained bromine		28,998	14,443	14,555	16,946	13,351
Value	thousands	$24,093	$18,166	$21,280	$26,445	$21,750
Imports:[3]						
Elemental bromine:						
Quantity		460	756	142	851	850
Value	thousands	$293	$508	$91	$522	$513
Compounds:						
Ammonium bromide:						
Gross weight		2,402	1,526	2,055	1,794	1,242
Contained bromine		1,960	1,245	1,676	1,463	1,013
Value	thousands	$3,471	$2,399	$3,129	$2,871	$2,024
Calcium bromide:						
Gross weight		7,770	11,634	14,610	5,365	9,652
Contained bromine		6,212	9,301	11,688	4,289	7,722
Value	thousands	$3,231	$5,236	$7,130	$3,212	$3,741
Potassium bromate:						
Gross weight		330	199	386	407	280
Contained bromine		139	42	185	195	134
Value	thousands	$918	$615	$1,244	$1,250	$892
Potassium bromide:						
Gross weight		590	593	888	883	1,179
Contained bromine		395	461	595	592	790
Value	thousands	$985	$1,028	$1,591	$1,663	$2,174
Sodium bromate:						
Gross weight		NA	NA	229	176	290
Contained bromine		NA	NA	121	93	153
Value	thousands	NA	NA	$391	$469	$725
Sodium bromide:						
Gross weight		1,369	1,630	3,036	1,097	1,266
Contained bromine		1,063	1,266	2,358	852	983
Value	thousands	$1,922	$2,130	$3,882	$1,617	$1,732
Other:						
Gross weight		28,005	11,591	11,646	11,741	12,465
Contained bromine		19,787	7,083	7,104	7,162	7,604
Value	thousands	$42,589	$50,414	$24,585	$21,477	$36,453
World: Production		[r]409,204	[r]389,680	[r]391,928	[r]392,703	[e]392,650

[e]Estimated. [r]Revised. NA Not available.

[1] Elemental bromine sold as such to nonproducers, including exports, or used in the preparation of bromine compounds by primary U.S. producers.

[2] Bureau of the Census. Includes methyl bromine and ethylene dibromide.

[3] Bureau of the Census.

TABLE 2
BROMINE-PRODUCING PLANTS IN THE UNITED STATES IN 1993

State and company	County	Plant	Production source	Elemental bromine plant capacity[1] (million kilograms)
Arkansas:				
Arkansas Chemicals Inc.	Union	El Dorado	Well brines	23
Ethyl Corp.	Columbia	Magnolia	do.	45
Do.	do.	do.	do.	73
Great Lakes Chemical Corp.	Union	El Dorado	do.	48
Do.	do.	Marysville	do.	36
Do.	do.	El Dorado	do.	23
Michigan:				
The Dow Chemical Co.	Mason	Ludington	do.	[2]9
Total				[3]256

[1] Actual production capacity is limited by brine availability.
[2] Bromine produced at this plant is reprocessed in Arkansas.
[3] Data do not add to total shown because of independent rounding.

TABLE 3
YEAREND 1993 PRICES FOR ELEMENTAL BROMINE AND SELECTED COMPOUNDS

Product	Value per pound (cents)	Value per kilogram (cents)
Ammonium bromide, National Formulary (N.F.), granular, drums, carlots, truckloads, f.o.b. works	131	289
Bromine:		
Drums, truckloads, works[1]	123	271
Bulk, tank cars, works[1]	56	123
Bromochloromethane, drums, carloads, f.o.b. Midland, MI	127	280
Calcium bromide, bulk[2]	67	148
Ethyl bromide, technical, 98%, drums, truckloads	127	280
Ethylene dibromide, drums, carloads	95	209
Hydrobromic acid, 48%, drums, carloads, truckloads, f.o.b.	42	93
Hydrogen bromide, anhydrous, cylinders, 2,500 pounds, truckloads	475	1,047
Methyl bromide, tank cars	77	170
Potassium bromate, granular, powdered, 200-pound drums, carloads, f.o.b. works	106	234
Potassium bromide, N.F., granular, drums, carloads, f.o.b. works	112	247
Sodium bromide, technical, truckloads	70	154

[1] Delivered prices for drums and bulk shipped west of the Rocky Mountains, 1 cent per pound higher. Bulk truck prices 1 to 2.5 cents per pound higher for 30,000-pound minimum and 4 to 5.5 cents per pound higher for 15,000-pound minimum.
[2] Bureau of the Census. Average c.i.f. import value.

Source: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 245, No. 1, Jan. 3, 1994, pp. 24-31.

TABLE 4
U.S. IMPORTS OF OTHER BROMINE COMPOUNDS

Compounds	Harmonized schedule code	1992		1993		Principal sources, 1993
		Gross weight (kilograms)	Value[1] (thousands)	Gross weight (kilograms)	Value[1] (thousands)	
Methyl bromide	2903301520	3,532	$3,641	3,570	$4,405	Israel 100%.
Chlorobromodifluormethane	2903400020	3,115	13,004	4,682	26,670	United Kingdom 51%, France 36%, Germany 4%, Japan 4%, Canada 3%, Netherlands 2%.
Hydrobromic acid	2811195050	299	NA	294	250	Israel 100%.
Dibromoethyldibromocycloxehane	2903590500	45	244	73	1,077	Netherlands 56%, Germany 35%, Slovakia 7%, United Kingdom 2%.
Dibromoneopentyl glycol	2905505000	56	255	88	215	Israel 100%.
Tetrabromobisphenol-A	2908102500	85	104	34	41	Do.
Decabromodiphenyl oxide and octabromodiphenyl oxide	2909300700	2,022	4,229	1,914	3,795	Do.
Bromoxynil[2]	NA	2,096	NA	1,398	NA	United Kingdom 100%.
Brominanine[2]	NA	491	NA	412	NA	Japan 100%.

NA Not available.

[1] Declared c.i.f. evaluation.

[2] The Journal of Commerce Port Import/Export Reporting Service.

Source: Bureau of the Census.

TABLE 5

WORLD BROMINE ANNUAL PLANT CAPACITIES AND SOURCES,[1] DECEMBER 31, 1993

Country and company	Location	Capacity (thousand kilograms)	Source
China:			
Laizhou Bromine Works	Shandong	11,500	Underground brines.
France:			
Atochem	Port-de-Bouc	13,600	Seawater.
Mines de Potasse d'Alsace S.A.	Mulhouse	8,600	Bitterns of mined potash production.
Germany:			
Kali und Salz AG: Salzdetfurth Mine	Bleichrode	[2]600,000	Do.
Do.	Sondershausen	3,500	Do.
India:			
Hindustan Salts Ltd.	Jaipur	1,500	Seawater bitterns from salt production.
Mettur Chemicals	Mettur Dam		
Tata Chemicals	Mithapur		
Israel:			
Dead Sea Bromine Co. Ltd.	Sodom	150,000	Bitterns of potash production from surface brines.
Italy:			
Societa Azionaria Industrial Bromo Italiana	Margherita di Savoia	900	Seawater bitterns from
Japan:			
Toyo Soda Manufacturing Co. Ltd.	Tokuyama	20,000	Do.
Spain:			
Derivados del Etilo S.A.	Villaricos	900	Seawater.
U.S.S.R.:[3]			
Government	NA	24,000	Well brines.
United Kingdom:			
Associated Octel Co. Ltd.	Amlwch	30,000	Do.

NA Not available.

[1] Excludes U.S. production capacity. See table 2.

[2] Closed 1993.

[3] Dissolved in Dec. 1991.

TABLE 6
BROMINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Azerbaijan	—	—	—	[e]5,000	4,000
China[e]	8,000	8,080	12,100	12,000	13,000
France[e]	18,000	3,100	[r]3,000	[r] [3]3,200	3,000
Germany: Western states	2,000	1,500	[e]1,500	[r] [e]750	750
India[e]	[3]1,272	1,300	1,300	1,300	1,400
Israel[e]	[3]134,725	130,000	135,000	135,000	135,000
Italy[e]	400	400	400	300	300
Japan[e]	15,000	15,000	15,000	15,000	15,000
Spain[e]	300	300	300	[r]250	200
Turkmenistan	—	—	—	[e]12,000	10,000
U.S.S.R.[e] [4]	25,000	25,000	24,000	—	—
Ukraine	—	—	—	[e]7,000	5,000
United Kingdom	29,907	[r] [e]28,000	[r]29,328	[r]29,903	28,000
United States[5]	174,600	177,000	170,000	[3]171,000	177,000
Total	[r]409,204	[r]389,680	[r]391,928	[r]392,703	392,650

[e] Estimated. [r] Revised.

[1] Table includes data available through May 4, 1994.

[2] In addition to the countries listed, several other nations, notably the Eastern states of Germany (the former German Democratic Republic), produce bromine but output data are not reported, and available general information is inadequate for formulation of reliable estimates of output levels.

[3] Reported figure.

[4] Dissolved in Dec. 1991.

[5] Sold or used by producers.

CEMENT

By Cheryl Solomon

Ms. Solomon, a physical scientist with 8 years of U.S. Bureau of Mines (USBM) experience, has been the commodity specialist for cement since 1992. Domestic survey data were prepared by Eric Dunkelberger, statistical assistant; and international survey data were prepared by Dave Mann, international data coordinator.

The industry's main product, portland cement, makes up 96% of the total domestic production. The remainder comes from masonry, hydraulic, and aluminous cements.

In 1993, U.S. demand for cement increased by approximately 8%. Domestic production of portland cement increased by 6%. Cement imported for consumption increased for the first time in 5 years to 7.06 million metric tons. Portland cement values increased to approximately $55 per metric ton.

The International Trade Commission (ITC) reaffirmed that the U.S. cement industry had been materially injured or threatened by imports of Japanese gray portland cement and cement clinker into the United States. The action was in response to an order from the Court of International Trade.

The International Trade Commission completed its review of gray portland cement and clinker from Mexico. The preliminary rates were revised. The final dumping margins ranged from 30.44% to 53.26%.

The ITC began an investigation of French calcium alumina cement and cement clinker shipped to the United States. The Commerce Department was to begin a pricing investigation of the shipments.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for cement are developed by means of the portland and masonry cement voluntary survey. Of the 121 cement manufacturing plants to which an annual survey collection request was made, 110 responded, representing 91% of the cement production and consumption data shown in table 1. Estimates were made for nonrespondents using monthly survey data and data received from previous annual surveys. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Section 4 of the Annual Book of the American Society for Testing and Materials (ASTM) publishes standards, test methods, definitions, recommended practices, classifications, and specifications for cement, lime, and gypsum.[1] Following is a brief discussion of various types of hydraulic cements and the materials from which they are made.

Clinker.—Clinker is produced by heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and iron oxide in a kiln to a temperature of about 2,700° F at which partial fusion occurs. The fused material, which ranges from fine sand grains to walnut size, is ground with small amounts, 3% to 5%, of calcium sulfate, usually gypsum or anhydrite, to make portland cement.

Portland Cement.—ASTM specification C-150 covers five types of portland cement: Type I, for use when special properties specified for other types are not required; Type II, for general use, especially when moderate sulfate resistance or moderate heat of hydration is desired; Type III, for use when high early strength is required; Type IV, for use when a low heat of hydration is desired; and Type V, for use when high sulfate resistance is required. ASTM specifications also include Type IA, Type IIA, and Type IIIA for the same uses but with the addition of air entraining compounds to protect concrete against freeze-thaw damage.

White Cement.—White cement is made from iron-free materials of exceptional purity, usually limestone, china clay or kaolin, and silica. The clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric ions. The clinker is then ground with high-purity white gypsum using ceramic balls and liners in grinding mills. White cement is used in decorative concrete, including terrazzo, median barriers, and architectural concrete.

Masonry Cement.—Masonry cement is a hydraulic cement used in mortars for masonry construction. It contains one or more of the following materials: portland cement, portland-pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime, limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity. ASTM designation C-91 contains specifications for masonry cement.

Blended Hydraulic Cement.—ASTM Specification C-1157, first developed in 1992, covers blended hydraulic cements for both general and special applications.[2] This is a specification giving performance requirements. There are no restrictions on the composition of the cement or its constituents. The specification classifies cements by type based on specific requirements for general use, high early strength, resistance to attack by sulfates, and heat of hydration. As a performance standard and not a rigid formula of ingredients, it does not replace ASTM's existing standards (C-595 for blended cement described below) but is an additional way to specify blended cements. ASTM designation C-595 covers four kinds of blended hydraulic cements, each with an optional provision for air entraining.

Portland-Blast Furnace Slag.—This is essentially an intimately interground mixture of portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of portland cement and fine granulated blast furnace slag in which the slag constituent ranges between 25% to 70% of the total weight of the cement.

Pozzolan.—Pozzolan is a siliceous and aluminous material that in itself possesses little or no cementitious value but will, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Fly ash is a pozzolanic material obtained from flue gases produced by coal combustion. Natural pozzolans are naturally occurring materials, such as diatomaceous earths, opaline cherts and shales, tuffs, volcanic ash, and pumicites. ASTM C-618 covers fly ash and natural pozzolans.

Portland-Pozzolan Cement.—Portland-pozzolan cement is produced by intergrinding portland cement clinker and pozzolan, by blending portland cement or portland-blast furnace slag cement and finely divided pozzolan, or a combination of intergrinding and blending in which the amount of the pozzolan is between 15% and 40% of the total weight of the cement.

Pozzolan-Modified Portland Cement.—The constituents in this type of cement are the same as those for portland-pozzolan cement, and the methods of production are also the same. However, pozzolan makes up less than 15% of the total weight of the blended cement.

Slag Cement.—Slag cement is a finely divided material made from a uniform blend of granulated blast furnace slag and hydrated lime. The slag constitutes at least 70% of the total weight of the blended cement.

Oil-Well Cement.—Oil-well cement was developed to seal oil and gas wells under pressures of 18 to 20,000 pounds per square inch and temperatures up to 400° F in oil and gas wells and 500° F in steam wells. This cement must remain fluid up to about 4 hours to be effective. The cement is modified by service companies to fit individual well conditions using additives. The average well depth is 4,600 feet, but can range from grass roots depth to 30,000 feet.

The American Petroleum Institute (API) specifications cover requirements for manufacturing eight classes of well cements—A, B, C, D, E, F, G, and H—and Grades O-Ordinary, MSR-Moderate Sulfate-Resistant Grade, and HSR-High Sulfate Resistant Grade.[3] Changes in the API specification were set down in 1991, including the elimination of specific well depths in classes A-H cement and the abolition of mandatory testing for classes A, B, and C cement among other changes. The physical and chemical requirements set down previously remained the same.

Expansive Cement.—Expansive cement is a hydraulic cement that tends to increase in volume after setting during the early hardening period. There are three types of expansive cements, types K, M, and S. Expansive cements are used primarily in shrinkage-compensating concrete. ASTM specification C-845 covers all expansive cements.

Aluminous Cement.—Sometimes known as calcium aluminate cement, or high-alumina cement, aluminous cement is a hydraulic nonportland cement. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulfate action, and refractory properties when used as "castable refractories" and mortars for furnaces and kilns.

Concrete.—Concrete is a proportioned mixture of coarse mineral aggregates of sand and gravel or crushed stone, bound together by a paste of hydraulic cement and water. Volume 04.02 of ASTM standards covers concrete and aggregates.

Admixtures.—Admixtures allow the concrete to be altered to the particular job. Factors such as the durability, appearance, versatility, and cost effectiveness of the concrete, can be manipulated. Most additives modify the hydration of portland cement in some way, by changing the speed of reaction or by dispersing the cement particles more thoroughly throughout the mix. Admixtures reduce the water-cement ratio required in the concrete mix. The following are admixtures in cement:[4]

Plasticizers.—Plasticizers are water-reducing agents that effectively reduce the quantity of cement required to achieve certain strength or workability characteristics.

Superplasticizers.—Superplasticizers produce highly workable flowing concrete that, for example, can be used for pumping applications. Superplasticizers also can produce high-strength concrete that has a reduced water content and a high compressive strength.

Air-Entraining Agents.—Air-entraining agents cause microscopic air bubbles to be distributed uniformly throughout the concrete. These act as reservoirs for the water when it freezes, allowing it to expand without harming the structure of the concrete. They also can act as crack inhibitors by preventing small cracks enlarging beyond the extent of the nearest air void. Concrete may be air-entrained to give protection from freeze-thaw cycles. Air-entraining mixtures may entail loss of compressive and tensile strength, and thus may be used with plasticizers to restore the strength properties. Fly ash and slag have an air-entraining effect.

Accelerators.—Accelerating admixtures increase the hardening rate of concrete, giving high early strength development. Calcium chloride is the most common accelerator and has been in use since 1885. Accelerators are used mainly in cold weather to normalize the setting time for concrete in a similar way that retarding plasticizers may be used in hot weather to slow down the process.

Waterproofing Aids.—Waterproofing aids are chemical admixtures that provide protection against the wind and rain and reduce the intake of ground water. Waterproofing aids form a water repellent surface on the concrete and thin hydrophobic layers and voids within the concrete structure.

Polypropylene Fibers.—Polypropylene fibers can inhibit cracks. The fibers take up the stress from drying concrete, thus reducing the tendency for it to crack. They add little to the overall strength of the hardened concrete; however, they impart elasticity during the initial plastic stage of the concrete, which is important for the inhibition of cracks.

Products For Trade and Industry

Portland cement makes up 96% of total domestic output; the remainder is mostly masonry cement with white, expansive, portland slag and pozzolan, waterproof, and a variety of miscellaneous cements accounting for a small percentage of the remainder.

Industry Structure

The industry is composed of 119 cement-producing plants in 37 States and 2 in Puerto Rico. Multiplant operations were being run by 18 companies. Fifteen independent importers have constructed terminals to receive foreign cement for markets near coastal areas.

The cement industry has been very active in vertically integrating the cement companies since 1985, when the Federal Trade Commission removed the ruling that prevented vertical integration in the construction materials industries. Vertical integration would include owning ready-mix concrete, concrete products, aggregate, and construction businesses that buy the cement. In addition, the cement companies own crushed stone, sand and gravel, hot-mix asphalt, and precast and prestressed concrete companies. Other companies may own fly ash, slag, chemical admixtures, colored cement, waste material including fuel, and cement distribution companies. Therefore, cement companies have moved beyond simply acquiring the cement consumers, but also are owning the fuel and cement distribution companies.

In 1993, one of the activities in the U.S. cement industry with respect to vertical integration was the sale of Blue Star Ready Mix of Moorpark, CA, to Southdown Corp., based in Houston, TX.[5] Other news relating to a vertically integrated company involved Centex Corp., which announced that its construction products subsidiary, Centex Construction Products (CCP), filed a registration statement for the intended sale of 51% of CCP's common stock in an initial public offering. CCP was comprised of Centex's cement, ready mix concrete, aggregate and gypsum wallboard operations.[6] Most of the vertically integrated cement companies in the United States were foreign-owned.[7] Such companies included Beazer U.S.A., owned by Hanson Industries; Blue Circle Cement Inc.; Calaveras Cement of Cimenteries CBR, S.A.; Dragon Products Co., owned by Cementos del Norte; Essroc Corp., owned by Ciments Francais; CSR; Lafarge Corp.; National Cement Co., owned by Ciments Vicats; Mitsubishi Cement Corp.; California Portland Cement, owned by Onoda Cement; and Tarmac. Southdown Inc. a wholly owned U.S. cement company, was integrated in California.

Resources

Primary raw materials required for cement clinker production are, in order of importance, limestone, clay and shale, and iron ore. In instances where essential chemical components are not present in primary raw materials in the required amount, other mined materials or industrial products may be used as additives to correct these deficiencies. Gypsum is added during the clinker grinding process to make finished portland cement.

Although raw materials for cement manufacturing have not been quantified, they are abundant in most countries. Some countries deficient in raw materials meet their requirements by importing. Many domestic companies have reported reserves of raw materials exceeding 100 years of supply.

Technology

Principal steps in manufacturing portland cement consist of crushing, grinding, mixing, and burning raw materials and grinding the resultant clinker. About 1.8 short tons of raw materials is required to make 1 short ton of cement.

Raw Material Grinding.—Both dry and wet grinding are used to obtain a fineness that may range from 75% to 90% passing through a 200-mesh sieve. In wetmilling, water is added with the mill feed to produce a slurry containing about 65% solids. The raw material then is dried and ground for burning.

Burning.—Burning is the most important operation in manufacturing cement. Because fuel consumption is a major expense, plant capacity is measured by kiln output, and strength and other properties of cement depend on the quality of the clinker. Burning takes place in a rotary kiln that is a refractory-lined steel cylindrical shell. It rotates on an axis inclined at 3/8 to 1/2 inch per foot toward the discharge end. U.S. kilns range in size from 116 to 760 feet long and 8 to 24 feet in diameter.

Byproducts and Coproducts

Cement kiln dust, which is captured in

the baghouse of a cement plant, is a byproduct which can be used for agricultural uses among others. Some kiln dusts with high-alkali content have been collected and used as fertilizer or processed to recover potash. Flotation, a method of beneficiation used by some companies to remove undesirable constituents from raw materials and usually to increase the calcium carbonate content of the kiln feed, produces waste, such as silica sand or mica fines, that may be marketed. Waste rock quarried in selective mining of usable raw material has been sold for riprap and fill materials or crushed and sold as aggregate for concrete or for road base.

Economic Factors

Prices.—Cement prices are greatly influenced by local or regional markets and by the availability of energy and raw materials required for cement manufacturing. Discounts for cash and large-quantity purchases, absorption of freight charges, and the cost of packing bags and pallets add to the complexity of cement price patterns. Competition among producers and, in some instances, stiff competition from imports also are factors that contribute to depressed prices and ultimately limit investment dollars available for capital improvement or expansion.

Costs.—The cement industry has cut energy consumption and costs considerably during the past 30 years by modernizing the kilns, utilizing secondary fuel burning, and improving efficiency. Energy costs account for about 35% of the total production costs for cement. Plant operating costs may make up 70% of the value of cement.

Tariffs.—For countries with most-favored-nation status, duties are imposed only on white cement in the amount of $0.22 per metric ton, including the weight of containers. Other hydraulic cement and clinker are duty free. The statutory import duty for countries without most-favored-nation status is $1.76 per metric ton and $1.32 per metric ton for white cement and for all other types of cement and clinker, respectively.

Operating Factors

Energy Requirements.—The U.S. cement industry consumed an average of 4.8 million British thermal units per short ton (Btu/short ton) in 1993.[8] Types of fuel consumed in the cement kiln were natural gas, bituminous and anthracite coal, and petroleum coke. High sulfur petroleum coke may be blended with coal and used as fuel in the cement kiln. (See tables 7 and 8).

The cement industry also has been using wastes derived from other industries as fuel for cement kilns since the 1980's. The waste fuel market is divided into two broad areas: hazardous waste and nonhazardous waste.[9] The hazardous-waste area contains wastes such as printing inks and dyes, paints, solvents, chemicals, plastics, and any other materials that have come into contact with these industrial wastes. Nonhazardous wastes include scrap tires, medical waste, used oil, nonhazardous plastics and chemicals, and municipal wastes.

During the past 6 years, the use of hazardous waste-derived fuels has increased steadily. Cement kilns are described by the industry as ideal waste disposal units because the clinkermaking process requires high temperatures, long burning times, and a high level of turbulence. Liquid wastes, solvents, used motor oil, and scrap tires can be burned effectively, cutting down on fuel costs.[10]

Currently, liquids are used more commonly as hazardous waste-derived fuels.[11] Solids and sludges can be introduced into the kiln in a variety of ways. Solids can be suspended in liquids and pumped into the kiln, or injected directly into the calcining zone. Preprocessed solids and sludges are dried, ground into powder, and air-conveyed into the hot end of the kiln. With any of these three processes, as fuel is consumed, the organic compounds are destroyed. The inorganic compounds recombine with the raw materials and are incorporated into the matrix of cement. Cement kilns may need to be modified to burn some of these wastes. Some kilns already have been retrofitted to use waste oil. Using scrap tires as fuel for preheater kilns is well known, but had not been an option for long kilns. New technology will allow whole tires to be inserted into the calcining zone. One automated bulk tire feeder can run unattended with a programmable controller.[12] The costs involved in converting to using wastes as fuel depend upon the type of waste, with hazardous waste being the most expensive and tires the least expensive. However, the cement kilns are paid approximately $50 per short ton for using hazardous liquids and $250- to $400-per short ton for solids. Other waste fuels that cement kilns may be recycling in the future include municipal wastes or waste timber.[13]

ANNUAL REVIEW

Legislation and Government Programs

The EPA has a mandate under the Bevill Amendment of the Resource Conservation and Recovery Act (RCRA) to study cement kiln dusts and to present a report to Congress by January 1995.[14]

Issues

The cement industry, in an effort to increase profitability, increased prices which had remained flat for at least a decade. The industry also attempted to increase profitability by retiring old plants, cutting costs, and improving the efficiency of cement plants.

The vertical integration which had taken place in the cement industry since the mid-1980's slowed somewhat; however cement company acquisitions and mergers were strong. (See Corporate Changes section of this report).

Production

One State agency and 45 companies operated 119 plants in 37 States. In addition, two companies operated two plants in Puerto Rico, manufacturing hydraulic cement. The production data obtained are listed by State or groups of States that form cement districts. A cement district may represent a group of States or a portion of a State. The States of California, Illinois, New York, Pennsylvania, and Texas are divided to provide more definitive marketing information within those States, as follows:

California, Northern.—Points north and west of the northern borders of San Luis Obispo and Kern Counties and the western borders of Inyo and Mono Counties.

California, Southern.—All other counties in California.

Chicago, Metropolitan.—The Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will.

Illinois.—All other counties in Illinois.

New York, Western.—All counties west of a dividing line following the eastern boundaries of Broome, Chenango, Lewis, Madison, Oneida, and St. Lawrence Counties.

New York, Eastern.—All counties east of the aforementioned dividing line, except Metropolitan New York.

New York, Metropolitan.—The five counties of New York City (Bronx, Kings, New York, Queens, and Richmond) plus Nassau, Rockland, Suffolk, and Westchester Counties.

Pennsylvania, Eastern.—All counties east of the eastern boundaries of Centre, Clinton, Franklin, Huntingdon, and Potter Counties.

Pennsylvania, Western.—All other counties in Pennsylvania.

Texas, Northern.—All counties north of a dividing line following the northern borders of Burnet, Crockett, Jasper, Jeff Davis, Llano, Madison, Mason, Menard, Milam, Newton, Pecos, Polk, Robertson, San Jacinto, Schleicher, Tyler, Walker, and Williamson Counties.

Texas, Southern.—All counties south of the aforementioned dividing line.

Clinker Production.—Clinker production in the United States, excluding Puerto Rico, increased by 4% to 65.7 million metric tons. California continued to lead all States in clinker production, followed by Texas, Pennsylvania, Missouri, and Michigan.

By yearend, multiplant operations were being run by 18 companies. The size of individual companies, as a percentage of total U.S. clinker production capacity, ranged from 0.4% to 12%. The 5 largest companies with clinker capacity provided about 40% of total clinker capacity; the 10 largest companies with clinker capacity provided a combined 60%. The 10 largest companies, in decreasing order of size of clinker production, were Holnam Inc.; Lafarge Corp.; Southdown Inc.; Lone Star Industries Inc.; Blue Circle Inc.; Ash Grove Cement Co.; Lehigh Portland Cement Co.; Medusa Corp.; Essroc Materials Inc.; and RC Cement.

Portland Cement.—Portland cement production, excluding Puerto Rico, increased by 6% to 70.85 million metric tons. The increase was attributed to greater demand for cement, primarily in Mountain states and others, such as Arkansas, Florida, Georgia, Louisiana, Massachusetts, Mississippi, Oklahoma, Tennessee, and Texas.

The industry operated 119 plants, including 8 grinding facilities, to produce various types of finished hydraulic cement.

The size of individual companies, as a percentage of total U.S. finished cement production capacity, ranged from 0.3% to 13%. The top 10 producing companies, in declining order of production, were Holnam Inc.; Lafarge Corp.; Southdown Inc.; Lone Star Industries, Inc.; Blue Circle Inc.; Ash Grove Cement Co.; Lehigh Portland Cement Co.; Medusa Cement Co.; Essroc Materials Inc.; and RC Cement Co., Inc.

Masonry Cement.—Production of masonry cement increased by 8% to 2.96 million metric tons. At yearend, 83 plants were manufacturing masonry cement in the United States.

Aluminous Cement.—Aluminous cement continued to be produced by Lehigh, Buffington, IN; Lafarge, Chesapeake, VA; and Aluminum Co. of America, Bauxite, AR.

Fuel Consumption.—Approximately 70% of all U.S. clinker was produced by the dry process method. Fuels consumed in this process included coal, 10 million metric tons; natural gas, 668 million cubic feet; and oil, 46 million liters. In addition, 70,000 metric tons of tires, 90,000 metric tons of solid waste fuel, and 743.7 million liters of liquid waste fuel were consumed in the cement kilns.

Corporate Changes.—Ash Grove Cement opened a new 2,200 ton per day plant on the Duwamish Waterway, close to downtown Seattle, WA.[15]

Carlow Group, based in Zanesville, OH, early in 1993, closed its subsidiary Midwest Portland Cement Co. plant in East Fultonham, OH. Essroc Materials, Inc., based in Nazareth, PA, acquired Midwest's marketing and sales areas.

Hanson Industries of Hanson PLC located in London, England, sold its interest in North Texas Cement Company of Midlothian, TX, to Ash Grove Cement Co. of Overland Park, KS.[16]

Heidelberger Zement AG of Heidelberger, Germany, acquired the controlling interest in the Belgian firm CBR (Cimenteries). In North America, CBR owned Calaveras Cement Co. in California and Inland Cement and Tilbury Cement Companies in Canada.[17]

Holnam, Inc., the wholly owned U.S. subsidiary of Holderbank Financiere Glaris Ltd., based in Switzerland, purchased the Boxcrow Cement Co. plant in Midlothian, TX.[18] Assets to be acquired in the transaction included the cement plant, related quarry operation, and working capital. The 1 million ton per year Box Crow plant was built in 1987 and had been operating under the supervision of a court-appointed trustee since the company declared bankruptcy in late 1992. Holnam was to hold 75% of the company and was to manage the company which would be a wholly owned Holnam subsidiary.

Holderbank, which had owned 95% of Holnam, Inc. shares, approved a merger designed to give it ownership of 100 percent of Holnam's shares.[19]

KRC Aggregates, a subsidiary of MDU Resources Group, Inc., with holdings in utilities, coal, and oil, acquired the assets of Alaska Basic Industries, Inc. and Anchorage Sand and Gravel.[20]

Lafarge Coppee, based in Paris, France, announced a $318 million share-swap bid for full control of Asland, the second-biggest Spanish cement company in which Lafarge already held a 54% share.[21]

Lafarge Corp., the U.S. cement subsidiary of Lafarge Coppee, installed new equipment in its Davenport, Iowa plant. Production was boosted to 940,000 tons, and testing of alternative fuels, such as tires and used plastics, was made possible by this equipment.

Lafarge Corp. restructured and consolidated its 11 operating units into six in its two main business lines, cement and construction materials.[22] The cement group was divided into Western, Eastern and U.S. regions, with regional headquarters in Calgary, Alba.; Montreal, Que.; and Southfield, MI. Corporate headquarters remained in Reston, VA, according to a Lafarge Corp. announcement.

Lone Star Industries, Inc. settled two class-action law suits brought against it and some of its officers for $40 million.[23] The suit charged that Lone Star provided certain investors with misleading financial information.

At yearend, Cuba reportedly was considering giving to Cemex of Mexico, the Lone Star Cement plant that it had seized in 1959 in order to settle some of the country's debt with Mexico.

Lone Star Industries, Inc. announced plans to sell its Nazareth, PA, cement plant and several joint ventures as part of a bankruptcy reorganization.[23]

Medusa Corp. purchased an 810,000-ton single-kiln cement plant in Demopolis, AL, and nine cement distribution terminals from Lafarge Corp. for $45 million.[24]. After the sale, Lafarge operated 15 full production cement plants in North America and more than 100 distribution terminals with an annual cement production capacity in excess of 15 million tons. Medusa operated 4 cement plants in Alabama, Georgia, Michigan, and Pennsylvania, in addition to 16 cement distribution terminals in the Midwest and Southeast.[25]

Southdown, Inc., the third largest cement producer in the United States in 1993 and one of only a handful of U.S.-owned cement companies, set aside its plans to sell up to 50% of its cement and concrete products operations in Florida and California. [26]

Consumption and Uses

Consumer demand for cement in the United States, excluding Puerto Rico, increased by 8%. According to U.S. Department of Commerce (DOC) data, housing starts increased 7% to 1.29 million units, in 1993. The value of new construction increased 7.1% to $466 billion. The value of residential construction increased 12% to $210 billion, primarily in single-unit structures. The value of nonresidential construction increased 3.2% to $90 billion, owing primarily to increases in commercial building construction other than industrial, office and education. Public construction climbed by 6.2% to $55.1 billion, partly resulting from spending for miscellaneous public construction, including recreation, power generating, and open parking facilities, transit systems, and airfields, among other categories. Other public construction experiencing increases were highways and streets, schools, and conservation and development.[27]

California continued to lead all States in the amount of portland cement consumed, followed by, in order of shipments received, Texas, Florida, Illinois, Ohio, and Pennsylvania. Together, these States consumed 38% of the total U.S. tonnage.

On a regional basis, six of the Bureau of Census districts experienced increases in consumption. The largest increases were experienced by the Mountain, West South Central, South Atlantic, and East South Central districts with increases, respectively, of 16.4%, 8.5%, 7.2% and 7.0%. New England and East North Central districts showed increases in consumption of 5.0% and 3.3%. Although the Pacific, West North Central, and Middle Atlantic districts had decreases respectively of 3.1%, 1.7% and 0.4%, respectively, not all of the states in those districts experienced declines. For example, in the Pacific district, Oregon, Northern California and Washington experienced increases, respectively, of 5.8%, 1.6% and 0.1%. In the West North Central district, Nebraska, South Dakota and Kansas had increases of 8.6%, 6.0% and 2.3% and in the Middle Atlantic district, New Jersey, Eastern New York, Western New York, and Eastern Pennsylvania had respective increases of 6.8%, 6.0%, 2.9% and 1.2%.

Shipments of domestically produced portland cement from U.S. mills increased by 4%, as shown in table 11, while masonry cement shipments climbed 13%. *(See table 11.)* Cement shipments that were not reported to the USBM according to the type of customers are shown under Government and Miscellaneous *(See table 13.)* Ready-mix concrete producers were the primary consumers of cement, accounting for about 59% of the total, followed by concrete product manufacturers, 11.5%; building material dealers, 6.1%; roadpaving contractors, 2.9%; and other contractors, including those that were unspecified contractors, 4.9%. Smaller amounts were consumed by Federal, State, and other government agencies, and by a variety of uses, such as waste stabilization and mining.

Markets and Prices

The average mill value of portland cement was approximately $55.48 per metric ton and the value of masonry cement was $77.32 per metric ton. The average value of cement by yearend reported by Engineering News Record (ENR), was $63.39 per short ton. The ENR prices are based on an average per-ton value of cement delivered to 20 cities.

The average price change for portland cement for October 1993 increased by 7.4% compared with October 1992.[28]

Foreign Trade

The U.S. International Trade Commission (ITC) reaffirmed that the United States was materially injured or threatened with injury by imports of Japanese gray portland cement and cement clinker into the United States. The action was in response to an order from the Court of International Trade (CIT). The original determination was made in April 1991 when the U.S. Department of Commerce had determined that Japanese cement and clinker were being sold in the United States at less than fair value. Subsequently, the determination was appealed to the CIT, and the CIT sent back the ITC's original determination.[29]

The ITC completed its review of gray portland cement and clinker from Mexico. The preliminary rates were revised. The final dumping margins ranged from 30.44 % to 53.26% [30]

The ITC began an investigation of French calcium alumina cement and cement clinker shipped to the United States.[31] The Commerce Department was to begin a pricing investigation of the shipments.

Exports of hydraulic cement and clinker, as reported by the Bureau of the Census, decreased 16% to 625,000 metric tons. Canada received 80% of the total.

New York led all States in the amount of imports received, with 16% of total U.S. imports, or 1,154,000 metric tons. Of this total, 54% were shipped through the Buffalo Customs District, 20% were shipped through the New York City Customs District, and 27% were shipped through the Ogdensburg Customs District. These imports comprised 53% of New York's portland cement consumption compared with total imports representing 9% of apparent consumption nationally. Eighty percent of imports into New York came from Canada, 16% came from Greece, 2% each came from Spain and from the United Kingdom. Michigan was the second largest recipient of imported cement, receiving 1.02 million tons or 14% of the total. All of the Michigan imports were shipped through the Detroit Customs District, and virtually all came from Canada.

Chinese cement continued to enter the United States through Lone Star Northwest's terminals in Seattle, WA, and Portland, OR. By yearend, the Chinese had exported 286,000 tons. SsangYong Cement shipped 33,000 tons of cement from its plant in Korea to a CenCal terminal, which was jointly owned by SsangYong and Riverside Cement Co. The last previous cement shipments from Korea were at the end of 1991.[32]

World Review

World cement production increased by 5% to 1.3 billion tons. China continued to lead all nations with 27% of production, followed by Japan with 7%, and the United States with 6%.

Large-scale consolidations continued to take place in the international cement industry. The largest world cement companies have been bent on acquiring other cement and building concerns with the goal of becoming even larger. This was the case with the five largest international cement companies: Holderbank Glaris of Switzerland, Lafarge-Coppee of France, Italcementi/Ciments Francais of Italy, Heidelberger Zement of Germany and Cementos Mexicanos of Mexico.

Many cement companies around the world were poised to export a large part of their production to developing countries, especially in Asia. Indonesia, Malaysia, the Phillipines, Singapore, and Vietnam all needed cement to build their infrastructure, although they were also busy installing their own cement capacity.

Countries with excess capacity continued to export cement to the United States. Twenty-four countries exported cement to the United States in 1993, one more than in 1992. The amount of cement imports increased by 14% because of increased demand in U.S. markets.

The high level of exports brought many anti-dumping cases in the international cement market. While anti-dumping investigations in the United States continued against France, Japan, and Mexico, Mexico was investigating cement from Venezuela, and Germany was charging that East European cement producers were dumping cement into Germany at unfair prices.[33]

Belgium.—Both cement consumption and shipments were estimated to have dropped about 5% to 5.4 million tons and 6.8 million tons, respectively.[34] Belgium was a net exporter of cement.

S.A. Cimenteries CBR announced that Societe Generale de Belgique sold its controlling interest in CBR to Heidelberger Zement A.G. of Germany.[35] The two cement companies were of comparable size and their combined sales of more than $3 billion made the new group the fourth largest European cement industry. Geographically, their business areas were very complementary, both in Europe and in North America. In Europe, CBR operated 10 cement plants in Belgium, the Netherlands, the Czech Republic, and Poland. CBR also had six cement plants in Western Canada and Western United States. *(See World Review, Germany for Heidelberger plants.)*

Brazil.—Cimento Correa Industrial, one of Brazil's leading cement producers, opened the Bodoquena plant, Mato Grosso do Sul, with a cement production capacity of 1,800 tons per day.[36] Lone Star Industries, Inc., sold its 49.6% share in its Brazilian cement subsidiary, Cimento Portland, to Paris-based Lafarge Coppee. Lafarge owned the other 50.4% of the company. Cimento Portland operated four plants in Brazil with about 2.2 million mt/yr capacity, according to R. Huhta of Rock Products.

Canada.—Essroc Canada merged its Quebec operations with those of Ciment Quebec, forming a new company. The new company included all of the cement manufacturing and distribution facilities of both Essroc and Ciment Quebec, as well as their ready-mixed concrete, concrete products, and aggregate operations.

China.—Guangzhou Investment Co. of Hong Kong purchased a 41% controlling stake in the Chinese Zhujiang Cement plant, of Guangzhou, Hong Kong, for $51 million from Guangzhou International Trust and Investment Corp. (GITIC). GITIC will retain a 49% holding in the plant, which produces 1.2 million mt/yr. The company was to operate as a special joint venture and have a 25-year production license.[37]

France.—Ciments Francais became the first western company to invest in the Russian cement industry by acquiring a 15% stake in the 1.9 million mt/yr Zelenogorsk plant in the Urals for approximately US$100,000.[38]

Germany.—Heidelberger Zement acquired a 42.6% controlling interest in CBR of Belgium for US$640 million. The new grouping was to become the fourth largest building materials supplier in the world. It was to operate either directly or through minority shares, about 39 cement plants in Northern Europe and North America with a combined production capacity of 38 million mt/yr.[39] Combined sales of both companies were expected to be $3 billion. Heidelberger operated six cement plants in Baden-Wurttemberg, Bavaria, and Rhineland in Germany, and held controlling interest in other Germany cement plants, two cement firms in the Czech Republic, three cement plants in Hungary, and one in Croatia. Heidelberger also had a minority interest in S.A. Vicat, a French cement company with seven plants. In North America, Heidelberger had controlling interest in Lehigh Portland Cement Co. with eight cement plants.[40]

Greece.—Greece exported 6.9 million metric tons of cement and clinker, a 15% increase compared to 1992.[41] It produced 13.9 million tons of cement, up 2.2% from the prior year, while it shipped 7.1 million tons within Greece, a 6.3% decrease over the prior year.

Italy.—Italcementi SpA acquired control of Ciments Francais, holding 45.63% of the voting-rights stock of Ciments Francais by yearend 1992. This moved Italcementi into one of the top three cement-producing companies worldwide.[42]

Calcestruzzi SpA, a cement producer, was to acquire Greece's Halkis Cement Co., but was sued by Halkis when it broke off discussions with the Greek company. A Greek court ordered the seizure of $208.7 million in assets in the Greek Heracles General Cement, acquired by Calcestruzzi in 1992.[43]

Japan.—Japan's fourth largest cement producer, Onoda Cement Co., and its sixth largest, Chichibu Cement Co., planned to merge their operations in 1994. The merger was expected to make the company the top cement producer in Japan with a 24% market share. Onoda and Chichibu each operated three plants.[44] In North America, Onoda owns California Portland Cement Co., with three plants and three terminals located in Northern California, Southern California, and another near Phoenix, Arizona. Onoda also has a 50% holding in CPC Terminals, an import operation near Los Angeles, CA.

Korea, Republic of.—Cement production was expected to reach around 50 million tons in 1993. Domestic demand was expected to be less than 46 million tons. The overcapacity seemed to indicate that Korea was planning to export significant amounts of cement. Korea's exporting companies were SsangYong Cement, Tong Yang Cement Corp. and Halla Cement Corp. Cement exports from these companies were likely to find potential markets in China, Hong Kong, Malyasia, Singapore, Taiwan, and Vietnam.[45]

Tong Yang completed kiln 7 at its Samchok plant, raising the company's production capacity to more than 11 million mt/yr.[46] The company was expected to extend its product range to include slag cement. A slag cement facility was to be constructed in Kwang Yang in the southern part of the peninsula and was expected to be operational in 1994. Blast furnace slag would be used from the Pohang Iron and Steel Co. operations.[47]

Halla Cement began construction of a fourth kiln at its Okke plant on the Eastern coast of Korea.[48] The project was to raise production capacity from the existing 5.6 million mt/yr to more than 7 million mt/yr upon completion in 1994. With domestic activity slowing, cement was likely to be exported from the plant, not only to Southeast Asia but also to North America and Latin America.

Mexico.—Cementos Mexicanos (Cemex), Mexico's largest cement producer and among the largest cement companies in the world, acquired Cementos Hidalgo, with a production capacity of 1,750 mt/d in Hidalgo, Nuevo Leon, Mexico.[49] Cemex also acquired eight concessions for port facilities offered by the Mexican government in its effort to privatize the country's port operations. The concessions were granted for the construction and operation of modern terminals at government-owned ports and were granted for a 20-year period.

Cementos Apasco, Mexico's second-largest producer, was to invest in a new plant in Tecoman, Colima in Mexico.[50] The cement plant, expected to start production in 1994, was to have a production capacity of 1.25 million mt/yr. The cement was not destined for the export market.

The U.S. Department of Commerce (DOC) increased the dumping margin on Cemex's cement exports to the United States from 30.44% to 40.72% for the period between April 1, 1990 and July 31, 1991. DOC also made a final determination that Cemex's dumping margin for the period August 1, 1991 to July 31, 1992 was 42.74%. Both decisions were made after the Department completed two of its three administrative reviews of the anti-dumping order issued against cement exported from Mexico. The third review, covering the period from August 1, 1992 to July 31, 1993, was still under administration review at yearend. The Mexican cement industry filed a complaint under the General Agreement on Tariffs and Trade (GATT) on the U.S. imposition of tariffs on cement exported to the United States.

Spain.—Ciments Francais purchased an additional 10% of the shares of Cementos Molins. This gave Ciments Francais 35.3% control of Cementos Molins equity. Cementos Molins operated two plants in Spain, producing about 3.5 million mt/yr.[51]

CURRENT RESEARCH

As in past years, research continued on the subject of the use of supplementary cementing materials (SCM's). Use of SCM's in reducing expansion of concrete and mortar caused by alkali-aggregate reaction was investigated by the Canada Centre for Mineral and Energy Technology (CANMET).[52] A total of 15 fly ashes, slags, condensed silica fumes and natural pozzolans were chosen to represent the wide range of physical and chemical features of SCM's commercially available in Canada. The effectiveness of SCM's in reducing expansion was compared with that of a low-alkali cement.

Coal-burning powerplants have generated a large amount of fly ash in the United States. A small fraction of the fly ash generated was being utilized in various applications, but a need persists to further utilize the fly ash. At Rutgers University in Piscataway, NJ, results from a recent study on development of a cement composite utilizing large amounts of fly ash were presented.[53] A flowable fly ash-cement sand composite was investigated for strength and permeability characteristics at various stages of maturity. The independent variables considered were fly ash content, sand content, and ratio of water to cementitious materials. Results of the study showed that high-volume fly ash composite could be proportioned to obtain compressive strengths as high as 21 Megapascals (MPa) or 3,000 psi after 180 days.

At the University of Pennsylvania in University Park, PA, the potential for use of fly ash and slag to be used as the main components in cement was studied. Alkali-activated fly ash-slag cement (AFC) was studied as a matrix for immobilization of nuclear waste.[54] The AFC was characterized by high early strength, high ultimate strength, low porosity, lower solubilities of the hydrates, and high resistance to chemical corrosion, in addition to freezing and thawing. All of these advanced properties are favorable to the immobilization of nuclear wastes.

An investigation was carried out at the Delft University of Technology in The Netherlands involving the cement equivalence factors for fly ash in concrete.[55] The work was part of research aimed at taking the contribution of fly ash to strength development and other properties of concrete into account with respect to the minimum cement content and maximum water-cement ratio required to achieve these properties. Dutch Concrete Standards were used. Three cements were studied — ordinary Portland, rapid hardening and Portland blast furnace slag cement. Four fly ashes, including two with low NO_x, were used for the study. Concrete compositions with a range of water-cement ratios, two fly-ash cement ratios, and three curing regimes were studied as functions of concrete compressive strength. The test results showed that the contribution of fly ash to strength was strongly dependent on the water-cement ratio, the type of cement, the fly ash quality, and the concrete age. The equivalence factor increased when the water-cement ratio decreased. This dependence was highest for rapid hardening Portland cement and lowest for the Portland blast furnace slag cement.

At the Building Research Establishment in Watford, England, studies were conducted on blended high alumina cement (HAC) that could lead to its use in structural concrete.[56] Cements were studied that were made by blending HAC with granulated blast furnace slag. The compressive strength of such concretes increased with time when kept in hot, wet conditions.

Research at the Slovak Academy of Sciences in the Slovak Republic was devoted to the study of the influence of the developed alkali-silicate admixture on mortar properties.[57] The results showed that the admixture significantly increased the strength of the mortars made from portland cement and silica fume or blast furnace slag. Further results showed that the mortars with alkali-silica admixture had an increased content of hydration products and had a substantially more dense pore structure than mortars of the same composition, but without the admixture.

Research at the Israel Institute of Technology was intended to clarify the nature of concrete strengthening in the presence of silica fume.[58] Compressive strength development of high-strength concrete and its paste-matrix was investigated. The results indicated that carbon black was effective in modifying the basic concrete-matrix strength relationship to an extent similar to that obtained by silica fume. It was suggested that the mechanism by which silica fume affects the concrete behavior was of a physical origin and was based on microfiller effect, prior to its action as a pozzolanic material. The microfiller effect was of greater significance to strength enhancement.

In the United Kingdom, the introduction and progressive development of soil stabilization of the natural soil conditions at Gatwick, Stansted, Heathrow and Glasgow Airports was studied.[59] The dual use of both lime and cement to modify and strengthen the natural subgrades and earthwork formation were described. The prime object of the paper was to make available full practical details of large-scale lime and cement soil stabilization work.

Continuing interest has been shown on materials that can be used in developing countries to complement cement. At the Wisconsin Department of Transportation, rice husk ash (RHA) was studied and found to possess some pozzolanic properties.[60] RHA could reduce the cost of building in Nigeria, since it can be used to replace cement in sandcrete blocks that are the major cost component of the most common building forms in the country. For a given hydration period and mix proportions, the strength of the blocks decreased with increasing RHA content. RHA could replace cement up to 30% or 40% for a sandcrete block or sandcrete mix respectively.

Developed countries could use sludge from municipal sewage treatment together with limestone and clay as raw materials for making cementitious building material.[61] A ground mixture of the raw materials was incinerated to produce cement. The effects of mixture compositions, incineration temperatures, and incineration durations on the properties of cement were investigated. From the results, an optimum condition of mixture composition of the raw materials, incineration temperature and duration, and curing condition upon the highest possible strength development of the cement was determined. The study showed that sewer sludge could be used to produce cement satisfying the strength requirements for masonry cement.

In Australia, the manufacture of cements based on calcium sulfoaluminate energy, as compared with ordinary portland cements, was studied.[62] The manufacture of cements based on calcium sulfoaluminates required lower firing temperatures and lower grinding energy when compared with ordinary portland cements. Some of the low-energy cements could be formulated in order to develop high early strength and other performances similar to ordinary portland cements. It was found that a number of industrial wastes and by-products such as phosphogypsum, bauxite fines, as well as fly ash and blast furnace slag, could be employed without negatively affecting the hydraulic behavior of these cements.

At the Institute of Materials in Athens, Greece, the diffusion of water into hardened cement samples containing different kinds of additives was studied for the first time using nuclear magnetic resonance imaging (NMRI).[63] The results indicated that NMRI could be used as a research and industrial method to evaluate the properties (e.g., permeability and durability) of the final cement product.

Composite cements were being considered for use in the construction of low-to-intermediate level radioactive waste repositories.[64] The interactions of ordinary portland cement and pulverized fuel ash mixes with high-sulfate- and high-carbonate-bearing ground waters at temperatures that could be attained in a repository were investigated as part of a larger work being carried out at the Building Research Establishment in the United Kingdom.

Other research focused on improvements to cement plant equipment.[65] The Group Cementos Lemona, S.A. in Spain, constructed a covered storage area for an effective capacity of 47,000 tons of cement clinker. The purpose was to avoid handling materials in open spaces, to increase storage capacity, to reduce the dust emission that is unavoidable in an open air store with overhead cranes, and to facilitate loading and unloading operations for lorries.

A large number of cement plants are still based on the wet process. This process includes preparation of slurry that is either fed directly to the kiln or first treated in a filtration unit.[66] The evaporation of the large amount of water results in elevated fuel bills. Plants could convert to a semi-dry-process—somewhat between the wet and dry—in order to increase market production, reduce production costs, and generally modernize the plant. The wet-process kiln could be converted to the semi-dry process by converting the kiln to a cyclone preheater kiln, with or without calciner, and then drying the feed to raw meal in a separate dryer. A dryer with a conventional preheater or a compact kiln system could be used for this purpose.

Gas leakage through a cemented wellbore annuli has been a major problem in many oil wells in the world and specifically in the United States.[67] Gas leakage could occur as a result of bad cement-formation bonding caused by incompatible contraction-expansion mechanism during cement setting. Work at the University of Oklahoma proposed the use of new cementing additives that could reduce the effect of the expansion-contraction mechanism during the cement slurry setting. The additives-filled contraction induced voids within the cement structure and between the pipe and cement, leading to an impermeable cement, thus eliminating the existence of micro-fractures and micro-annulus. The materials were economical to use and readily available. It was proposed that the cement bond index be estimated in the laboratory using the ultrasonic test prior to the cement job.

OUTLOOK

Demand for cement was expected to increase due to pent-up demand for highway construction and some residential construction. In addition, heavy flooding in the Midwest damaged many homes and structures that would eventually need to be replaced.

Cement prices were forecast to continue to rise following cement price increases that began in 1993.

Cement imports were expected to continue to increase as cement plants met their capacity.

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TABLE 1
SALIENT CEMENT STATISTICS

(Thousand metric tons unless otherwise specified)

	1989	1990	1991	1992	1993
United States:[1]					
Production[2]	70,025	69,954	[r]67,193	[r]69,585	73,807
Shipments from mills[2] [3]	78,234	78,199	[r]68,999	[r]69,203	72,770
Value[2] [3] [4] thousands	$4,242,931	$4,280,105	[r]$3,832,096	[r]$3,779,286	$4,049,820
Average value per ton[2] [3] [4]	$54.23	$54.73	[r]$55.54	[r]$54.61	$55.65
Stocks at mills,[2] Dec. 31	5,715	5,637	[r]6,009	[r]5,272	4,788
Exports	464	503	633	746	625
Imports for consumption	14,280	12,041	7,893	6,166	7,060
Consumption, apparent[5] [6]	82,260	81,305	[r]74,000	[r]75,400	81,700
World: Production	[r]1,148,912	[r]1,149,369	[r]1,184,530	[r]1,241,217	[e]1,303,360

[e]Estimated. [r]Revised.

[1] Excludes Puerto Rico and the U.S. Virgin Islands.

[2] Portland and masonry cement only.

[3] Includes imported cement shipped by domestic producers.

[4] Value received, f.o.b. mill, excluding cost of containers.

[5] Quantity shipped plus imports minus exports.

[6] Adjusted to eliminate duplication of imported clinker and cement shipped by domestic cement manufacturers.

TABLE 2
PORTLAND CEMENT PRODUCTION, CAPACITY, AND STOCKS IN THE UNITED STATES, BY DISTRICT[1]

District	1992					1993				
	Plants active during year	Production[2] (thousand metric tons)	Capacity[3]		Stocks[4] at mills, Dec. 31 (thousand metric tons)	Plants active during year	Production[2] (thousand metric tons)	Capacity[3]		Stocks[4] at mills, Dec. 31 (thousand metric tons)
			Finish grinding (thousand metric tons)	Percent utilized				Finish grinding (thousand metric tons)	Percent utilized	
New York and Maine	5	2,881	3,996	72.1	244	5	3,298	4,550	72.5	227
Pennsylvania, eastern	8	3,824	4,782	80.0	354	8	3,848	4,833	79.6	339
Pennsylvania, western	4	1,496	1,991	75.1	152	4	1,517	1,961	77.4	139
Illinois	4	2,533	2,867	88.4	174	4	2,431	2,971	81.8	102
Indiana	4	2,207	2,803	78.7	177	4	2,065	2,708	76.3	165
Michigan	5	4,900	5,720	85.7	W	5	5,115	5,756	88.9	314
Ohio	4	1,321	1,996	66.2	75	4	1,494	2,064	72.4	78
Iowa, Nebraska, South Dakota	6	3,754	5,488	68.4	351	6	3,656	5,761	63.5	265
Kansas	4	1,372	1,769	77.6	137	4	1,382	1,796	76.9	109
Missouri	5	[r]4,256	4,548	[r]93.6	356	5	4,057	4,808	84.4	334
Florida	6	2,664	4,740	56.2	239	6	3,470	4,770	72.7	193
Georgia and South Carolina	5	3,001	4,353	68.9	177	5	3,212	4,368	73.5	246
Maryland, Virginia, West Virginia	6	2,811	4,001	70.3	329	6	3,036	4,082	74.4	244
Alabama	5	[r]3,754	[r]4,654	80.7	[r]216	5	3,748	4,481	83.6	219
Kentucky, Mississippi, Tennesse	4	1,894	2,184	86.7	167	4	2,010	2,129	94.4	178
Arkansas and Oklahoma	5	2,043	2,722	75.1	200	4	2,461	2,762	89.1	167
Texas, northern	6	3,085	4,507	68.4	227	6	3,519	4,466	78.8	191
Texas, southern	6	4,022	5,364	75.0	147	6	4,609	5,529	83.4	131
Arizona and New Mexico	3	1,414	2,288	61.8	90	3	1,707	2,288	74.6	46
Colorado and Wyoming	4	1,705	2,308	73.9	129	4	1,867	2,377	78.5	100
Idaho, Montana, Nevada, Utah	6	2,071	2,294	90.3	141	6	2,064	2,312	89.3	142
Alaska, Hawaii, Oregon, Washington	5	1,665	2,295	72.5	121	4	1,769	2,204	80.3	143
California, northern	3	2,425	2,880	84.2	W	3	2,427	2,867	84.7	80
California, southern	8	5,744	7,398	77.6	261	8	6,084	7,725	78.8	236
Total or average[5]	121	66,841	87,947	76.0	4,872	119	70,845	89,567	79.1	4,389
Puerto Rico	2	1,299	1,956	66.4	32	2	1,310	1,957	66.9	33

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total or average."

[1] Includes Puerto Rico. Includes data for three white cement facilities as follows: California (1), Pennsylvania (1), and Texas (1). Includes data for grinding plants as follows: California (1), Florida (2), Iowa (1), Michigan (1), Ohio (1), Pennsylvania (1), and Texas (1).

[2] Includes cement produced from imported clinker.

[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.

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

TABLE 3

CLINKER CAPACITY AND PRODUCTION IN THE UNITED STATES IN 1993,[1] BY DISTRICT

District	Active plants Process used			Total	Number of kilns	Daily capacity (thousand metric tons)	Average number of days maintenance	Apparent annual capacity[2] (thousand metric tons)	Production[3] (thousand metric tons)	Percent utilized
	Wet	Dry	Both							
New York and Maine	4	1	—	5	6	11	79	3,157	3,051	96.6
Pennsylvania, eastern	2	5	—	7	16	14	44	4,443	3,689	83.0
Pennsylvania, western	3	1	—	4	8	6	56	1,834	1,620	88.3
Illinois	—	4	—	4	8	8	31	2,524	2,270	89.9
Indiana	2	2	—	4	8	8	37	2,689	2,149	79.9
Michigan	1	2	—	3	8	12	35	4,075	3,896	95.6
Ohio	2	1	—	3	5	5	87	1,347	1,240	92.1
Iowa, Nebraska, South Dakota	—	4	1	5	9	13	49	3,925	3,347	85.3
Kansas	2	2	—	4	11	5	47	1,691	1,458	86.2
Missouri	2	3	—	5	7	13	55	4,106	3,975	96.8
Florida	2	2	—	4	8	9	28	3,182	3,052	95.9
Georgia and South Carolina	2	2	1	5	11	11	27	3,743	3,139	83.9
Maryland, Virginia, West Virginia	2	4	—	6	20	12	45	3,671	3,102	84.5
Alabama	—	5	—	5	7	14	45	4,290	3,567	83.1
Kentucky, Mississippi, Tennesse	2	2	—	4	5	6	34	2,008	1,865	92.9
Arkansas and Oklahoma	2	2	—	4	10	8	36	2,517	2,354	93.5
Texas, northern	3	3	—	6	14	12	37	3,941	3,586	91.0
Texas, southern	—	4	1	5	6	13	33	4,162	3,734	89.7
Arizona and New Mexico	—	3	—	3	9	7	26	2,288	1,577	68.9
Colorado and Wyoming	1	3	—	4	6	6	25	1,933	1,697	87.8
Idaho, Montana, Nevada, Utah	4	2	—	6	9	6	34	1,923	1,941	100.9
Alaska, Hawaii, Oregon, Washington	1	3	—	4	4	5	59	1,560	1,410	90.4
California, northern	—	3	—	3	3	9	69	2,485	2,349	94.5
California, southern	—	8	—	8	16	21	60	6,357	5,675	89.3
Total or average[4]	37	71	3	111	214	234	NA	73,851	65,745	89.0
Puerto Rico	—	1	1	2	7	7	15	2,437	1,212	49.7

NA Not available.

[1] Includes Puerto Rico and white cement producing facilities.

[2] Calculated on individual company data; 365 days minus average days for maintenance times the reported 24 hour capacity.

[3] Includes production reported for plants that added or shut down kilns during the year.

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

TABLE 4

RAW MATERIALS USED IN PRODUCING PORTLAND CEMENT IN THE UNITED STATES[1]

(Thousand metric tons)

Raw materials	1991	1992[r]	1993
Calcareous:			
Limestone (includes aragonite, marble, chalk)	[r]71,213	70,897	78,958
Cement rock (includes marl)	[r]19,140	23,388	19,186
Coral	1,577	1,577	754
Argillaceous:			
Clays	[r]4,275	4,432	4,200
Shale	[r]4,147	4,142	5,066
Other (includes staurolite, bauxite, aluminum dross, alumina, volcanic material, other)	[r]354	314	442
Siliceous:			
Sand and calcium silicate	[r]1,794	1,954	2,046
Sandstone, quartzite, other	[r]541	571	571
Ferrous: Iron ore, pyrites, millscale, other iron bearing material	[r]886	914	1,097
Other:			
Gypsum and anhydrite	[r]3,287	3,531	3,696
Blast furnace slag	[r]79	72	38
Fly ash	[r]670	957	888
Other, n.e.c.	[r]390	378	224
Total[2]	[r]108,352	113,127	117,165

[r] Revised.

[1] Includes Puerto Rico.

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

TABLE 5
MASONRY CEMENT PRODUCTION AND STOCKS IN THE UNITED STATES, BY DISTRICT

District	1992 Plants active during year	1992 Production (thousand metric tons)	1992 Stocks[1] at mills, Dec. 31 (thousand metric tons)	1993 Plants active during year	1993 Production (thousand metric tons)	1993 Stocks[1] at mills, Dec. 31 (thousand metric tons)
New York and Maine	4	88	19	5	84	19
Pennsylvania, eastern	6	203	43	6	165	39
Pennsylvania, western	4	94	12	4	83	13
Illinois	—	—	W	—	—	(2)
Indiana	4	W	W	4	W	W
Michigan	5	213	40	5	216	38
Ohio	3	W	W	3	W	W
Iowa, Nebraska, South Dakota	4	42	11	4	49	6
Kansas	4	20	14	4	W	20
Missouri	3	W	W	3	W	W
Florida	4	305	26	4	351	29
Georgia and South Carolina	4	304	34	4	374	30
Maryland, Virginia, West Virginia	5	216	35	5	199	20
Alabama	4	237	28	4	277	39
Kentucky, Mississippi, Tennessee	3	89	11	3	105	13
Arkansas and Oklahoma	4	98	16	4	102	17
Texas, northern	4	W	8	4	93	9
Texas, southern	5	75	7	5	152	16
Arizona and New Mexico	3	41	5	3	W	4
Colorado and Wyoming	2	W	W	2	W	W
Idaho, Montana, Nevada, Utah	3	W	W	2	W	W
Alaska, Hawaii, Oregon, Washington	1	W	W	2	W	4
California, northern	1	W	W	1	W	W
California, southern	1	W	W	2	W	W
Total or average[3]	81	2,744	400	83	2,96	399

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

[1] Includes imported cement.

[2] Less than 1/2 unit.

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

TABLE 6
CLINKER PRODUCED AND FUEL CONSUMED BY THE PORTLAND CEMENT INDUSTRY IN THE UNITED STATES,[1] BY PROCESS

Process	Clinker produced			Fuel consumed			Waste fuel		
	Plants active during year	Quantity (thousand metric tons)	Percent of total	Coal (thousand metric tons)	Oil (thousand liters)	Natural gas (thousand cubic meters)	Tires (thousand metric tons)	Solid (thousand metric tons)	Liquid (thousand liters)
1992:									
Wet	39	18,228	28.4	2,847	103,084	401,078	—	—	—
Dry	70	43,744	68.0	5,832	49,782	587,014	—	—	—
Both	4	2,322	3.6	327	477	62,787	—	—	—
Total[2]	113	64,294	100.0	9,007	153,343	1,050,879	—	—	—
1993:									
Wet	37	19,700	29.4	3,328	10,152	231,111	20	74	489,988
Dry	72	44,696	66.8	6,298	35,386	375,769	50	15	253,706
Both	4	2,561	3.8	408	8	61,143	—	—	—
Total[2]	113	66,957	100.0	10,034	45,546	668,024	70	90	743,693

[1] Includes Puerto Rico.
[2] Data may not add to totals shown because of independent rounding.

TABLE 7
ELECTRIC ENERGY USED AT PORTLAND CEMENT PLANTS IN THE UNITED STATES,[1] BY PROCESS

Process	Electric energy used						Finished cement produced (thousand metric tons)	Average electric energy used (per ton of cement produced kilowatt-hours)
	Generated at portland cement plants		Purchased		Total			
	Plants active during year	Quantity (million kilowatt-hours)	Plants active during year	Quantity (million kilowatt-hours)	Quantity (million kilowatt-hours)	Percent		
1992:								
Wet	—	—	38	2,661	2,661	26.2	18,518	14.4
Dry	6	525	69	6,582	7,107	70.0	45,318	15.7
Both	1	110	3	274	384	3.8	2,485	15.5
Total[2]	7	634	110	9,518	10,152	100.0	66,322	15.3
Percent of total electric energy used	—	6.2	—	93.8	—	—	—	—
1993:								
Wet	1	149	34	2,412	2,562	25.6	20,303	12.6
Dry	6	571	65	6,449	7,020	70.2	47,290	14.8
Both	—	—	4	421	421	4.2	2,677	15.7
Total[2]	7	720	103	9,282	10,002	100.0	70,270	14.2
Percent of total electric energy used	—	7.2	—	92.8	—	—	—	—

[1] Includes Puerto Rico.
[2] Data may not add to totals shown because of independent rounding.

TABLE 8
SHIPMENTS OF PORTLAND CEMENT FROM MILLS IN THE UNITED STATES,[1] IN BULK AND IN CONTAINERS, BY TYPE OF CARRIER

(Thousand metric tons)

	Shipments from plant to terminal		Shipments to ultimate consumer				Total shipments[3]
			From plant to consumer		From terminal to consumer		
	In bulk	In containers	In bulk	In containers	In bulk	In containers	
1992:							
Railroad	[r]9,757	[r]63	[r]2,443	[r]368	[r]1,193	—	[r]4,003
Truck	[r]3,323	125	[r]38,151	[r]1,758	[r]18,601	361	[r]58,871
Barge and boat	[r]8,126	8	[r]161	—	[r]913	—	[r]1,075
Unspecified[2]	[r]2,187	8	[r]1,952	60	1,869	14	[r]3,894
Total[3]	[r]23,393	204	[r]42,707	[r]2,186	[r]22,575	374	[r] [4]67,842
1993:							
Railroad	8,879	89	3,782	495	490	41	4,808
Truck	2,955	131	41,040	1,822	19,063	454	62,378
Barge and boat	6,319	12	582	—	477	—	1,059
Unspecified[2]	484	—	2,377	12	455	15	2,859
Total[3]	18,637	232	47,780	2,329	20,485	510	[5]71,104

[r] Revised.

[1] Includes Puerto Rico.

[2] Includes cement used at plant.

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

[4] Bulk shipments were 96.2% and container (bag) shipments were 3.8%.

[5] Bulk shipments were 96.0% and container (bag) shipments were 4.0%.

TABLE 9

PORTLAND CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES, BY DISTRICT[1]

District	1992			1993		
	Quantity (thousand metric tons)	Value (thousands)	Average per ton	Quantity (thousand metric tons)	Value (thousands)	Average per ton
New York and Maine	2,833	$145,977	$51.53	3,055	$154,901	$50.70
Pennsylvania, eastern	3,582	180,307	50.34	3,780	195,824	51.81
Pennsylvania, western	1,434	78,580	54.80	1,484	81,501	54.92
Illinois	2,595	118,982	45.85	2,592	130,962	50.53
Indiana	2,238	110,737	49.48	2,235	117,638	52.63
Michigan	4,997	262,063	52.44	4,922	301,425	61.24
Ohio	1,320	77,053	58.37	1,428	86,338	60.46
Iowa, Nebraska, South Dakota	3,863	193,782	50.16	3,467	210,971	60.85
Kansas	1,552	79,464	51.20	1,560	83,390	53.46
Missouri	4,287	[r]225,272	[r]52.55	4,274	211,765	49.55
Florida	2,898	161,969	55.89	3,428	173,329	50.56
Georgia and South Carolina	3,009	142,785	47.45	3,442	181,546	52.74
Maryland, Virginia, West Virginia	2,765	149,829	54.19	3,092	157,658	50.99
Alabama	3,722	180,763	48.57	3,345	170,300	50.91
Kentucky, Mississippi, Tennessee	2,081	105,534	50.71	2,255	113,196	50.20
Arkansas and Oklahoma	1,790	76,470	42.72	2,335	107,946	46.23
Texas, northern	2,809	142,874	50.86	3,377	178,152	52.75
Texas, southern	4,032	220,564	54.70	4,677	215,887	46.16
Arizona and New Mexico	1,386	79,876	57.63	1,707	107,621	63.05
Colorado and Wyoming	1,831	106,938	58.40	2,120	138,420	65.29
Idaho, Montana, Nevada, Utah	2,000	135,706	67.85	2,034	147,731	72.63
Alaska, Hawaii, Oregon, Washington	1,796	151,674	84.45	1,518	131,399	86.56
California, northern	1,979	134,337	67.88	1,935	109,608	56.64
California, southern	5,310	293,679	55.31	5,732	312,291	54.48
Total[2] [3] or average	[r]66,107	[r]3,555,216	53.80	69,795	3,819,797	54.73
Foreign imports[4]	438	24,752	56.49	—	—	—
Puerto Rico	1,298	119,643	92.17	1,309	124,999	95.49
Grand total[3] [5] or average	67,842	3,699,611	54.53	71,104	3,944,796	55.48
Grand total short tons	74,783	XX	XX	78,379	XX	XX

[r] Revised. XX Not applicable.

[1] Includes Puerto Rico. Includes data for three white cement facilities as follows: California (1), Pennsylvania (1), and Texas (1). Includes data for grinding plants as follows: California (1), Florida (2), Iowa (1), Michigan (1), Ohio (1), Pennsylvania (1), and Texas (1).

[2] Includes cement produced from imported clinker.

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

[4] Cement imported and distributed by domestic producers only.

[5] Does not include cement consumed at plant.

TABLE 10
MASONRY CEMENT SHIPPED BY PRODUCERS IN THE UNITED STATES,[1] BY DISTRICT

District	1992			1993		
	Quantity (thousand metric tons)	Value (thousands)	Average per ton	Quantity (thousand metric tons)	Value (thousands)	Average per ton
New York and Maine	[r]86	$6,300	[r]$73.26	85	$6,319	$74.34
Pennsylvania, eastern	207	15,665	75.68	171	12,240	71.58
Pennsylvania, western	88	[r]7,467	[r]84.85	79	6,692	84.71
Illinois	W	W	—	W	W	—
Indiana	W	W	73.88	W	W	76.79
Michigan	213	20,381	95.69	220	17,707	80.49
Ohio	103	10,260	99.61	105	12,813	122.03
Iowa, Nebraska, South Dakota	59	5,919	100.32	52	4,115	79.13
Kansas	30	1,914	63.80	31	2,099	67.71
Missouri	W	W	[r]55.14	W	W	44.13
Florida	310	22,424	72.34	356	27,645	77.65
Georgia and South Carolina	302	22,810	75.53	360	27,859	77.39
Maryland, Virginia, West Virginia	188	11,854	63.05	204	16,184	79.33
Alabama	193	13,069	67.72	260	20,610	79.27
Kentucky, Mississippi, Tennessee	93	6,258	67.29	106	8,108	76.49
Arkansas and Oklahoma	87	4,513	51.87	89	6,889	77.40
Texas, northern	W	W	94.56	W	W	78.85
Texas, southern	75	5,065	67.53	154	11,184	72.62
Arizona and New Mexico	W	W	60.98	W	3,254	57.09
Colorado and Wyoming	W	W	59.19	W	W	76.70
Idaho, Montana, Nevada, Utah	W	W	54.00	W	W	89.50
Alaska, Hawaii, Oregon, Washington	11	W	170.73	10	W	120.50
California, northern	W	W	77.55	W	W	77.78
California, southern	W	W	60.16	W	W	66.79
Total[2] [3] or average	[r]2,658	[r]199,318	[r]74.99	2,975	230,022	77.32
Grand total thousand short tons	[r]2,930	XX	XX	3,279	XX	XX

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total or average." XX Not applicable.

[1] Does not include quantities produced on the job by masons.

[2] Calculated on unrounded data.

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

TABLE 11
CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand metric tons)

Destination and origin	Portland cement			Masonry cement		
	1991	1992	1993	1991	1992	1993
Destination:						
Alabama	1,195	1,297	1,296	95	106	122
Alaska	89	101	106	W	W	W
Arizona	1,582	1,672	1,845	W	W	W
Arkansas	673	791	818	39	45	51
California, northern	2,966	2,776	2,820	—	—	—
California, southern	5,412	5,200	4,846	W	W	W
Colorado	1,176	1,765	2,086	13	15	19
Connecticut[2]	598	596	587	12	13	15
Delaware[2]	175	233	233	8	8	9
District of Columbia[2]	173	91	108	(3)	(3)	(3)
Florida	[r]4,650	4,925	5,262	338	354	437
Georgia	2,115	2,223	2,483	144	158	186
Hawaii	497	514	442	8	7	7
Idaho	310	373	405	(3)	[r]1	1
Illinois	1,236	1,330	1,301	21	23	23
Chicago, metropolitan[2]	1,802	2,001	1,998	47	51	50
Indiana	1,602	1,778	1,757	80	91	91
Iowa	1,187	1,398	1,308	11	13	12
Kansas	1,058	1,098	1,124	14	14	15
Kentucky	974	1,146	1,180	70	84	86
Louisiana[2]	1,621	1,556	1,689	34	41	46
Maine	220	248	224	5	6	5
Maryland	1,061	1,010	1,015	82	75	79
Massachusetts[2]	[r]745	881	1,002	22	24	24
Michigan	2,073	2,191	2,285	100	117	115
Minnesota[2]	1,313	1,428	1,388	31	35	34
Mississippi	637	727	880	37	44	45
Missouri	1,596	1,963	1,882	36	35	38
Montana	167	230	415	1	[r]1	1
Nebraska	774	808	877	9	10	11
Nevada	896	985	1,131	(3)	(3)	(3)
New Hampshire[2]	[r]193	215	222	6	7	6
New Jersey[2]	[r]1,134	1,335	1,425	[r]44	50	54
New Mexico	500	567	688	5	5	6
New York, eastern	479	537	569	24	24	24
New York, western	[r]807	792	815	38	38	34
New York, metropolitan[2]	1,085	868	783	44	35	35
North Carolina[2]	1,691	1,810	1,946	197	210	237
North Dakota[2]	[r]220	267	239	3	4	3
Ohio	2,824	2,895	3,225	147	157	169
Oklahoma	1,069	997	1,051	27	31	35
Oregon	810	773	818	(3)	(3)	(3)
Pennsylvania, eastern	[r]1,637	1,736	1,756	58	57	57
Pennsylvania, western	1,137	1,187	1,080	65	74	73
Rhode Island[2]	129	126	134	4	4	3

See footnotes at end of table.

TABLE 11—Continued

CEMENT SHIPMENTS, BY DESTINATION AND ORIGIN[1]

(Thousand metric tons)

Destination and origin	Portland cement			Masonry cement		
	1991	1992	1993	1991	1992	1993
Destination—Continued:						
South Carolina	908	919	970	99	98	106
South Dakota	247	312	331	5	5	5
Tennessee	[r]1,383	1,402	1,536	122	142	165
Texas, northern	3,001	3,330	3,784	68	104	133
Texas, southern	[r]3,408	3,605	3,810	74	68	83
Utah	715	819	910	3	2	2
Vermont[2]	95	101	107	4	3	4
Virginia	1,483	1,500	1,621	132	131	145
Washington	1,589	1,621	1,623	7	7	5
West Virginia	375	419	441	26	30	32
Wisconsin	[r]1,552	1,788	1,811	35	40	41
Wyoming	[r]258	213	230	2	1	1
U.S. total[4]	[r]69,305	73,470	76,717	[r]2,495	2,699	2,984
Foreign countries[5]	220	302	345	52	49	53
Puerto Rico	1,254	1,294	1,306	—	—	—
Total shipment[4]	[r]70,779	75,066	78,368	[r]2,547	2,748	3,037
Total shipment (thousand short tons)	[r]78,020	82,746	86,386	[r]2,808	3,029	3,348
Origin:						
United States[6]	[r]62,471	68,404	71,053	[r]2,384	2,576	2,901
Puerto Rico	1,254	1,294	1,306	—	—	—
Foreign:[7]	[r]7,054	5,368	6,009	[r]162	172	136
Total shipment[4]	[r]70,779	75,066	78,368	[r]2,547	2,748	3,037
Total shipment thousand short tons	[r]78,020	82,746	86,386	[r]2,808	3,029	3,348

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Foreign countries."

[1] Includes cement produced from imported clinker and imported cement shipped by domestic producers, Canadian cement manufacturers, and other importers. Includes Puerto Rico.

[2] Has no cement producing plants.

[3] Less than 1/2 unit.

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

[5] Direct shipments by producers to foreign countries and U.S. possessions and territories; includes States indicated by the symbol W.

[6] Includes cement produced from imported clinker by domestic producers.

[7] Imported cement distributed by domestic producers, Canadian cement manufacturers, and other importers. Origin of imports withheld to avoid disclosing company proprietary data.

TABLE 12

CEMENT SHIPMENTS,[1] BY DESTINATION (REGION AND SUBREGION)

Region and subregion[2]	Portland cement				Masonry cement			
	Thousand metric tons		Percent of grand total		Thousand metric tons		Percent of grand total	
	1992	1993	1992	1993	1992	1993	1992	1993
Northeast:								
New England	2,167	2,276	3	3	57	56	2	2
Middle Atlantic	6,455	6,428	9	8	278	278	10	9
Total	8,622	8,704	12	11	335	334	12	11
South:								
Atlantic	13,131	14,078	18	19	1,065	1,233	39	41
East Central	4,572	4,892	6	6	376	419	14	14
West Central	10,279	11,152	14	15	289	348	11	12
Total[3]	27,982	30,122	38	39	1,730	2,000	64	67
Midwest:								
East	11,983	12,377	16	16	479	490	18	16
West	7,274	7,149	10	9	116	118	4	4
Total	19,257	19,526	26	25	595	608	22	20
West:								
Mountain	6,624	7,710	9	10	25	30	1	1
Pacific	10,985	10,655	15	14	14	12	1	—
Total[4]	17,609	18,365	24	24	39	42	2	1
Grand total[3]	73,470	76,717	100	100	2,699	2,984	100	100

[1] Includes imported cement shipped by importers.

[2] Geographic regions as designated by the U.S. Department of Commerce, Bureau of the Census.

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

[4] Does not include proprietary data from table 11.

TABLE 13
PORTLAND CEMENT SHIPMENTS IN 1993, BY DISTRICT OF ORIGIN AND TYPE OF CUSTOMER[1]

(Thousand metric tons)

District of origin	Building material dealers	Concrete product manufacturers[2]	Ready mixed concrete	Contractors[3]	Oil well, mining, waste[4]	Government and miscellanous [5]	Total[6]
New York and Maine	91	197	608	21	—	2,138	3,054
Pennsylvania, eastern	375	676	1,887	218	—	624	3,780
Pennsylvania, western	92	191	835	195	22	151	1,484
Illinois	319	184	1,808	169	113	—	2,593
Indiana	85	319	1,708	98	9	16	2,234
Michigan	820	579	2,878	407	12	228	4,922
Ohio	32	152	1,063	171	10	—	1,429
Iowa, Nebraska, South Dakota	89	492	2,321	347	52	165	3,467
Kansas	114	83	1,014	144	21	184	1,560
Missouri	162	378	2,576	510	—	648	4,274
Florida	229	535	1,535	192	1	937	3,428
Georgia and South Carolina	174	604	2,338	182	2	141	3,442
Maryland, Virginia, West Virginia	39	311	1,320	93	—	1,328	3,092
Alabama	256	578	2,175	264	2	70	3,346
Kentucky, Mississippi, Tennessee	114	232	1,755	100	6	49	2,255
Arkansas and Oklahoma	25	108	1,211	308	28	656	2,335
Texas, northern	141	341	1,880	244	288	483	3,377
Texas, southern	330	210	2,177	213	176	1,571	4,677
Arizona and New Mexico	52	260	1,060	115	11	207	1,707
Colorado and Wyoming	36	299	1,145	618	22	1	2,120
Idaho, Montana, Nevada, Utah	46	159	1,538	200	38	52	2,035
Alaska, Hawaii, Oregon, Washington	90	175	1,080	150	—	24	1,518
California, northern	102	209	1,486	37	86	14	1,935
California, southern	424	717	3,980	474	99	38	5,732
Total[6] or average	4,237	7,988	41,377	5,473	998	9,722	69,794
Puerto Rico	536	118	590	19	—	46	1,309

[1] Includes Puerto Rico.

[2] Concrete product manufacturers included in thousand metric tons: brick-block—1,127 in the United States, 22 in Puerto Rico; precast—675 in the United States, 2 in Puerto Rico; pipe—55 in the United States, 5 in Puerto Rico; and other—5,633 in the United States, and 90 in Puerto Rico. Other includes unspecified amounts of brick/block, precast, and pipe.

[3] Contractors included in thousand metric tons: roadpaving—2,055 in the United States; soil cement—333 in the United States and other—2,427 in the United States and 19 in Puerto Rico. Other includes unspecified amounts of road paving, and soil cement.

[4] Oil well, mining, and waste included in thousand metric tons in the United States: oil well drilling—885; mining—42; and waste stabilization—72.

[5] Included in this amount are cement shipments which were unspecified by type of customer.

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

TABLE 14

PORTLAND CEMENT SHIPPED FROM PLANTS IN THE UNITED STATES,[1] [2] BY TYPE

(Thousand metric tons)

Type	1992	1993
	Quantity	Quantity
General use and moderate heat (Types I and II)	[r]61,844	64,806
High early strength (Type III)	[r]2,529	[r]2,659
Sulfate resisting (Type V)	1,176	1,570
Block	W	471
Oil well	836	804
White	[r]376	263
Portland slag and portland pozzolan	285	264
Expansive	W	W
Regulated fast setting	80	W
Miscellaneous[3]	[r]650	137
Total[4] [5] or average	[r]67,842	71,104
Total thousand short tons	[r]74,783	78,379

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total or average."

[1] Includes Puerto Rico.

[2] Values of portland cement types not collected in 1993: value of grey portland cement $54.97; value of white portland cement $192.40.

[3] Includes waterproof and lowheat (Type IV).

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

[5] Does not include cement consumed at plant.

TABLE 15

AVERAGE MILL VALUE, IN BULK OF CEMENT IN THE UNITED STATES[1]

(Per metric ton)

Year	Portland cement	Prepared masonry cement[2]	All classes of cement
1989	53.94	76.15	54.80
1990	54.53	75.93	55.34
1991[r]	54.65	76.46	55.46
1992[r]	54.53	74.99	55.30
1993	55.48	77.32	56.36

[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 16
U.S. EXPORTS OF HYDRAULIC CEMENT AND CEMENT CLINKER, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992		1993	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
Bahamas, The	74	3,020	131	5,418	44	2,227
Canada	482	33,720	536	34,712	502	36,028
Ghana	12	950	13	1,006	2	145
Mexico	23	3,286	19	3,328	21	3,424
Netherlands	2	417	2	336	2	307
Other[2]	41	4,381	46	3,920	54	5,641
Total[3]	633	45,774	746	48,720	625	47,772
Total thousand short tons	698	XX	823	XX	689	XX

XX Not applicable.

[1] Free alongside ship (f.a.s.) value is the value of exports at the U.S. seaport, or border port of export, based on the transaction price, including inland freight, insurance, and other changes incurred in placing the merchandise alongside the carrier at the U.S. port of exportation. The value excludes the cost of loading.

[2] Includes 47 countries in 1991; 59 in 1992; and 60 in 1993.

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

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991			1992			1993		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs[1]	C.i.f.[2]		Customs[1]	C.i.f.[2]		Customs[1]	C.i.f.[2]
Canada	2,837	117,757	131,992	2,997	121,992	132,003	3,629	147,747	158,670
Colombia	1,090	39,133	49,900	507	16,744	22,174	550	18,017	23,201
France	427	28,902	35,293	421	23,678	29,037	216	14,833	17,237
Greece	632	21,305	29,071	235	8,143	9,995	282	8,884	11,931
Japan	300	9,664	13,248	278	10,129	13,547	43	1,667	2,116
Korea, Republic of	—	—	—	—	—	—	33	891	1,254
Mexico	947	35,291	42,817	825	32,098	38,023	783	29,074	35,482
Spain	634	22,654	29,667	446	17,193	24,377	597	25,745	31,382
Venezuela	837	47,743	55,310	54	2,383	2,857	269	9,837	12,344
Other	189	10,837	15,279	400	17,349	25,160	659	26,436	37,721
Total[3]	7,893	333,286	402,577	6,166	249,708	297,174	7,060	283,131	331,337
Total thousand short tons	8,701	XX	XX	6,797	XX	XX	7,782	XX	XX

XX Not applicable.

[1] Customs value price actually paid or payable for merchandise when sold for exportation to the United States, excluding U.S. import duties, freight, insurance, and other charges incurred in bringing the merchandise to the United States.

[2] C.i.f. (Cost, insurance and freight) import value represents the landed value of the merchandise at the first port of arrival in the United States. It is computed by adding "import charges" to the "customs value."

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

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF CLINKER, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991			1992			1993		
	Quantity	Value		Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Australia	(2)	NA	22	81	2,864	4,925	133	4,518	6,417
Canada	545	15,192	16,011	1,003	28,029	28,589	883	27,917	28,262
Colombia	510	13,947	20,043	198	5,553	7,471	239	6,724	9,060
France	84	8,195	9,430	58	7,921	8,844	118	9,458	10,717
Greece	—	—	—	45	2,022	2,522	26	814	1,179
Mexico	—	—	—	(2)	2	2	—	—	—
New Zealand	(2)	NA	149	135	3,849	6,072	78	2,282	3,344
Other	188	5,538	7,753	[r]45	[r]1,351	[r]1,883	30	800	1,074
Total[3]	1,326	42,872	53,408	1,566	51,591	60,307	1,508	52,513	60,054
Total thousand short tons	1,462	XX	XX	1,726	XX	XX	1,662	XX	XX

[r] Revised. NA Not available. XX Not applicable.

[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 19
U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand metric tons and thousand dollars)

Customs district and country	1992 Quantity	1992 Value Customs	1992 Value C.i.f.[1]	1993 Quantity	1993 Value Customs	1993 Value C.i.f.[1]
Anchorage:						
Canada	7	643	1,013	6	655	895
China	—	—	—	14	504	679
Colombia	15	492	864	—	—	—
Japan	15	1,046	1,461	43	1,392	1,782
Total[2]	36	2,181	3,338	62	2,551	3,355
Baltimore:						
Brazil	—	—	—	(3)	12	14
France	—	—	—	(3)	2	2
Japan	(3)	10	13	(3)	46	56
Netherlands	(3)	131	139	(3)	57	60
United Kingdom	—	—	—	(3)	18	22
Total[2]	(3)	141	152	(3)	135	154
Boston:						
Greece	33	1,008	1,068	—	—	—
Netherlands	—	—	—	(3)	24	27
Niger	—	—	—	(3)	12	14
Total[2]	33	1,008	1,068	(3)	36	41
Buffalo:						
Canada	664	36,239	39,146	621	32,841	35,225
Germany	(3)	6	6	—	—	—
United Kingdom	(3)	15	16	—	—	—
Total	664	36,260	39,168	621	32,841	35,225
Charleston:						
United Kingdom	—	—	—	(3)	24	31
Venezuela	12	412	549	—	—	—
Total	12	412	549	1	24	31
Chicago:						
Japan	(3)	20	25	(3)	46	56
Switzerland	—	—	—	(3)	3	3
United Kingdom	(3)	11	12	—	—	—
Total[2]	(3)	32	38	(3)	49	59
Cleveland: Canada	108	3,338	4,305	319	10,801	11,243
ColumbiaSnake:						
China	—	—	—	188	6,891	9,122
Japan	184	6,164	8,243	(3)	2	2
Total[2]	184	6,164	8,243	189	6,893	9,124
Detroit:						
Canada	990	32,400	33,124	1,021	39,866	41,070
Germany	(3)	1	1	—	—	—
Japan	—	—	—	(3)	4	4
United Kingdom	(3)	9	10	—	—	—
Total[2]	990	32,411	33,135	1,021	39,869	41,074
Duluth: Canada	91	3,224	3,795	93	3,352	3,900
El Paso: Mexico	81	3,027	4,000	91	3,322	4,313

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand metric tons and thousand dollars)

Customs district and country	1992			1993		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Great Falls:						
Canada	146	3,223	3,518	279	9,679	10,303
Germany	(3)	9	20	—	—	—
United Kingdom	(3)	45	51	(3)	40	47
Total[2]	146	3,277	3,589	279	9,719	10,350
Honolulu:						
Australia	82	2,864	4,925	132	4,518	6,417
Colombia	73	1,985	2,910	42	1,134	2,084
New Zealand	134	3,849	6,072	78	2,282	3,344
Total	289	8,698	13,907	253	7,933	11,845
Houston-Galveston:						
Germany	(3)	11	12	—	—	—
Japan	(3)	70	88	(3)	90	111
Singapore	—	—	—	(3)	2	3
Spain	—	—	—	33	1,365	1,365
United Kingdom	—	—	—	(3)	11	15
Total	(3)	81	100	33	1,469	1,494
Laredo:						
China	—	—	—	1	242	266
Hong Kong	1	93	117	—	—	—
Mexico	34	2,867	3,284	28	2,376	2,710
Total	35	2,960	3,401	29	2,618	2,976
Los Angeles:						
Colombia	25	826	1,058	—	—	—
Japan	(3)	43	54	(3)	46	54
Mexico	482	18,564	21,480	376	14,338	16,747
Total[2]	508	19,434	22,592	376	14,384	16,801
Miami:						
Belgium	7	464	576	2	219	296
Colombia	152	5,615	7,197	208	7,528	9,539
Denmark	16	1,110	1,419	24	1,397	2,138
Greece	—	—	—	18	664	874
Honduras	2	55	61	—	—	—
Spain	124	5,851	7,359	210	9,911	12,058
United Kingdom	(3)	2	2	(3)	11	11
Venezuela	3	101	127	51	1,910	2,390
Total[2]	305	13,197	16,739	513	21,641	27,307
Milwaukee: Canada	—	—	—	139	4,147	4,884
Minneapolis: Germany	(3)	19	23	(3)	25	28
New Orleans:						
Belgium	(3)	26	28	(3)	28	31
France	79	5,907	7,168	37	3,567	3,989
Spain	142	4,618	8,392	196	7,479	9,224
Total[2]	220	10,551	15,588	233	11,074	13,244
New York:						
Greece	127	4,493	5,659	182	5,529	7,705

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand metric tons and thousand dollars)

Customs district and country	1992			1993		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
New York—Continued:						
Netherlands	(3)	57	80	(3)	6	7
Spain	16	1,478	1,770	22	2,008	2,551
United Kingdom	46	1,368	1,900	22	698	904
Total[2]	190	7,396	9,409	227	8,242	11,167
Nogales: Mexico	227	7,479	9,059	287	8,848	11,456
Norfolk:						
France	48	7,619	8,477	40	7,192	8,104
Greece	75	2,642	3,269	81	2,691	3,352
Netherlands	(3)	95	107	(3)	57	65
Total[2]	123	10,357	11,853	122	9,940	11,521
Ogdensburg:						
Canada	184	6,470	6,783	305	10,408	11,260
Mexico	—	—	—	(3)	13	13
Morocco	1	19	20	—	—	—
United Kingdom	—	—	—	(3)	13	14
Total	184	6,489	6,803	306	10,434	11,286
Pembina: Canada	73	2,348	2,813	69	2,148	2,657
Philadelphia:						
France	—	—	—	(3)	11	13
United Kingdom	(3)	38	45	(3)	13	16
Total	(3)	38	45	(3)	25	29
Portland: Canada	1	91	105	5	192	253
San Diego:						
Mexico	2	161	200	(3)	13	18
Spain	—	—	—	38	1,652	2,047
Total[2]	2	161	200	38	1,666	2,065
San Francisco:						
Croatia	(3)	4	6	—	—	—
Germany	—	—	—	(3)	2	4
Japan	(3)	97	115	(3)	2	4
Korea, Republic of	—	—	—	33	891	1,254
New Zealand	—	—	—	(3)	13	16
Total[2]	(3)	101	121	33	908	1,278
San Juan:						
Belgium	5	415	680	10	860	1,819
Colombia	34	840	1,137	—	—	—
Denmark	14	1,146	1,911	9	746	1,259
Mexico	—	—	—	1	165	226
Spain	(3)	4	4	—	—	—
Total[2]	52	2,405	3,732	20	1,772	3,304
Savannah:						
Germany	—	—	—	(3)	2	3
Italy	(3)	6	12	—	—	—
Total[2]	(3)	6	12	(3)	2	3
Seattle:						
Canada	648	31,318	34,160	665	30,382	32,634
China	19	697	941	83	3,041	4,083

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT AND CLINKER, BY CUSTOMS DISTRICT AND COUNTRY

(Thousand metric tons and thousand dollars)

Customs district and country	1992			1993		
	Quantity	Value		Quantity	Value	
		Customs	C.i.f.[1]		Customs	C.i.f.[1]
Seattle—Continued:						
Colombia	34	1,175	1,843	44	1,485	1,789
Japan	78	2,674	3,545	(3)	39	47
Total[2]	779	35,863	40,489	792	34,946	38,552
St. Albans:						
Canada	87	2,697	3,242	67	1,819	2,263
Netherlands	(3)	12	14	(3)	60	68
Total[2]	88	2,708	3,256	68	1,878	2,331
Tampa:						
Canada	—	—	—	29	968	1,429
Colombia	136	4,539	5,662	239	7,097	8,902
Denmark	64	4,365	5,463	72	4,135	6,344
France	294	10,151	13,391	139	4,061	5,129
Spain	164	5,243	6,853	100	3,329	4,136
Venezuela	3	136	177	121	4,396	5,443
Total[2]	661	24,435	31,546	699	23,985	31,384
U.S. Virgin Islands:						
Barbados	—	—	—	11	79	92
Colombia	38	1,272	1,504	18	773	887
Denmark	—	—	—	(3)	1	1
Italy	1	38	48	—	—	—
Japan	(3)	3	4	—	—	—
Panama	2	65	75	3	94	119
Trinidad and Tobago	8	304	369	9	296	339
Venezuela	38	1,735	2,005	44	1,479	1,765
Total[2]	87	3,417	4,004	85	2,721	3,202
Washington: Venezuela	—	—	—	5	244	338
Wilmington:						
Canada	—	—	—	13	492	654
Venezuela	—	—	—	47	1,807	2,407
Total[2]	—	—	—	60	2,300	3,061
Grand total[2]	6,166	249,708	297,174	7,060	283,131	331,337
Grand total thousand short tons	6,797	XX	XX	7,782	XX	XX

XX Not applicable.

[1] Cost, insurance, and freight.

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

[3] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS FOR CONSUMPTION OF CEMENT AND CLINKER

(Thousand metric 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)
1989	12,339	[r]412,454	1,583	50,014	358	29,183	14,280	[r]491,651
1990	10,009	[r]359,084	1,682	56,910	350	28,045	12,041	[r]444,040
1991	6,235	247,137	1,326	42,872	331	43,276	7,893	333,286
1992	4,284	171,584	1,566	51,591	317	26,534	6,166	249,708
1993	5,178	199,499	1,508	52,513	375	31,118	7,060	283,131

[r] Revised.

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

Source: Bureau of the Census.

TABLE 21
HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Afghanistan[e]	100	112	112	115	115
Albania[e]	[2]754	750	[r]600	[r]200	200
Algeria	6,819	6,337	6,319	[r]6,400	6,400
Angola[e]	[r]300	[r]260	[r]260	[r]300	250
Argentina	4,470	3,629	[r e]3,500	[r]4,905	5,000
Armenia[e]	—	—	—	[r]500	200
Australia	6,900	7,068	[r]6,108	[r]5,412	5,500
Austria	4,749	4,903	5,016	[r]5,020	5,000
Azerbaijan[e]	—	—	—	600	400
Bahrain	158	148	150	150	150
Bangladesh[3]	[r]344	[r]337	275	[r]273	275
Barbados[e]	[r]225	[r]200	200	175	175
Belgium	6,720	6,929	7,184	[r]8,073	8,000
Belarus[e]	—	—	—	1,600	1,000
Benin[e]	250	300	320	370	380
Bolivia	505	560	592	[r]600	600
Bosnia and Herzegovina[e]	—	—	—	[r]150	150
Brazil	25,926	25,848	27,490	[r]24,920	28,000
Bulgaria	[r]5,036	[r]4,710	[r]2,374	[r]2,500	2,500
Burma	394	420	[r]435	[r]465	412
Cameroon	614	624	622	620	620
Canada	12,591	11,745	9,396	[r]5,698	6,672
Chile	2,010	2,115	2,251	[2]2,645	2,600
China[e]	207,000	203,000	[r]252,610	304,000	356,000
Colombia	6,643	6,253	[r 2]6,302	6,807	6,900
Congo	122	90	103	[r]115	114

See footnotes at end of table.

TABLE 21—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Costa Rica	610	620	[e]700	[e]700	650
Côte d'Ivoire[e]	500	500	500	[r]510	500
Croatia[e]	—	—	—	[r]2,000	2,000
Cuba	[2]3,138	3,000	2,000	2,000	2,000
Cyprus	1,042	1,133	1,134	[r]1,131	1,089
Czech Republic[4]	—	—	—	—	6,000
Czechoslovakia[5]	10,888	10,215	8,299	[r]8,500	—
Denmark	2,004	1,656	2,016	[r]2,072	2,100
Dominican Republic	[e]1,600	1,060	1,231	[r]1,365	1,300
Ecuador	2,250	2,250	2,300	[r]2,250	2,200
Egypt	12,480	14,111	[2]16,427	[r][2]17,000	17,000
El Salvador	633	641	680	[r]419	450
Estonia[e]	—	—	—	600	500
Ethiopia	[r]—	340	290	[e]320	350
Fiji	58	[r]78	[r]79	[r]84	81
Finland	1,596	1,666	1,324	[r]1,129	1,100
France	26,835	26,388	26,507	[r]21,165	22,000
Gabon	115	[r]116	117	[r]116	[2]132
Georgia[e]	—	—	—	1,000	700
Germany:					
Eastern states	12,264	7,228	—	—	—
Western states	28,499	30,456	—	—	—
Total	40,763	37,684	34,396	[r]37,529	37,000
Ghana	565	675	750	[2]1,024	[2]1,203
Greece	12,535	13,561	13,580	[r]13,620	13,500
Guadeloupe[e]	215	225	[e]240	[e]235	230
Guatemala	[r]1,613	[r]1,675	[r]1,442	[r][e]1,400	1,400
Haiti[e]	215	200	250	200	100
Honduras	649	652	693	[e]650	645
Hong Kong	2,141	1,808	[r]1,677	[r]1,643	1,712
Hungary	3,857	3,933	2,529	2,236	2,000
Iceland	[r]116	114	106	[r]100	100
India	46,000	49,000	51,000	[e]50,000	52,000
Indonesia	14,099	13,762	16,153	17,280	18,000
Iran[e]	12,500	13,000	15,000	18,000	20,000
Iraq[e]	12,500	10,000	5,000	10,000	10,000
Ireland[e]	[r]1,600	1,625	1,600	1,600	1,600
Israel	2,289	2,868	[r][e]3,550	[r]3,500	3,500
Italy	39,385	[r]39,975	[r]40,806	41,347	42,000
Jamaica	436	442	395	[r]481	480
Japan	79,717	84,445	89,564	[r]88,253	87,000
Jordan	1,930	1,820	1,754	[r]2,733	2,700
Kazakhastan[e]	—	—	—	6,000	5,000
Kenya	1,216	1,512	[r][2]1,423	[r][2]1,508	1,500
Korea, North[e]	16,000	16,000	16,000	17,000	17,000

See footnotes at end of table.

TABLE 21—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Korea, Republic of	30,474	33,600	[r]34,999	[r]42,650	47,000
Kuwait	1,110	900	300	500	500
Kyrgyzstan[e]	—	—	—	1,000	800
Latvia[e]	—	—	—	400	300
Lebanon[e]	900	900	900	[r]1,000	1,000
Liberia	85	[2]49	[r][2]2	[2]8	8
Libya	2,700	2,700	2,369	2,300	2,300
Lithuania[e]	—	—	—	2,000	1,500
Luxembourg	590	636	[r]688	[e]600	600
Macedonia[e]	—	—	—	500	500
Madagascar[e]	60	60	60	60	60
Malawi	77	99	120	[r]112	115
Malaysia	4,794	5,881	7,451	[r]8,366	8,806
Mali[e]	[2]20	20	20	20	20
Martinique[e]	244	250	[e]245	[e]240	220
Mauritania[e]	90	90	90	90	90
Mexico	22,766	23,824	25,100	26,900	27,100
Moldova[e]	—	—	—	1,700	1,500
Mongolia[e]	[r]513	441	[r]227	[r]133	270
Morocco[e]	4,200	4,200	5,770	[r][2]6,340	6,300
Mozambique	75	79	[r][e]80	[e]30	20
Nepal	218	107	136	[r]196	180
Netherlands	3,541	3,729	3,546	[r]3,410	3,400
New Caledonia[e]	67	[e]65	90	[r]90	90
New Zealand	729	[e]750	576	579	600
Nicaragua	[r]205	219	239	[r]277	275
Niger	27	19	20	[r]29	29
Nigeria[e]	3,500	3,500	3,500	3,500	3,500
Norway	1,375	1,261	1,147	1,266	1,250
Oman	948	1,000	[r]995	[r]970	100
Pakistan	6,936	7,488	7,762	7,793	8,000
Panama	169	300	[r][e]300	[r][e]250	300
Paraguay[e]	326	[e]326	[e]326	[e]326	326
Peru	2,105	2,185	[e]2,200	[r]2,089	2,089
Philippines	3,624	6,360	[r]6,913	[r]6,734	6,500
Poland	17,125	[r]12,518	[r]12,012	[r]11,908	[2]12,228
Portugal[e]	[r]6,743	[r]7,277	[r]7,473	[r]7,638	7,600
Qatar	300	267	[r]527	[r][2]544	544
Romania	13,265	[r]10,838	[r]7,300	[r]6,900	7,000
Russia[e]	—	—	—	[r]64,000	60,000
Rwanda	68	60	[e]60	[e]60	60
Saudi Arabia	11,442	[r]11,983	[r]11,371	[r]15,300	15,300
Senegal	380	470	503	601	601
Serbia and Montenegro	—	—	—	[r]2,036	2,000
Singapore	1,706	1,852	[e]2,000	[e]1,900	1,900
Slovakia[4]	—	—	—	—	2,500

See footnotes at end of table.

TABLE 21—Continued

HYDRAULIC CEMENT: WORLD PRODUCTION BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Slovenia	—	—	—	[r][e]950	950
Somalia[e]	50	40	10	25	25
South Africa, Republic of	8,030	7,811	[r]7,296	[r]7,361	8,000
Spain (including Canary Islands)	27,374	28,092	[r]28,008	[r]25,067	26,000
Sri Lanka[e]	400	400	400	[r]817	800
Sudan[e]	150	[2]167	170	250	250
Suriname[e]	50	50	50	50	50
Sweden	2,431	2,475	[r]2,395	[r][e]2,200	[2]2,200
Switzerland	5,461	5,206	4,700	4,260	4,000
Syria	3,501	3,500	3,500	[r]3,700	3,800
Taiwan	18,043	18,459	19,389	[r]21,464	23,971
Tajikistan[e]	—	—	—	300	250
Tanzania	540	[e]540	[e]540	540	540
Thailand	15,024	18,054	18,054	[r]21,832	23,000
Togo	389	399	388	[r]350	350
Trinidad and Tobago	[e]380	438	485	[r]482	485
Tunisia[e]	3,228	3,300	3,300	3,300	3,300
Turkmenistan[e]	—	—	—	700	500
Turkey	23,796	24,416	[r]26,091	28,607	30,000
Uganda	14	27	[e]50	[e]50	5
Ukraine[e]	—	—	—	20,000	17,000
U.S.S.R.[6]	140,436	137,322	[e]127,000	—	—
United Arab Emirates	3,387	3,264	3,473	[r]3,800	3,500
United Kingdom	16,849	[e]14,000	11,662	10,720	10,000
United States (including Puerto Rico)	71,268	71,407	66,753	71,426	[2]75,117
Uruguay[e]	[2]560	500	500	500	500
Uzbekistan[e]	—	—	—	6,000	5,000
Venezuela	4,510	5,230	6,337	[r]6,585	6,650
Vietnam[e]	2,000	2,500	3,000	3,000	3,000
Yemen	700	828	850	[r]800	800
Yugoslavia[7]	8,560	7,954	[e]7,500	—	—
Zaire	[e]460	461	[e]250	[r]174	150
Zambia	386	[r]437	367	[r][e]347	350
Zimbabwe	719	700	865	[e]900	1,000
Total thousand metric tons	[r]1,148,912	[r]1,149,369	[r]1,184,530	[r]1,241,217	1,303,360
Total thousand short tons	[r]1,266,458	[r]1,266,962	[r]1,305,721	[r]1,368,207	1,436,707

[e]Estimated. [r]Revised.

[1] Table includes data available through Sept. 2, 1994.

[2] Reported figure.

[3] Data are for the year ending June 30 of that stated.

[4] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved Dec. 31, 1992.

[6] Dissolved in Dec. 1991.

[7] Dissolved in Apr. 1992.

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 22 years of U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by Nicole Picciotta, statistical assistant; and chromite and ferrochromium world production data, by country, were prepared by Amy Burke, international data specialist. Cost of production data were prepared by Edward H. Boyle, Minerals Availability Field Office, Division of Resource Evaluation. (All tonnages are in metric tons unless otherwise specified.)

Chromium has a wide range of uses in metals, chemicals, and refractories. It is one of the Nation's most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardenability and resistance to corrosion and oxidation. The use of chromium to produce stainless steel and nonferrous alloys is one of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, surface treatments, and refractories.

Because the United States has no chromite ore reserves and a limited reserve base, domestic supply has been a concern during every national military emergency since World War I. World chromite resources, mining capacity, and ferrochromium production capacity are concentrated in the Eastern Hemisphere. The National Defense Stockpile (NDS) contains chromium in various forms, including chromite ore, chromium ferroalloys, and chromium metal in recognition of the vulnerability of long supply routes during a military emergency.

Research is conducted by the Federal Government to reduce U.S. vulnerability to potential chromium supply interruption. That research covers both domestic resource utilization and alternative materials identification. Domestic chromium resources include mineral deposits and recyclable materials. The U.S. Geological Survey and the U.S. Bureau of Mines evaluate U.S. territory for chromium mineral deposits. The U.S. Bureau of Mines also studies minerals extraction and processing and materials substitution and recycling. Alternative materials research also is conducted by the National Aeronautics and Space Administration, the National Institute of Standards and Technology, the Department of Defense, and the Department of Energy.

World chromite ore reserves are more than adequate to meet anticipated world demand.

DOMESTIC DATA COVERAGE

Domestic data coverage of the primary consuming industries—chemical, metallurgical, and refractory—are developed by the U.S. Bureau of Mines by means of the voluntary monthly "Chromite Ores and Chromium Products" survey. The companies listed in table 10 by industry accounted for 100% of the chromite consumption data by industry in the current year of table 12. All of the metallurgical, refractory, and chemical companies that consumed chromite in 1993 reported to the U.S. Bureau of Mines.

Domestic production data for chromium ferroalloys and metal are developed by the U.S. Bureau of Mines by means of two separate, voluntary surveys. These two surveys are the monthly "Chromite Ores and Chromium Products" and the annual "Ferroalloys." Production by the metallurgical companies listed in table 10 represented 100% of the domestic production shown in the current year of table 11.

BACKGROUND

Chromium owes its prominence as a commodity to its use in stainless steel. Stainless steel was invented in the early 1900's. Soon thereafter electric furnaces evolved that could smelt chromite into ferrochromium. Before about 1960, ferrous alloys required the addition of as little carbon as possible because carbon could not efficiently be removed from molten steel. Thus, the production of low-carbon, high-chromium alloys (typically less than 0.1% carbon and more than 65% chromium) in or near steel-producing centers was the common practice. To make this ferrochromium, high chromium-to-iron ratio ores were required (ratios greater than about 2:1).

Since 1960, major changes have occurred in the chromium industry because of changes in steelmaking technology. The development of ladle refining techniques (i.e., processes that permit the chemical modification of liquid metal), such as argon-oxygen decarburization, permitted the steel industry to shift from the more costly low-carbon ferrochromium to the less costly high-carbon ferrochromium as its major source of chromium units. This shift in ferrochromium grade has been accompanied by a shift in quantity of production among ferrochromium-producing countries. Since the 1970's, chromite ore-producing countries have developed their own ferrochromium production capacities. As a result, ferrochromium production has moved from the major stainless steel-producing centers in Japan, the United States, and

Western Europe to chromite-producing countries—Finland, the Republic of South Africa, Turkey, and Zimbabwe. With the exception of Japan, only minor ferrochromium production remains in the major stainless steel-producing countries. In particular, the Republic of South Africa, whose ores have a chromium-to-iron ratio of about 1.2:1, has increased its high-carbon ferrochromium production dramatically. Significant, but declining, quantities of ferrochromium continue to be produced in Japan.

Once chromium is incorporated into stainless steel, it is used in many different ways. Stainless steel is used in many industrial applications that benefit from oxidation or corrosion resistance or in applications that benefit from the ease with which stainless steel may be cleaned. Uses that are common to the experience of many people include kitchen and eating utensils, sinks, and automobile exhaust components or systems. Chromium also is used in chemicals for a variety of purposes.

Chromite, the mineral from which chromium is derived for use in the metallurgical and chemical industries, is used directly by the refractory industry to produce heat-, spalling-, corrosion-, and abrasion-resistant bricks for metallurgical and high-temperature industrial mineral processing applications. Chromite is not mined domestically; thus, the United States is 100% import dependent to meet domestic chromite demand. Some domestic chromium demand is met by recycling. Chromium is a critical and strategic material contained in the NDS to ensure adequate supply in the event of a national defense emergency.

Definitions, Grades, and Specifications

U.S. industry sets chemical and physical specifications for chromium materials through the American Society for Testing and Materials (ASTM). Other organizations also make specifications for chromium materials. The Defense Logistics Agency (DLA), in cooperation with the Department of Commerce, maintains purchase specifications for chromium materials contained in the NDS. The Department of the Treasury, in cooperation with the Department of Commerce and signatories to the General Agreement on Tariffs and Trade, maintains definitions of chromium materials for the purpose of recording trade and applying tariff duties.

The import category "chromite ore and concentrates made therefrom" is subdivided by chromic oxide content as follows: containing not more than 40% chromic oxide, containing more than 40% and less than 46% chromic oxide, and containing 46% or more chromic oxide. Producers of chromite ore and concentrate typically specify chromic oxide content; chromium-to-iron ratio; and iron, silica, alumina, magnesia, and phosphorus contents. They also specify the size of the ore or concentrate. Typically, chromic oxide content ranges from 36% to 56%, with values in the 40% to 50% range being most common. Chromium-to-iron ratios typically range from about 1.5:1 to about 4:1, with typical values of about 1.5:1 to 3:1. In trade, the chromite ore also is called chromium ore, chromite, chrome ore, and chrome.

The import category "chromium ferroalloys" is subdivided into ferrochromium and ferrochromium-silicon. Ferrochromium-silicon, also called ferrosilicon-chromium and chromium silicide, is not further classified. Ferrochromium is classified by its carbon content as containing not more than 3% carbon, more than 3% but not more than 4% carbon, or more than 4% carbon. Producers of ferrochromium typically classify their material as low- or high-carbon or charge-grade ferrochromium. Charge-grade ferrochromium also is called charge chrome. Producers of chromium ferroalloys typically specify chromium, carbon, silicon, phosphorus, and sulfur contents and material size. Ferrochromium-silicon typically contains 24% to 40% chromium, 38% to 50% silicon, and 0.05% to 0.1% carbon. Ferrochromium typically contains 50% to 75% chromium and 0.05% to 8% carbon. Low-carbon ferrochromium typically contains 55% to 75% chromium and 0.02% to 0.1% carbon. High-carbon ferrochromium typically contains 60% to 70% chromium and 6% to 8% carbon. Charge-grade ferrochromium typically contains 50% to 55% chromium and 6% to 8% carbon.

Products for Trade and Industry

Chromium is primarily used in the metallurgical industry as an alloying element. Small quantities of chromium are alloyed with a base metal to achieve certain desired properties not attainable with the base metal alone. Before its use as an alloying element, chromium was used predominantly in chemicals to make pigments or to plate metals. Chromite is used as a refractory material. Refractories resist degradation when exposed to heat. As a pigment, chromium provides color to many end products and corrosion protection to ferrous metals. As a plating material, chromium provides a lustrous or a hard finish and corrosion protection to the substrate metal. As a refractory, chromite found major use in blast furnace iron production. The decline in use of this process has resulted in a corresponding decline in chromite refractory use. Environmental concern over hexavalent chromium contamination has resulted in reduced use or increased expense of chromium use in pigments and plating. Chromium is traded primarily as chromite ore or as ferrochromium. Substantial amounts of chromium chemicals, pigments, and metal also are traded.

Industry Structure

Stainless steel was developed in about 1900. Since then, stainless steel has grown to become the major end use of chromium. Chromium is used in stainless steel production in the form of ferrochromium, a product of smelting chromite ore with a carbonaceous material (chemical reductant) and silicious materials (flux material). The production of stainless steel evolved in association with the major steel-producing centers. The production of ferrochromium developed in conjunction with the production of stainless steel at those steel-producing locations.

In a trend toward vertical integration, chromite-producing countries have been developing ferrochromium and stainless steel production capacity. This trend has worldwide impact. Formerly, ferrochromium was produced mainly by Europe, Japan, and the United States, the major steel producers. The U.S. trend to obtain chromium in the ferroalloy form is a result of the world trend to produce ferrochromium in chromite-producing countries.

The structure of the chromium industry from a material processing perspective begins with mining of chromite ore. (See figure 1, chromium material flow.) Once mined, ore that is not sold directly is beneficiated. The resulting chromite ore or concentrate made therefrom may be consumed in the refractory, chemical, or metallurgical industry. Chromite ore is consumed in the refractory industry for its chromite mineral content. The chromite is typically crushed, ground, and sized. It then is mixed with magnesite to make chrome-magnesite bricks that are subsequently consumed in the steel, glass, or cement industry. The chromite refractories are used to line steelmaking furnaces, cement kilns, or heat exchangers associated with glass production. *(See figure 1.)*

Chromite ore consumed in the chemical or metallurgical industry is processed to extract the chromium from the chromite mineral. Chromite ore consumed in the chemical industry is kiln roasted. Using water, the chromium is leached out of the kiln roast product in the form of sodium chromate. The sodium chromate is processed further to make chromic acid, sodium bichromate, and other chromium chemicals and pigments. Chromic oxide is a chemical industry product. Chromite ore consumed in the metallurgical industry is smelted to produce ferrochromium. In effect, the oxygen is removed from the iron-chromium-oxygen mineral, leaving an iron-chromium alloy, ferrochromium. Ferrochromium is produced to meet a variety of chemical and physical specifications. Several variations of the ferrochromium production process are practiced; the submerged electric arc furnace is central to each process. Ferrochromium is the source of chromium units for alloys, especially ferrous alloys. When nonferrous alloys require chromium and the iron is undesirable, chromium metal is used. Chromium metal is produced from ferrochromium by an electrolytic process or from chromic oxide by an aluminothermic process.

The major vertical structure of the chromium industry is mining-smelting-stainless steelmaking. In some instances, the ownership of mining operations, smelters, and stainless steel production facilities is integrated. In many other cases, integration is limited to mining and smelting or to smelting and stainless steelmaking. Often the ownership of operations is shared. Major mining, smelting, or stainless steel production facilities are typically privately owned by large companies or groups of companies. *(See tables 1 and 2.)*

Geology-Resources

The geology of many chromium deposits has been characterized.[1] The data in table 21 are rated reserves and reserve base for major chromite ore-producing countries.[2] The data on chromite reserves and resources are categorized according to a general U.S. Bureau of Mines-U.S. Geological Survey classification system applicable to all minerals. The definition of reserves and reserve base are published in Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." The distribution of chromite deposits into reserves, reserve base, and resources categories is determined by the physical and chemical nature of the ore (physical factors) and by mining and market economics (economic factors). Resources are a concentration of naturally occurring material from which a commodity may currently or potentially be extracted. Resources are divided into identified and undiscovered. As used here, resources refers only to identified resources that are further subdivided into demonstrated and inferred resources. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base includes those resources that are currently economic, marginally economic, and some of those that are currently subeconomic.

Reserves are that part of the reserve base that could be economically extracted or produced at the time of determination. Reserves include only recoverable materials. Reserve values are included in reserve base values.

The term "reserves" is commonly used with a variety of definitions. Even when the definition given here is used, the quantitative value of reserves could vary owing to differing physical and economic criteria applied to a deposit by different analysts.

Technology

Mining.—A wide variety of mining technology is applied to the surface and subsurface mining of chromite ore. Most ore comes from large mechanized mines. However, small labor-intensive mining operations contribute to world supply.

Beneficiation.—The amount of beneficiation required and the techniques used depend on the ore source and end-use requirements. When the chromite is clean, only hand sorting of coarse material and gravity separation of fine material may be required. When the ore is lumpy and mixed with host rock, heavy-media separation may be used. When the chromite mineral occurs in fine grains intermixed with host rock, crushing may be used in conjunction with gravity separation and magnetic separation.

Smelting.—The smelting of chromite ore to produce ferrochromium requires electric arc furnace technology. Early electric furnaces having power ratings in the kilovolt-ampere range have developed into modern furnaces having power ratings of about 50 megavolt-amperes. Closed and partially closed electric arc furnaces replaced open furnaces in the 1970's to improve pollution control, efficient furnace operation, and safety.

Ferrochromium is produced from chromite ore by smelting a mixture of the ore, flux materials (e.g., quartz, dolomite, limestone, and aluminosilicates), and a carbonaceous reductant (wood, coke, or charcoal) in an electric arc furnace. If the ore is lumpy, it can be fed directly into the furnace. However, if the ore is not lumpy, it must be agglomerated before it is fed into the furnace. (See Energy Requirements under Operating Factors.) Efficient operations recover chromium lost to furnace fume by collecting and remelting the dust and recover chromium lost to slag by crushing and beneficiating the slag. The chromium content of the ferrochromium is determined by the chromium-to-iron ratio of the chromite ore.

The shift from high-chromium, low-carbon ferrochromium to low-chromium, high-carbon ferrochromium, commonly called charge-grade ferrochromium, permitted the use of low chromium-to-iron ratio ore for smelting to ferrochromium. The Republic of South Africa is the most abundant and low-cost source of such ore. Unfortunately, this ore is friable (breaks easily into small pieces), and the finer fractions of such ore are blown out of a furnace before it can be smelted. Agglomeration technology has been developed to permit the use of fine chromite ore in the electric arc furnace. Briquetting and pelletizing are practiced. Efficient production technology uses prereduced and preheated pelletized furnace feed. Industry is developing new production technologies using high-temperature plasmas or using alternatives to electrical power supply. The new production technologies are expected to be more cost competitive than traditional production technology under some conditions. Advanced smelting technologies that use abundant friable ore have been and are being developed. Plasma processes, including transferred and nontransferred arc processes, have been applied to ferrochromium production. The kiln roasting prereduction process has been applied to ferrochromium production.

Recycling.—Recycling is the only domestic supply source of chromium. Stainless steel and superalloys are recycled, primarily for their nickel and chromium contents. As much as 50% of electric furnace stainless steel production can result from recycled (i.e., new and old) stainless steel scrap. Advanced stainless steel production technology such as continuous casting reduces prompt scrap generation and permits a higher product yield per unit of raw material feed. See figure 2 depicting the general recycling of chromium material flow industry structure. *(See figure 2.)*

Byproducts and Coproducts

Chromite ore is mined as a primary product. Chromite is not a byproduct or coproduct of the mining of any mineral, nor are there byproducts or coproducts associated with chromite mining. Chromite has the potential of becoming a byproduct of platinum mining in the Republic of South Africa or of lateritic nickel mining. Platinum and chromite are present in the UG2 seam of the Bushveld Complex in the Republic of South Africa. At present, most platinum mining is from the Merensky Reef. However, as platinum mining from the UG2 seam continues and as new mining operations that exploit the UG2 seam are developed, chromite-containing tailings will continue to grow. The feasibility of utilizing these resources has been demonstrated, and new ferrochromium production facilities under development by Samancor Ltd. are designed to permit the use of these resources. It appears to be only a matter of time before economic conditions favor the use of those tailings, thereby making chromite a byproduct of some platinum operations.

Economic Factors

Prices.—Inadequate supplies of ferrochromium in the late 1980's resulted from strong demand for stainless steel in all three major producing regions: Europe, Japan, and the United States. This inadequate supply resulted in increasing ferrochromium prices until mid-1989, when supply exceeded demand and prices began to decline. In 1989 and 1990, new ferrochromium plants and plant expansions were under construction or being completed. Increased supply of ferrochromium, resulting from producer expansions and new plant construction, resulted in declining ferrochromium prices in 1990. The dissolution of the U.S.S.R. in 1991, along with political and economic reforms and reduced demand for materials in the Commonwealth of Independent States (C.I.S.), permitted C.I.S. chromite ore and ferrochromium producers to enter Western markets, further exacerbating excess supply and low prices.

The historical values of chromite ore by grade, ferrochromium by grade, and chromium metal imported to the United States are shown in tables 3 and 4. These values show that as chromite ore is processed to ferrochromium and to chromium metal, the added value is quite large. On a per unit of contained chromium basis for recent years, the value of ferrochromium is about 5 times that of chromite ore and the value of chromium metal is about 30 times that of chromite ore. Variations of the value of ore are shown to follow those of ferrochromium, indicating values of chromite ore change in response to demand, with ferrochromium value first to reflect demand changes.[3] Ferrochromium values show greater variation than those of chromite ore. The unit value of chromium materials has increased by 10% to 15% per year in actual value since 1963. *(See tables 3 and 4.)*

Costs.[4]—Operation and transportation are the two major components of chromite ore cost in the marketplace.

Operating cost includes mining (the production of run-of-mine ore) and beneficiation (the production of marketable chromite ore or concentrate from the run-of-mine ore). Mining cost is typically in the range of 70% to 90% of operating cost but exceeds 90% in some cases. Labor cost is the major component of mining and of beneficiation cost. Labor cost is typically in the range of 20% to 70% of mining cost and from 25% to 90% of beneficiation cost, but can be higher.

Excluding the delivered cost of chromite ore, electrical energy, other raw materials, and labor are the major components of smelting (i.e., production of ferrochromium from chromite ore) cost. (Note that smelting cost excludes the cost of chromite ore feed material.) Electrical energy cost is in the range of 20% to 55% of smelting cost; raw materials (excluding chromite ore), 15% to 35%; and labor, 10% to 30%.

The U.S. Bureau of Mines has studied the availability of chromium and analyzed the cost and availability of chromium materials. The chromium materials included exportable chromite products (metallurgical, chemical, refractory, and foundry sands) and chromium ferroalloy products in 10 market economy countries (MEC's). These various chromium materials were simultaneously analyzed for cost and availability. The product breakdown among chromium materials was based on mine and smelter production capacities and known operating relationships circa the 1987-88 time period.

A total of about 874 million tons, gross weight, of in situ material containing about 203 million tons of chromium was analyzed. Extraction and beneficiation of this material were estimated to yield about 475 million tons of chromite products, of which 289 million tons would be available for export and the remaining 187 million tons would be smelted in the country in which it was mined to produce about 80 million tons of chromium ferroalloys. The chromium ferroalloys would then be available for use in the country of production or for export. The 80 million tons of chromium ferroalloys included about 74 million tons of high-carbon ferrochromium, 4 million tons of low-carbon ferrochromium, and 2 million tons of ferrochromium-silicon.

The countries of the Republic of South Africa and Zimbabwe contained about 80% of the in situ chromium contained in chromite ore. Finland and India accounted for an additional 11% of the contained chromium; another 8% of the contained chromium was fairly evenly split among Brazil, the Philippines, Turkey, and the United States; and the remainder was in Greece and Madagascar.

Based on Cr_2O_3 content of in situ chromite ore, the 10 MEC's split into 2 groups, a high-grade group and a low-grade group. The high-grade group, those with ore grades ranging from 34% to 43% Cr_2O_3, included India, Madagascar, the Republic of South Africa, Turkey, and Zimbabwe. The low-grade group, those with ore grades ranging from 9% to 27% Cr_2O_3, included Brazil, Finland, Greece, the Philippines, and the United States. The grade differences between the two groups resulted in a wide disparity in their respective weighted average Cr_2O_3 contents. The high-grade group averaged 39% Cr_2O_3 and the low-grade group only 16% Cr_2O_3.

Table 5 shows the results of the U.S. Bureau of Mines analysis. Chromium material costs were calculated on a weighted average basis, f.o.b. ship at the port of export. Chromite costs shown in table 5 include chromite ore mining and beneficiating (including mine capital and operating costs and taxes) and chromite product transportation to port facilities. Chromium ferroalloy costs include chromite ore but exclude smelter capital cost. On a weight basis, the U.S. Bureau of Mines analysis shows that the Republic of South Africa and Zimbabwe could produce about 78% of metallurgical chromite ore, 93% of chemical chromite ore, 85% of refractory chromite ore, and 93% of foundry chromite ore that could be produced at their respective estimated break-even cost. The Republic of South Africa and Zimbabwe also could produce about 69% of the high-carbon ferrochromium, 89% of the low-carbon ferrochromium, and 100% of ferrochromium-silicon that could be produced at their respective estimated break-even cost. *(See table 5.)*

The low-carbon ferrochromium availability curve is shown in figure 3; high-carbon ferrochromium is shown in figure 4. The costs shown in figures 3 and 4 include mining and beneficiation operating and capital costs, transportation to specific smelters, smelting operating costs, taxes, and transport costs to specific port cities for export. Recovery of initial capital costs at the ferrochromium smelters has not been included. Figure 3 shows that the MEC's studied support total production of 4 million tons of low-carbon ferrochromium at a cost ranging from about $0.42 to $0.95 per pound, contained chromium, for 0 percent discounted cash-flow rate of return. Figure 4 shows that the same MEC's studied support total production of about 74 million tons of high-carbon ferrochromium at a cost of about $0.28 to $1.07 per pound, contained chromium, at a 0 percent discounted cash-flow rate of return. *(See figures 3 and 4.)*

Consumer cost and producer competitiveness can be significantly impacted by currency exchange rates. Ferrochromium is usually sold on a U.S. dollar basis. Production costs are mostly based in local currency. In the short term, a ferrochromium producer whose local currency declines in value relative to the U.S. dollar, without a change in its local production cost structure, achieves a competitive advantage. It can earn the same amount of local currency while selling its product for fewer U.S. dollars because of the change in exchange rates. In the long term, the producer may become less competitive if it must buy new equipment, replacement parts, or get capital in U.S. dollars.

An economic analysis of the South African ferroalloy industry[5] identified those business factors that were perceived as most important to determining new plant feasibility. In descending order of importance, the study found those factors to be: market opportunities for the salable product, local metal-ore deposits, energy costs and availability, and exchange-rate projections. Factors of less importance, again in descending order of importance, were as follows: capital costs and availability, escalation in other production and transport costs, State export incentives, skilled work force availability, domestic consumption of the final product, and other (including taxation and labor relations). The study found that domestic processing of South African ore increased from 6.8% in 1960 to 61% in 1988 and estimated that domestic processing could reach 80%. The cost distribution of charge-grade ferrochromium production in the Republic of South Africa was found to be, in dollars per ton of product: electricity (at 4,390 kilowatt-hours per ton), $135; transport (from plant to market), $122; ore, $75; carbon materials, $58; labor, $36; fluxes, electrodes, etc., $16; working capital, $10; and other direct costs, $97. In this study, exchange rate stability was found to be important because lack of exchange rate stability makes projected income indeterminate in cost analysis studies.

Tariffs.—Import tariffs are typically imposed to protect the domestic industry. Where there is no domestic industry, such as chromite ore production in the United States, there is no tariff. (See Foreign Trade section of this report for U.S. tariff duties on chromium materials.) In some cases, such as ferrochromium imports to the European Community, import tariffs are used with import quotas. That is, a duty-free quota is allocated to member countries. The quotas may be revised as necessary to meet the needs of domestic consumers and producers. Only in a few cases, such as ferrochromium exports from China and certain grades of chromite ore exports from India, are export duties applied.

Operating Factors

Environmental Issues.—Chromium is an essential trace element for human health. However, some chromium compounds are acutely toxic, chronically toxic, and/or carcinogenic. Chromium releases into the environment are regulated by the Environmental Protection Agency (EPA). Workplace exposure is regulated by the Occupational Safety and Health Administration.

Health.—Chromium is a trace mineral required by the human body for good health.[6] A daily intake in the range of 50 to 200 micrograms has been recommended. Chromium is a cofactor for insulin, a hormone that participates in carbohydrate and fat metabolism. A cofactor is a material that acts with the material. The dietary chemical compound form of chromium is trivalent. Because humans cannot convert trivalent (III) chromium to hexavalent (VI) chromium, the carcinogenicity of hexavalent chromium compounds bears no relevance to the nutritional role of trivalent chromium.

Toxicity.—The effect of an element on the human body depends on several factors. These factors include the chemical or class of chemical, the route of exposure, the quantity and duration of exposure, and characteristics of the exposed subject.[7]

The chemical distinctions typically made about chromium chemicals include whether the compound is synthetic or naturally occurring. Synthetic chromium compounds are typically classified by their oxidation state. Trivalent and hexavalent chromium compounds are two such classifications. Exposure to chromium compounds could typically occur through one or more of three routes: skin contact, ingestion, or inhalation. Exposure can also vary in intensity (concentration of the chemical) and duration (length of time for which exposure occurs). Response to chemical exposure is dependent on such human characteristics as age, sex, general health, and sensitivity. The effect of chemical exposure on the human body can be good or bad. Chromium is one of those elements that is both essential to good health and detrimental to good health. The detrimental effects of chemical exposure are classified as acutely toxic when small amounts of the chemical cause significant damage in a short time; chronically toxic when exposure over a long time causes measurable damage; and carcinogenic when exposure can result in cancer.

Background levels of chromium may be estimated from natural abundances. At about 185 parts per million, chromium is the 13th most common element in the Earth's crust, and at 0.2 parts per billion, the 26th most common element in seawater.

Under some conditions, chromium compounds cause systemic damage to the human body.[8] Because experimentation on human subjects is morally unacceptable, most toxicity data result from workplace, coincidental, or accidental human exposure or animal experimentation. EPA concluded that there is sufficient evidence in animals and humans for the carcinogenicity of chromium (VI) compounds, while evidence for the carcinogenicity of chromium (III) compounds in humans and animals is largely nonpositive. The acute toxicity of chromium (III) compounds is low whereas the acute toxicity of chromium (VI) compounds is in the high to moderate range. Chronic toxicity of chromium (III) is considered low.

Chromium generally forms chemical compounds in which chromium has either the hexavalent or trivalent oxidation state. Hexavalent chromium compounds are generally recognized as toxic. Chronic occupational exposure to hexavalent chromium has been associated with an increased incidence of bronchial cancer. The toxic status of trivalent chromium compounds is not clear. However, trivalent chromium compounds are less toxic than hexavalent chromium compounds. Chemical compounds containing chromium in lower valence states are generally recognized as benign.

The American Congress of Governmental Industrial Hygienists (ACGIH) adopted new threshold limit values for chromium materials. The time weighted average threshold value in units of milligrams per cubic meter of air recommended by ACGIH are as follows:

chromium metal, 0.5; trivalent chromium compounds, 0.5; hexavalent (insoluble) chromium compounds, 0.5; and hexavalent (soluble) chromium compounds, 0.1. ACGIH reported hexavalent chromium compounds to be "confirmed human carcinogens," and chromium metal and trivalent chromium compounds to be "not classifiable as human carcinogens."[9]

The U.S. Department of Health & Human Services, Public Health Service, updated its toxicological profile for chromium.[10] It found trivalent chromium to be an essential nutrient that helps the body use sugar, protein, and fat. It also report that breathing in high levels (i.e., greater micrograms per cubic meter of air) of hexavalent chromium can cause irritation to the nose and that long-term exposure could result in lung cancer.

Environmental Releases and Transfers.[11]—The EPA regulates and monitors industrial impact on the environment. As part of its monitoring activity, EPA collects data on toxic chemicals; that information is made available in the Toxic Release Inventory (TRI). TRI is mandated under title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Chromium has been identified as a toxic material by the EPA. Companies that release chromium-containing materials into the environment are required to report those releases to EPA. In turn, EPA collates the reported information and makes it publicly available in the form of the TRI data base.

EPA has been collecting environmental release information since 1987 from manufacturing facilities that employ 10 or more persons and used a threshold amount of chromium contained in chromium compounds. [A manufacturing facility is one whose product is included in Standard Industrial Classification (SIC) Division E Codes 20 through 39. EPA does not cover Division B, Mining, Groups 10 through 14.] The threshold amount decreased from 1987 to 1989, after which time it remained constant. The threshold limit for a facility that manufactured or processed chromium compounds was about 34 tons of contained chromium in 1987, about 23 tons in 1988, and about 11 tons in 1989 and subsequent years. The threshold limit for facilities that otherwise used chromium compounds has been and remains about 5.4 tons. (Note that EPA has definitions for the terms manufacture, process, and "otherwise use" for the purpose of reporting releases.) When reporting chromium releases, a facility must add up the chromium released from all sources that exceed a DeMinimis amount. The DeMinimis amount for chromium compounds is 0.1%. Facilities report the amount of chromium released to the air, water, and earth environment; the amount of chromium recovered onsite; and the amount transferred to offsite locations. The collected data are called the TRI. EPA reported total releases and transfers of chromium in chromium and chromium compounds.

EPA reported releases and transfers have averaged (1987 through 1992) to about 40,000 tons of chromium contained in chromium and chromium compounds per year.

Energy Requirements.—Electric arc furnace ferrochromium production is an electrical energy-intensive process (requiring about 4,000 kilowatt-hours per ton of ferrochromium produced) that produces similar volumes of ferrochromium and slag. However, heat recovery can reduce energy requirements. Energy-efficient processes using preheating can reduce the energy requirements to about 2,500 to 2,800 kilowatt-hours per ton of ferrochromium produced. Typically, all of the energy required to smelt chromite is supplied in the form of electricity. Electrical energy requirements can be reduced by preheating or prereducing charge material using alternative energy sources such as coal, natural gas, or fuel oil. Advanced production technology permits the use of liquid or gas fuel to provide part of the energy required. Alternative production technology is being developed that would permit nonelectrical energy sources to supply a significant fraction of the energy required to smelt chromite ore. Western World power consumption per ton of ferrochromium product was estimated to range from 2,000 kilowatt-hours to 5,000 kilowatt-hours and averaged 3,950 kilowatt-hours from 1988 to 1991.[12]

Transportation.—Chromite ore is typically transported by trackless truck or conveyor belt from the mine face to storage or processing facilities on the mine site. From there it is transported by truck from the mine site to the local railhead. It is then transported by rail to ports or to smelters. Smelters that do not have associated loading and unloading facilities for ships transport their product by rail to ports. Following transport by ship to consumer countries, chromium materials typically are barged or hauled by truck and/or rail to end users who have no loading and unloading facilities for ships.

ANNUAL REVIEW

In 1993, chromium apparent consumption was about 523,000 tons of contained chromium. The reported consumption of chromite by the chemical and metallurgical industry and by the refractory industry decreased. Chemical and metallurgical industry chromite consumption includes material consumed as part of the NDS program to convert chromite ore to ferrochromium. Imports of chromite ore increased. Reported consumption of chromium ferroalloys decreased while imports decreased. *(See table 6.)*

U.S. supply consisted of recycled and imported chromium materials. The United States recycled about 606,000 tons, gross weight, of stainless steel scrap and imported about 677,000 tons of chromite ore, ferroalloys, chemicals, and pigments valued at about $279 million. The United States exported about 48,000 tons of chromium materials valued at about $65 million. Compared to those of 1992, both quantity and value of imports of chromium materials decreased, while both quantity and value of exports increased in 1993.

Legislation and Government Programs

Dissolution of the U.S.S.R. into the C.I.S. and other independent states at the end of 1991 resulted in the reevaluation of the NDS. The absence of a single large adversary encouraged many to advocate reduction of the NDS. Others argued that history has demonstrated the need for a stockpile because periods of relative peace have been interspersed with conflict and that there is no reason to expect this pattern to change. Based on new international political conditions, DLA submitted to Congress its annual materials plan and identified the following for disposal: 299,371 tons of chromite ore in 1993, and 335,658 tons of chromite ore and 43,359 tons of ferrochromium in 1994.[13]

In accordance with the President's November 1982 directive and Public Law 99-591, the DLA continued to upgrade NDS chromite ore to high-carbon ferrochromium. The Agency reported conversion of chromite ore to ferrochromium on a contract year basis. DLA signed a contract with Macalloy Corp., Charleston, SC, in 1990 to upgrade NDS chromite ore. The contract period covers the years 1990-94, the last 2 years of which are optional for DLA. DLA contracted with Macalloy to have chromite ore converted to about 73,000 tons ferrochromium between September 1992 and October 1993. DLA has the option of extending its contract to have about another 7,000 tons produced to satisfy the public law mandating the program. *(See table 8.)*

As part of its plan to modernize the NDS, DLA contracted with Elkem Metals Co., Marietta, OH, to upgrade NDS nonspecification-grade low-carbon ferrochromium into electrolytic (vacuum melting-grade) chromium metal. Elkem converted low-carbon ferrochromium to chromium metal in 1989, 1990, and 1991. In 1992, DLA contracted with Elkem to convert low-carbon ferrochromium to about 1,600 tons of chromium metal. *(See table 9.)*

Strategic Considerations

Supply Security.—There is no production of chromite ore in the United States; primary consumption of chromium by U.S. industry is by companies that use chromite ore to produce ferrochromium, chromium chemicals, and chromite refractories and by chromium metal producers that use ferrochromium. World chromite ore reserves are abundant, ensuring adequate long-term supply. However, supply sources are few and remote from the United States, making supply vulnerable to disruption. The problem for the United States is one of national security. Ferrochromium is essential to stainless and some alloy steel production, which are in turn essential to the domestic economy and to the production of military hardware.

Use.—Strategic use of chromium is primarily in the metallurgical and chemical industries. Chromium is used in stainless steel and nickel- and cobalt-base superalloys. There are no substitutes for chromium in these uses. Stainless steel is essential to many industrial applications. Superalloys are essential to the production of gas turbine engines and to other high-temperature applications. Chromium chemicals are used for metal surface treatment and pigments.

Stockpile.—The NDS contains the following chromium materials: chromite ore, chromium ferroalloys, and chromium metal. The purpose of the NDS is to supply military, essential civilian, and basic industrial needs of the United States during a national defense emergency; by law, the stockpile cannot be used for economic or budgetary purposes. In addition to private and Government stocks, there exists a large unreported inventory of chromium contained in products, trader stocks, and scrap. The amount of these stocks varies with demand and price of the material. Under severe price pressures resulting from primary chromium shortages, recycling of consumer materials could add to the supply.

Chromite ore must be converted to ferrochromium before it can be used to make steel. Prompt response during a national defense emergency requires that conversion be carried out by domestic industry. However, domestic ferrochromium production capacity is not adequate to meet anticipated domestic demand under mobilization conditions. To ensure prompt NDS response to a national defense emergency, the President chose to convert stockpiled chromite ore to ferrochromium. Changes in industrial capacity and new manufacturing and technological developments have rendered selected chromium materials in the NDS inventory obsolete, either in quality or form or both, and in need of upgrading. Subsequent to legislative mandate, DLA began modernizing chromium materials in the NDS by converting nonspecification-grade low-carbon ferrochromium into chromium metal. (See Legislation and Government Programs section of this report.)

As a result of reduced threat to the territory of the United States, stockpile goals have been reduced and may be reduced further. Disposals of stockpile material have been made and were expected to continue until all excess material is disposed. Disposal takes the form of sale or payment for services contracted by DLA. In 1993, the DLA disposed of 192,000 tons of metallurgical-grade chromite ore and 59,000 tons of high-carbon ferrochromium, together containing about 97,124 tons of chromium. *(See table 9.)*

Issues

World ferrochromium production capacity in 1993 significantly exceeded demand, resulting in low capacity utilization. Strong demand for ferrochromium, resulting from high levels of stainless steel production worldwide in 1987-89, resulted in ferrochromium plant expansions and new plant construction. Since 1970, the trend has been for ferrochromium production capacity to move from major stainless steel-producing countries (e.g., Japan, the

United States, and Western Europe) to major chromite ore-producing countries (e.g., Finland, India, Kazakhstan, the Philippines, the Republic of South Africa, Turkey, and Zimbabwe). This has occurred through the creation of new plants or furnaces in chromite ore-producing locations and the closure of furnaces in other geographic areas where ferrochromium production was formerly strong. The increase in and change in location of world annual gross weight production capacity has continued that trend. Most of the added capacity was in chromite ore-producing countries. All of the capacity contraction was in nonchromite-producing countries. The largest addition to national annual capacity was in the Republic of South Africa, increasing the Republic of South Africa's capacity by about 30% in the 1989-90 time period. The supply shortage in 1988 was estimated to have been about 200,000 tons or about 5% of 1988 world production capacity. The expansion of 1989 and 1990 represented about 16% of 1988 world production capacity.

Stainless steel is the major chromium end use. Despite strong stainless steel production in 1993, ferrochromium production capacity exceeded demand, and weak prices resulted. Ferrochromium producers limited production and planned plant closings to reduce supply of ferrochromium in the expectation that reduced supply would stimulate prices to increase.

With Western World stainless steel production growing at a long-term average annual rate of 3% to 4%, it is estimated that it will take until 1995 (about 5 years of average industry performance) for demand to catch up with added capacity. Experience shows that short-term variations in chromium consumption and production can be significantly larger than long-term trends. The integration of the former U.S.S.R. with Western country economies started with the dissolution of the U.S.S.R. in 1991. This event complicated the recovery process by introducing additional chromite ore and ferrochromium supply capacity. As a result of political and economic changes, demand for chromium materials in the former U.S.S.R. declined. It was anticipated that a new world market balance would be achieved and that demand in the former U.S.S.R. would recover as production facilities in that region converted to cost-based pricing systems.

Production

The major marketplace chromium materials are chromite ore and chromium metal, ferroalloys, and chemicals. In 1993, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore. *(See tables 10 and 11.)*

Consumption and Uses

Domestic consumption of chromite ore and concentrate was 336,582 tons in 1993. Of the total chromite consumed, the chemical and metallurgical industry used 313,708 tons, and the refractory industry, 22,874. 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 1993 was in stainless steel. Of the 357,614 tons of chromium ferroalloys, metal, and other chromium-containing materials reported consumed, stainless steel accounted for 78.2%; full-alloy steel, 7.7%; high-strength, low-alloy, and electric, 3.1%; cast irons, 1.4%; superalloys, 1.6%; and other end uses, 8.0%. The primary use of chromium in the refractory industry was in the form of chromite to make refractory bricks to line metallurgical furnaces.

The chemical industry consumed chromite for manufacturing sodium bichromate, chromic acid, and other chromium chemicals and pigments. Sodium bichromate is the material from which a wide range of chromium chemicals are made. *(See tables 12 and 13.)*

Stocks

Reported consumer stocks of chromite in the United States decreased from 320,973 tons in 1992 to 274,756 tons in 1993. Chemical and metallurgical industry stocks decreased as did refractory industry stocks. At the 1993 annual rate of chromite consumption, consumer stocks represented about 10 months of supply in the chemical and metallurgical industry and 8 months of supply in the refractory industry. Producer stocks of chromium ferroalloys, metal, and other materials decreased from 5,723 tons in 1992 to 5,612 tons in 1993. Consumer stocks decreased from 17,628 tons in 1992 to 16,685 tons in 1993. At the 1993 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 0.7-month supply. *(See table 14.)*

Prices

Chromite ore price information indicated a price decline in 1993. Published prices indicated a decrease for South African chemical-, foundry-, and refractory-grade ore while Philippine ore remained steady, as reported by Industrial Minerals. U.S. minimum, maximum, and weighted average chromite ore import unit values declined. The price of South African and Turkish chromite ore remained steady, as reported by Metals Week. Import unit values are from import quantity and value data collected by the Department of the Treasury, distributed by the Department of Commerce, and edited and published by the Department of the Interior, U.S. Bureau of Mines, and represent imports from Philippines, South Africa, and Turkey in 1992 and from Philippines and South Africa in 1993.

The Metals Week price of the Republic of South African Transvaal chromite, 44% Cr_2O_3 (no specific chromium-to-iron ratio), ranged from $50 to $60 per ton, f.o.b. the Republic of South African ports throughout the year.

The Metals Week price of Turkish ore ranged from $105 to $110 per ton, f.o.b. Turkish ports throughout the year.

Domestic ferrochromium prices remained steady throughout the year. The published price of domestic high-carbon ferrochromium (50% to 55% chromium) remained unchanged at 52 cents per pound of chromium content (¢/lb-Cr) throughout the year. The published price of domestic low-carbon [0.05% and 0.015% (Simplex) carbon] ferrochromium remained unchanged at 166 ¢/lb-Cr throughout the year.

The published price of electrolytic chromium metal remained at 370 ¢/lb throughout the year. The price of elchrome-grade electrolytic chromium metal remained at 450.0 ¢/lb. (Elchrome is a vacuum degassed chromium metal product produced by Elkem Metals Co.)

The published price of imported high-carbon (50% to 55% and 60% to 65% chromium) ferrochromium varied throughout the year. The published price of 50% to 55% high-carbon ferrochromium started at a range of from 36 to 39 ¢/lb-Cr and ended the year at 35.5 to 38 ¢/lb-Cr. The published price of imported 60% to 65% high-carbon ferrochromium started the year at a range of 33.5 to 34.5 ¢/lb-Cr and ended the year at 35 to 36 ¢/lb-Cr. The published price of imported low-carbon (0.05% carbon) ferrochromium varied throughout the year from a range of from 71.5 to 74 ¢/lb-Cr to a range of from 71 to 73 ¢/lb-Cr. *(See table 15 and figures 5 and 6.)*

Foreign Trade

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments. *(See tables 16 through 20.)*

World Review

Industry Structure.—The chromium industry is composed primarily of chromite ore producers, ferrochromium producers, and stainless steel producers. Other industry components are chromium chemical and chromite refractory producers. Brazil, Finland, India, Japan, Turkey, the Republic of South Africa, and Russia are countries that mine chromite ore, produce ferrochromium, and produce stainless steel. In Finland, Outokumpu Oy, a major share of which is state-owned, owns and operates the only chromite mining, ferrochromium production, and stainless steel production facilities, making it completely vertically integrated. In the Republic of South Africa, chromium-related companies are privately owned. Typically, major shares of a company are owned by other companies and the remainder, if any, is openly traded. Samancor owns and operates chromite mining, ferrochromium production, and the only stainless steel production facilities. In Brazil, the mining and smelting of chromium is vertically integrated, but stainless steel production is independent of the mining-smelting operations. The major mining companies are subsidiaries of Cia. de Ferro Ligas da Bahia S.A. Stainless steel is produced primarily by Companhia Acos Especiais Itabira. Other chromite operations in Brazil are also vertically integrated. Bayer AG (Germany) owns a chromite mine and chromium chemical plant. Refractory chromite operations also are vertically integrated from chromite production through refractory material production. Chromite mining and ferrochromium production in India is mostly vertically integrated. Ferro Alloys Corp. is the only stainless steel producer in India that is integrated from chromite ore mining through ferrochromium and stainless steel production. In Japan and Russia, chromite ore production is minor. In Japan, some ferrochromium producers are associated with stainless steel plants by location, ownership, or both. In Russia, production facilities are Government owned. In Kazakhstan, chromite ore mining and ferrochromium production is vertically integrated. In Turkey, the chromium industry is composed of both large and small chromite ore producers, with one major producer, Etibank, integrated from mining through ferrochromium production. The chromium industry of Zimbabwe is composed of large companies vertically integrated from chromite mine production through ferrochromium production, small independent chromite mines, and chromite mines operated independently on behalf of the large vertically integrated companies.

Capacity.—Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical chromium trade data have been used to estimate production capacity. Rated production capacity changes result both from changes in facilities and changes in knowledge about facilities. Capacities have been rated for the chromite ore, ferrochromium, chromium chemical, and chromium metal industries. *(See table 21.)*

Reserves.—The United States has no chromite ore reserves. However, the United States has a reserve base and resources that could be exploited. (For further information on domestic reserves, reserve base, and resources, see Geology-Resources section of this report.) *(See table 21.)*

Production.—World chromite ore production in 1993 was estimated at about 10.0 million tons, a 10% reduction from that of 1992. World ferrochromium production in 1993 was estimated at about 3.1 million tons, a 9% reduction from that of 1992. *(See tables 22 and 23.)*

Albania.—**National Developments.**—Albchrome, a semiautonomous organization responsible for chromite mining and ferrochromium production industry, was established in 1992 for the purpose of encouraging private investment in the country's chromium industry. The chromium industry was previously under the control of the Chrome Bureau under the Ministry of Industry, Mines and Energy. Albchrome was formed in preparation for the privatization of the Albanian chromium industry. With the assistance of the European Bank for Reconstruction and Development, Albania invited, received, and negotiated proposals from prospective investors. Albania sought an 8-year development program to build upon its current chromium industry, including chromite mining and ferrochromium production with an emphasis on increasing domestic ferrochromium production. Basic infrastructure, including access roads, electrical power lines, and water pipelines, are in place and there is excess electrical power supply. Several problems were identified by Albchrome. Included among them were the following: (1) The cooperatives, including the mining cooperatives, were used for social control with political and criminal elements assigned to some chromite mines as forced labor. (2) Inadequate historical investment has resulted in antiquated inefficient operations. Only a small portion of chromium industry income was reinvested in the chromium industry, a condition characteristic of the mining industry in general. (3) As a result of the country having been run by decree, the legal system was ambiguous and did not recognize and spell out the rights of private ownership. (4) The national Government did not appear to have decided the degree to which private entities will be granted autonomous control.

Chromite Ore.—Chromite ore production was reported to have been about 316,000 tons in 1989 and 38,300 tons in 1992 at an average grade of 44% Cr_2O_3.

Ferrochromium.—Albania also operated two ferrochromium plants, one at Burrel and one at Elbasan. Each plant had three 9 megavolt-ampere furnaces of Korean construction; however, owing to a lack of spare parts, only three of the furnaces were operational. The Burrel ferrochromium plant was commissioned in 1979 with two furnaces; a third was added in 1987. Nameplate capacity of the three furnaces was in the range of 40,000 to 60,000 tons of ferrochromium per year. The Elbasan plant started ferrochromium production in 1988 with three furnaces. Production was reported to have been 22,000 tons of high-carbon ferrochromium in 1992 and projected to reach 35,000 tons in 1993 from two furnaces at Burrel and one at Elbasan. Albania planned to increase ferrochromium production capacity up to 120,000 to 200,000 tons per year during the next 8 years through private investment.

Australia.—Dragon Mining NL continued development of its Range Well lateritic chromiferous deposit in Western Australia. Dragon planned to truck chromite ore from the mine to the port city of Geraldton where it would be smelted in a 12-megawatt electric arc furnace to produce a 10% to 12% iron-chromium alloy that would then be cast for use as a high-chromium grinding medium. Dragon planned to mine about 50,000 tons per year of lateritic chromite ore from a surface resource of about 31 million tons. Dragon was having Commonwealth Steel perform the semicommercial-scale smelting and casting tests.

Brazil.—**National Developments.**—Brazil imposed a 13.6% duty on imports of high-carbon ferrochromium from South Africa effective in February for a duration of 5 years. The duty resulted from a dumping complaint filed in 1991. Companhia de Ferro-Ligas da Bahia S.A. requested the Government to review the duty, arguing that it should be increased owing to economic changes since the request was made in 1991. Brazil imposed a provisional 18.97% duty on imports of low-carbon ferrochromium from the C.I.S. effective in September for a duration of 120 days. The duty was based on a request by Associação Brasileira Dos Produtores De Ferroligas (ABRAFE) made in September 1992.

Chromite Ore and Ferrochromium.—ABRAFE identified two ferrochromium producers in 1992—Companhia de Ferro-Ligas da Bahia S.A. and Companhia de Paulista Ferro-Ligas—with capacity in December 1992 rated at 120,000 tons of high-carbon ferrochromium from five furnaces rated together at 96.5 megawatts; 10,000 tons of ferrochromiumsilicon from one furnace rated at 10 megawatts; and 14,000 tons of low-carbon ferrochromium from two furnaces rated together at 7 megawatts. ABRAFE reported production in 1992 as 85,085 tons of high-carbon ferrochromium, 6,015 tons of low-carbon ferrochromium, and 6,759 tons of ferrochromiumsilicon from 248,113 tons of chromite ore; exports as 23,915 tons of high-carbon ferrochromium and 400 tons of ferrochromiumsilicon; and imports as 5,155 tons of high-carbon ferrochromium and 3,536 tons of low-carbon ferrochromium.[14] The Departamento Nacional da Produção Mineral reported chromite ore and concentrate production in 1992 as 460,044 tons graded at 43% Cr_2O_3.[15] Brazilian chromium apparent consumption was about 174,000 tons of contained chromium in 1993.

The chemical and textural characteristics of the chromitite found along the Jacobina fault of the Campo Formoso ultramafic complex located in Bahia State were found to have characteristics peculiar to podiform- and stratiform-type deposits. The chromite deposit of the Campo Formoso district was subdivided into seven levels ranging in width from 1/2 to 8 meters and to have a chromite chemistry of 45% to 56% Cr_2O_3 by weight.[16]

Bulgaria.—The Dobromvitsi chromite deposits were reported in southern Bulgaria near the border of Greece and near the border between the Plovdiv and Khaskovo oblast boundaries. There was insufficient information to indicate the current status of chromite resources.

Canada.—**National Developments.**—The Hall and Hall extension chromite ore bodies were studied. These ore bodies are 5 kilometers south of Thetford Mines, Coleraine Township, Quebec. The deposit was found to be composed of dunitic rock hosting chromitite. The chromitite was found to show three textures; massive, antinodular, and chain.[17]

Ferrochromium.—The Provincial government of Manitoba, in cooperation with Dow Corning Energy Systems Inc., studied the possibility of master alloy containing chromium and nickel being produced for the stainless steel industry. Dow started to study the possibility of converting its silicon furnace at Selkirk, Manitoba, to nickel-chromium master alloy production.

Ressources Minières Coleraine Inc. planned a high-carbon ferrochromium plant in Quebec with a production capacity of about 23,000 tons per year. Coleraine sought to raise $C40 million to finance the project, including construction through the first 6 months of operation.

China.—**National Developments.**—China had a 40% export tax on ferrochromium. Tax exempt economic zones were established in February. China reported trade statistics for 1992 and 1993. Chinese chromium trade has been dynamic. China imported chromite ore as follows: 641,267 tons in 1990, 544,648 tons in 1991, 901,020 tons in 1992, and an estimated 620,000 tons in 1993. The dramatic increase in Chinese imports of chromite ore reportedly resulted from the conversion of ferroalloy production capacity to ferrochromium partly for foreign sale. China exported ferrochromium as follows: 11,463 tons in 1990, 29,767 tons in 1991, 60,543 tons in 1992, and an estimated 130,000 tons in 1993. China imported 964 tons of ferrochromium in 1992. In addition to chromium ferroalloys, China also produces chromium chemicals, chromium metal, and stainless steel. Chinese stainless steel production was estimated to have been about 450,000 tons in 1993 accounting for about 226,000 tons of domestic ferrochromium consumption.

Chromite Ore.—Chromite ore deposits in China were reviewed. Chromite deposits in China were characterized as being of podiform, stratiform, or sedimentary type. The Dadao deposit in the Qilian-Qinling ophiolite belt was identified as the largest exploited stratiform deposit.[18]

Ferrochromium.—China shifted ferroalloy production capacity to ferrochromium production, resulting in a greater role for China in chromite ore and ferrochromium markets starting in 1991 and continuing into 1992 and 1993. Ferrochromium producers in China were reported to have been: Xibei, Gansu Province; Hanzhong, Shanxi Province; Jilin, Jilin Province; Liaoyang and Jinzhou, Liaoning Province; Nanjing, Jiangsu Province; Shanghai, Shanghai Municipality; Hengshan, Zhejiang Province; Minfu, Fujian Province; Lianyuan, Hunan, and Xiangtan, Hunan Province; and Fuling, Chongqing, and Emei, Sichuan Province.

Commonwealth of Independent States.—It was reported that since the major chromite ore deposits in the Ural mountain range were discovered in 1937, chromite exploration was limited to that region. The major, exploited deposits are the Donskie deposit in the Kempirasi massif in the southern part of the Ural mountain range (Kazakhstan) and the Saranovskoye deposit in the middle part of the Ural mountain range (Russia). A third, as yet unexploited chromite deposit was recently found (reported in 1986) in the Burqakovskij massif, northern region of Karelia (Russia).[19]

Croatia.—Dalmacija Dugi Rat operated a high-carbon ferrochromium smelter. Dalmacija closed one furnace in December 1992 owing to insufficient power supply. The remaining furnace was closed in February for the same reason. Dalmacija did not restart production until November because the area experienced its worst drought in more than 100 years, causing short supply of hydroelectric power.

Egypt.—The mineralogy and geochemistry of chromite resources from the Abu Dahr and El Galala areas of the Eastern Desert were studied. The chromite was found to occur as lenses with grades ranging from 7.55% Cr_2O_3 to 51.9% Cr_2O_3.[20]

Ethiopia.—Podiform chromitites from Kenticha Hill, southern Ethiopia, were studied. The deposit was found to be of Precambrian age and to contain chromite grading in excess of 58% Cr_2O_3. The mineralogy, mineral chemistry, and platinum-group element distribution were found to establish the podiform or layered affinity of these chromitites and, possibility, their geodynamic environment.[21]

European Community.—The European Community imposed an antidumping penalty duty on low-carbon (i.e., 0.05% or less carbon) ferrochromium imported from Kazakhstan, Russia, or Ukraine. The duty was provisionally imposed in April at the rate of about $0.23 per pound of contained chromium. However, the final duty was introduced in October at the rate of about $0.26 per pound of contained chromium. The European Community planned to impose packaging legislation to limit the chromium content of chromium to 100 parts per million. Sociopolitical changes in Eastern Europe in the early 1990's were found to have a profound impact on the minerals industries of that region, which, in turn, will impact the European Community.[22]

Finland.—The chromium industry of Finland is vertically integrated from chromite ore mining through stainless steel production under Outokumpu Steel Oy. The Kemi chromite deposit was discovered in 1959 followed by a decision to mine in 1964 and industrial scale production in 1968. It is 7 kilometers northeast of Kemi city. Reserves reportedly are about 150 million tons of 26% Cr_2O_3 average grade. The ferrochromium plant started production in 1968 with an annual production capacity of 30,000 tons of ferrochromium. Periodic upgrades, including the addition of a new pelletizing plant in 1989, boosted production capacity to its current annual level of 230,000 tons of high-carbon ferrochromium graded at 52% chromium and 6% to 8% carbon. Commercial stainless steel production began in 1976 with a planned annual production capacity of 50,000 tons of stainless steel. Today, molten ferrochromium is transported by train to the stainless steel works. The stainless steel plant capacity is about 250,000 tons of cold-rolled stainless steel and 100,000 tons of hot-rolled products.[23] Reorganization of the world chromium industry reportedly impacted Finland's chromium industry. Finland produces chromite ore and ferrochromium for world markets in addition to consuming much of its own production. Previously, before anti-Apartheid sanctions were lifted and the former U.S.S.R. began reorganizing its economy, Sweden was a secure market for Finnish ferrochromium. As a result of the fact that Sweden is now free to import South African ferrochromium and the C.I.S. ferrochromium producers have entered the European market, Finland planned to enter the North American market to maintain its exports.

France.—MG France, a wholly owned French subsidiary of Metallgesellschaft (Germany), purchased Chromeurope and converted it into a stainless steel dust recycling plant. MG France planned to process about 40,000 tons of stainless steel dust per year in one of Chromeurope's two furnaces to produce 7,200 tons per year of chromium-containing alloy for steel industry use.

Greece.—Hellenic Ferroalloys SA (HFA) closed in June 1991 and, under Government administration, was offered for sale. The Government planned to sell Hellenic Ferroalloys, which includes the ferrochromium smelter at Tsingeli and mines at Vourinos and Skoumisa in Macedonia. The smelter produced high-carbon ferrochromium graded at 52% chromium with annual production capacity of about 50,000 tons from one 27-megavolt-ampere furnace built in 1984 by Krupp (Germany). The Vourinos Mine produced chromite ore with a run-of-mine annual production capacity of 100,000 tons and a concentrator with an annual production capacity of 50,000 tons. The Skoumisa Mine produced chromite ore with a run-of-mine annual production capacity of 180,000 tons and a concentrator with an annual production capacity of 80,000 tons.

The results of drilling for chromite in the Voidolakkos ore district of the Vourinos ophiolite complex were reported. There are about 780 chromite occurrences in the Vourinos complex. The largest deposit in the complex is contained in the Xerolivado dunite with reported potential resources of 6 million tons of 22% modal Cr_2O_3.[24]

Greenland.—Chromite mineralization is found in a layered and folded anorthosite complex in the Archaean belt that covers about 650 kilometers along the southwest coast of Greenland. Chromite horizons are distributed over an area of about 3,200 square kilometers. Reported resource estimates include 2.5 million tons of 32.7% Cr_2O_3 at one location and a more spread out 100 million tons of lower grade mineralization.

India.—National Developments.—The Indian Government opened its chromite mining industry to private and foreign investment of up to 50% ownership.

Chromite.—India reported total chromite ore geological resources of 182 million tons, 96% of which was in Cuttack district of Orissa State. Reserves were 88.351 million tons (98% in Orissa, 1% in Karnataka, and the remainder in Andhra Pradesh, Bihar, Maharashtra, Manipur, and Tamil Nadu). The major chromite mining companies were Tata Iron and Steel Co. Ltd., Orissa Mining Corp. Ltd., Ferro Alloys Corp. Ltd., and Mysore Minerals Ltd. Chromite production was 926,148 tons in 1988-89, 1,050,406 tons in 1989-90 (average Cr_2O_3 content of 43%), and 916,386 tons in 1990-91. India reported a chromite ore domestic consumption of 395,700 tons in 1987, 427,500 tons in 1988, and 448,100 tons in 1989-90. The distribution of production in 1989-90 was 86% to ferrochromium production, 8% to refractory production, and 6% to chemical production.[25]

Orissa Mining Corp. started production from its new chromite ore beneficiation plant at its Kaliapani Mine, Cuttack district, Orissa State. The plant was planned to consume about 100,000 tons per year of chromite ore graded at 50% Cr_2O_3 to produce about 84,000 tons per year of chromite ore concentrate (62,000 tons of sand and 22,000 tons of fine concentrate) graded at 54% to 55% Cr_2O_3. SiO_2 was to be kept at less than 1%.

Indian Metals and Ferro Alloys sought to increase its chromite ore leases to avoid the necessity of buying ore from its competitors. Holdings were distributed as follows: Tata Iron and Steel Ltd., 69%; Orissa Mining Corp, 21%; and Ferro Alloys Corp., 4%. Indian Metals and Ferroalloys and other companies held the remainder.

The geology, geochemistry, and petrography of chromite mineralization in the mafic-ultramafic complex of the Usgaon, Goa, were reported. Ultramafics host chromite mineralization at Usgaon, Bondla, southwest of Paikul and Ganji areas. Chromite mineralization is mainly observed to be of disseminated, blotchy, or cumulus type forming the "leopard ore"; massive chromitite layers are generally of granular type and occasionally of remobilized, vein type associated with asbestos veinlets. In the Bondla forest area, a major chromite body of 19.5% to 28.5% Cr_2O_3 extends over a length of 1,200 meters with an average width of 200 meters. A bulk sample of float ore from Bondla forest analyzed 21% Cr_2O_3 with a beneficiated concentrate analyzed at 43% Cr_2O_3.[26]

Ferrochromium.—India reported ferrochromium (i.e., ferrochrome plus charge chrome) production of 151,167 tons in 1988-89, 137,301 tons in 1989-90, and 130,465 tons in 1990-91. The major ferrochrome producers were Ferro Alloys Corp. Ltd., Visvesvaraya Iron and Steel Ltd., and Indian Development Corp. The major charge chrome producers were Orissa Mining Corp., Ferro Alloys Corp. Ltd., Indian Metals and Ferro-alloys, and Indian Charge Chrome Ltd. with a combined annual capacity of 145,000 tons. India reported 1989-90 ferrochrome consumption of 15,500 tons, 89% of which went into alloy steel.[27]

Indian Metals and Ferro Alloys Corp. Ltd. operated two ferrochromium plants, Indian Charge Chrome Ltd. (ICCL) at Choudhar and Indian Metals and Ferro Alloys (IMFA) at Therubali. ICCL operated one 48-megavolt-ampere furnace with an annual charge-grade high-carbon ferrochromium production capacity of 60,000 tons and a captive 108 megawatt, coal-fired powerplant. The captive powerplant supplied both plants.

Chemicals.—Narco Chemicals Ltd. planned to manufacture sodium dichromate, basic chrome sulfate, and sodium sulfate at the Fatuha Industrial Area of Bihar. Production was to have started in June with an annual production capacity of 875 tons of sodium dichromate, 3,500 tons of basic chromium sulfate, and 2,100 tons of sodium sulfate. The chemicals were to supply the leather tanning industry.

Iran.—Iran signed a bilateral agreement with China to co-operate in establishing ferrochromium production.

Italy.—Britton Commerce and Merchandise, a company based in Dublin, Ireland, and representing Saudi Arabian interests, purchased Ferroleghe SpA. Ferroleghe had an annual production capacity of about 45,000 tons of high-carbon ferrochromium. Britton planned to invest $7 million to renovate the existing furnaces and add one furnace to attain an annual production capacity of about 80,000 tons in 1994.

Japan.—Japan operated a two-part stockpiling program, Government and private. Japan's long-term goal was to acquire a stockpile of chromium materials adequate to serve the needs of Japanese industry for 60 days. Japan planned to have the Government finance and stockpile 70% of the material, the private sector the remaining 30%, and the 60 day-supply target to be reached in 1995. Metal Mining Agency of Japan, under the supervision of the Ministry of International Trade and Industry, operated the Government stockpile, while Japan Rare Metals Stockpiling Association operated the private stockpile. In fiscal year 1992 (April 1992-March 1993), Metal Mining Agency of Japan acquired 5,145 tons of ferrochromium. As of March 1993, the Government stockpile reached the equivalent of 32.7 days of chromium supply while the private stockpile reached the equivalent of 14 days of chromium supply. In fiscal year 1993, Metal Mining Agency of Japan acquired 4,484 tons of ferrochromium and Japan Rare Metals Stockpiling Association acquired 1,939 tons of ferrochromium. Japan planned to continue its stockpiling program despite the dissolution of the former U.S.S.R. in 1990 because its stockpile is intended to serve as both a strategic and economic purpose. Stockpile planners anticipated growth in stainless steel demand that would result in demand growth for stockpiled chromium materials and noted that new investments in production facilities have not been made for a long time, resulting in the potential for tight supply.

Japan imported 601,629 tons of chromite ore, 548,581 tons of ferrochromium, 1,468 tons of chromium metal, and 203,344 tons of stainless steel scrap. Japan's ferroalloy industry produced about 224,963 tons of ferrochromium, a decline of 25% compared with that of 1992. (Japan's annual ferrochromium production has ranged from about 225,000 tons to 360,000 tons in the 1980-93 time period with the lower limit set in 1993.) Japan reported a hot-rolled stainless steel production of 2,649,127 tons in 1992, an increase of 0.1% compared to that of 1992. Japan exported 1,277 tons of ferrochromium and 896,393 tons of stainless steel. Ferrochromium imports represented 71% of market share (up 11% over those of 1992) while stainless steel exports represented 33.8% of production. Japan's ferrochromium industry lost its market share in 1993. This was attributed to lower ferrochromium prices (down 20% based on unit value of imports) and a 13% yen value rise. Ferrochromium consumers reportedly were shifting their strategy from buying 10% to 15% of their demand on the spot market to buying about 50% of their demand on the spot market to take advantage of currently low spot market prices. Based on chromite ore, ferrochromium, and chromium metal trade, chromium apparent consumption in Japan was about 483,000 tons contained chromium in 1993.

Tosoh Corp. planned to cease production of chromic acid and electrolytic chromium metal at its Yamagata City, Yamagata Prefecture plant. Chromic acid anhydride production stopped in October, and chromium metal production was planned to cease by 1995. Tosoh's chromium metal annual production capacity was about 3,600 tons; its production in 1992 was about 2,800 tons. Tosoh closed its plant as part of Yamagata City's urban development program. Tosoh and Samancor (South Africa) studied the feasibility of establishing a chromium metal plant in South Africa. The planned plant development was abandoned owing to weak market conditions.

Nippon Denko, a ferrochromium producer, made a joint-venture agreement with Samancor (South African chromite ore and ferrochromium producer). (See South Africa in this section.) Japan Metals and Chemicals' Kyushu works relined and repaired its rotary kiln over a 2-month period. Japan Metals and

Chemicals' Oguni works planned to close its ferrochromiumsilicon furnace, electing to use imported ferrochromiumsilicon instead for its low-carbon ferrochromium. Nippon Steel, a stainless steel producer, studied the possibility of a joint-venture agreement with Anglo American (South African chromite ore and ferrochromium producer). Nippon Denko is a coowner of Integrated Charge Chrome (Philippines).

Nippon Steel Corp. planned a joint venture with Consolidated Metallurgical Industries (South Africa) to develop a chromite ore mine in South Africa. (See South Africa in this section.)

Kazakhstan.—**National Developments.**—Chromium-related activity centered around reorganization of the industry as a result of national economic and political reorganization. The Kazakhstan chromium industry moved from state control of the chromite ore mining and two ferrochromium plants in 1990 to semi-independent operations in 1991. As a result of that change and the subsequent entrance of Kazakhstani chromium producers into the world market, Kazakhstan is developing its new organization and the role it will play relative to its old and new trading partners. Kazakhstani ferrochromium producers have been assessed import duties for dumping in Brazil, Europe, and the United States. The necessity for the Kazakhstani chromium industry to respond to foreign litigation resulted in the formation of the International Chrome Committee of Kazakhstan. Internally, the Kazakhstan chromium industry and politicians debated the export of chromite ore, especially to China and Russia, two countries that compete with Kazakhstani ferrochromium, a downstream chromium industrial product. There was reported disparity between Kazakhstan and Russia in chromite ore pricing with domestic ferrochromium producers getting the lowest prices. Russian chromite ore consumers reportedly built up large debts. The situation is complicated by the fact that Kazakhstani ferrochromium producers are dependent on Russian electrical power. The Kazakhstani and Russian chromium industry companies briefly organized under the name Kazrochrom. Efforts to organize the Kazakhstani chromium industry were started by the industry itself and by the Government. No solution to issues of pricing, payment schedules, competitive products, and reinvestment have evolved yet. The Government instituted an export tax on ferrochromium only to withdraw it later in the year. The Government organized the chromium industry into holding companies with Donskoy and Aktubinsk in one company (Kramds) and Yermakovsky in another. The Government planned to develop a vertically integrated chromium industry from chromite ore mining through ferrochromium production to stainless steel production through Kramds.

Chromite Ore.—Donskoy Ore Dressing Complex mines and beneficiates chromite ore, annually producing about 3.5 million tons and exporting about one-third of production. Mining was primarily from the 40th Anniversary of Kazakhstan Soviet Socialist Republic open pit and the Molodiozhnaya underground mines with capacities of 1.8 million tons (ore grade of 47% to 49% Cr_2O_3) and 2 million tons (ore grade of about 44.9% Cr_2O_3), respectively. The Tsentralnaya Mine was under development. The Tsentralnaya Mine was planned to come into production in the year 2000 whereupon annual production capacity would increase to 4 million tons. Run-of-mine chromite ore was processed in one of two chromite ore beneficiation plants operated at the mine site. To upgrade marketable product, the Donskoy was constructing a briquetting plant of 200,000-ton-per-year capacity for commissioning in 1994 and a pelletizing plant of 700,000-ton-per-year capacity for commissioning in 1995.[28]

Ferrochromium.—Aktubinsk Ferroalloy Plant put in pollution control equipment to control effluent discharged into the Ilek River. Aktubinsk produced about 120,000 tons of ferrochromium in 1992 from an annual ferrochromium production capacity of 300,000 to 340,000 tons. Aktubinsk, in cooperation with Donskoy Mining Complex, planned to build a 125-megawatt electrical powerplant fueled by Kazakhstani natural gas at a cost of about $88 million.

Yermakovsky Ferroalloy Plant planned to convert six furnaces to ferrochromium production. Yermakovsky was building a briquetting plant with an annual capacity of 200,000 tons to improve production. It also planned a slag beneficiation program with the capacity to process 600,000 tons per year of slag and to put in a baghouse for dust collection.

Korea, Republic of.—Korea implemented a tariff change on ferrochromium imports. Under the new system, the tariff on the first 50,000 tons of ferrochromium is 2.5% ad valorem; after 50,000 tons, 5% ad valorem. Korea planned to increase its stainless steel production capacity to about 120,000 tons by 1996. Korea reported consumption of more than 110,000 tons of ferrochromium in 1992.

Madagascar.—Kraomita Malagasy operated mined chromite ore. It reported that in 1992 chromite ore production was 157,000 tons, export was 109,000 tons, and in 1993 production was 145,000 tons, and export was 119,000 tons. Thus despite significant typhoon-caused damage to rail and road systems, Kraomita increased its production and shipments.

Mexico.—Cia. Minera Autlan SA de CV was privatized when it was sold to Grupo Ferrominero, a consortium of Mexican companies, for $23 million. Autlan has produced ferrochromium but is not currently doing so. Autlan operates two plants, one at Tamos and one at Teziutlant. Quimica Central reportedly suspended sodium bichromate production.

Oman.—Oman reported 2 million tons of chromite ore reserves distributed over more than 450 sites. The Oman Chromite Co. operated southwest of Sohar in the area of Far Far and Simera.

Small producers operated near Rajmi. Because most deposits are small, the Government of Oman encouraged native Omani tribes to mine them.

Philippines.—**National Developments.**—National Power Corp., the national electrical energy supplier on Mindanao Island proposed a 40% price increase in electricity for major electrical energy consumers. The price increase was to be implemented in 1994.

Chromite Ore.—Chromite ore production is centered on Luzon Island where Benguet Corp mines refractory-grade chromite from the Coto Mine.

Ferrochromium.—Ferrochromium producers on Mindanao Island were closed for part of the year owing to lack of electrical power owing to low water levels.

Romania.—Ferom-Joint Stock Co., a Government-owned ferroalloy company, produced low-carbon and high-carbon ferrochromium. Ferom operated a 33-megavolt-ampere furnace with an annual production capacity of 52,000 tons of high-carbon ferrochromium and a 3.5-megavolt-ampere refining furnace to produce low-carbon ferrochromium from high-carbon, with an annual capacity of 9,600 tons. Ferom installed a dust collection system. It also requested the Government limit imports from the C.I.S. to protect its domestic market.

Russia.—**Ferrochromium.**—Chelyabinsk Electrometallurgical Works reported production of about 210,000 tons of ferrochromium, of which 168,000 tons was low-carbon and 42,000 tons was high-carbon. As a result of antidumping cases against C.I.S. ferrochromium in Europe, Chelyabinsk contracted with Mannesman Demag (Germany) to convert low-carbon ferrochromium production capacity to high-carbon ferrochromium at a cost of $4 to $5 million.

Serovsk reported annual marketable product production capacity at 80,000 tons of high-carbon ferrochromium, 150,000 tons of medium- and low-carbon ferrochromium, and 40,000 tons of ferrochromiumsilicon. Serovsk produced 228,000 tons of ferrochromium, of which 148,000 tons was low-carbon and 80,000 tons was high-carbon. Serovsk used chromite ore from Russia and Kazakhstan. To produce high-carbon ferrochromium, Serovsk required lump ore from Kazakhstan to mix with Russian fines. To reduce dependence on Kazakhstan lump ore, Serovsk planned to put in a briquetting plant with production capacity of 300,000 tons per year. Serovsk produced low-carbon ferrochromium from nine furnaces, ferrochromiumsilicon from five furnaces, and high-carbon ferrochromium from four furnaces.

Chromium Metal.—Polema, Tula Chermet Complex, Tula City, reported electrolytic chromium metal production with an annual production capacity of about 1,000 tons.

Slovakia.—Ovarske Ferozria Inarske Zavody, Istebne City, produced high-carbon ferrochromium with an annual production capacity of about 45,000 tons graded at 62% to 70% chromium.

Slovenia.—Tovarna Dušika Ruše produced high-carbon ferrochromium at about 60% of capacity in 1993. Tovarna stops ferrochromium production from December through March when electrical energy cost is highest.

South Africa, Republic of.—South African economic policy is one of vertical integration of industries that are based on its domestic mineral assets. To this end, the chromium industry of South Africa has moved from being a major world chromite ore supplier to being the major supplier of chromite ore and ferrochromium to Western markets. South Africa planned to increase stainless steel annual production capacity to 526,000 tons in 1995, most of which was destined for export.

Chromium production capacity utilization in South Africa was low in 1993. The high price of ferrochromium in 1988-89 that resulted from demand by stainless steel producers in excess of capacity put capital in the ferrochromium producers' hands and stimulated investment in new ferrochromium plants and equipment. In 1990, existing ferrochromium producers increased their production capacity by acquiring smaller producers or by expanding their production facilities. At this time, CMI added a furnace and acquired Purity Ferrochrome, a new producer; Samancor added furnaces at its Tubatse smelter; MS&A started construction of a new ferrochromium production facility using a new production process (kiln furnace prereduction followed by electric furnace smelting) at Middelburg and increased the transformer capacity of its DC transferred plasma arc furnace at Krugersdorp; and Chromecorp Technology added a furnace. (Feralloys made no changes.) In 1991, Samancor bought MS&A.

During and following the introduction of this new ferrochromium production capacity in South Africa and other capacity around the world, Western stainless steel production continued to grow steadily. However, because ferrochromium production capacity was added faster than stainless steel demand growth, the world ferrochromium market moved into a state of excess supply and prices declined. In addition, actions in the former U.S.S.R. and China exacerbated the situation. The collapse of the U.S.S.R. followed by the integration of C.I.S. with Western economies, a process that may continue for years to come, changed the chromium markets. Economic recession in the East (i.e., former U.S.S.R.) resulted in declining chromium demand in Eastern markets and the entry of Eastern raw materials suppliers into Western markets adding to chromium excess supply and downward pressure on prices. China, seeing an opportunity to increase ferroalloy sales, shifted some of its production capacity to ferrochromium. China has been increasing (about doubling annually) its ferrochromium exports since 1990. China's significant ferrochromium exports in 1992-93 added to excess supply. (See Kazakhstan and China in this section.)

With an annual ferrochromium production capacity of about 1.6 million tons (gross weight) per year, nearly one-third of world ferrochromium production capacity, South Africa is greatly impacted by these changes. Ferrochromium accounts for nearly one-half of South African ferroalloy export earnings, and ferroalloys are about the third largest export earner following gold and coal and about equal to that of platinum-group metal export earnings. South Africa has lost chromium market share because of changing market conditions resulting in low-capacity utilization. South African chromium producers carried out major company restructuring, including closing mines, shutting down furnaces, reducing production rates, and reducing personnel to accommodate changing world market conditions. The South African chromium industry thus bore the major share of the integration of the chromium industry of the former U.S.S.R. into the world economy.

By yearend 1993, South African ferrochromium producers ranked by production capacity as follows: Samancor, 1,000 kt/yr (thousand metric tons, gross weight, per year); CMI, 320 kt/yr; CCT, 200 kt/yr; and Feralloys, 100 kt/yr. Samancor's annual chromite ore production capacity was about 4,000 kt/yr or nearly one-third of world annual production. Hernic's annual chromite ore production capacity was about 300,000 tons.

South Africa's Minerals Bureau reported 1992 South African (including Bophuthatswana) chromite ore production at 3,363,000 tons, a decrease of 34% over that of 1991. Reported 1992 chromite ore sales were domestic, 2,039,000 (down 46% over that of 1991), and foreign, 1,087,000 tons (up 8% over that of 1991). Reported 1992 chromium ferroalloy production was 664,900 tons, a decrease of 41% over that of 1991. Reported 1992 chromium ferroalloy sales were domestic, 39,900 tons (down 43% over that of 1991), and foreign, 663,700 tons (down 31% over that of 1991).[29]

Chromite Ore.—The chromite ore industry suffered work force reductions and reduced production. In 1992, the South African chromite mining industry work force was reduced about 2,800 persons (34% of 1991 work force). Additional work force reductions were announced in 1993.[30]

Consolidated Metallurgical Industries (CMI), Nippon Steel Corp. (Japan) (NSC), and Mitsui and Co. (Japan) studied the feasibility of starting a new chromite mining operation at Thorncliff, Transvaal. CMI planned an operation with annual marketable production capacity of 600,000 tons, primarily to feed its smelter but also for export. CMI would increase its vertical integration through such a mine development, and NSC would gain access to secure ore supply for its domestic ferrochromium suppliers. NSC elected to not pursue the project when its ferrochromium suppliers pursued alternative strategies. In particular, Nippon Denko supplemented its production through a joint venture with Samancor; Japan Metals and Chemicals switched to using Kazakhstani chromite ore; and Pacific Metals shifted from producer to sales agent for South African-, Chinese-, and C.I.S.-produced ferrochromium.

The Chroombronne and Cashan Mines were operated by Chrome Corp. Technology in the western outcrop of the Bushveld Complex. Chroombronne Mine started production in 1979 and currently has a run-of-mine chromite ore production capacity of about 1.2 million tons per year with reserves of about 36 million tons. Ore is crushed and sized and fines are beneficiated by spirals. Cashan Mine has a production capacity of about 320,000 tons per year.

Ferrochromium.—Samancor and Nippon Denko (Japan) made a joint-venture agreement under the name NST Ferrochrome Pty. Ltd. wherein Nippon Denko purchased interest in production from one furnace at Samancor's Tubatse smelter. The furnace has a transformer capacity of 37 megavolt-amperes and high-carbon ferrochromium annual production capacity of 60,000 tons. Through this agreement, Samancor gains a more secure consumer market and Nippon Denko can use this capacity to displace its more expensive domestic capacity.

CMI produced ferrochromium at near 50% of capacity owing to weak market conditions. CMI tried to control cost and increase productivity at its Lydenburg and Rustenburg plants. CMI reported that the weakening rand exchange rate provided some financial relief.

Feralloys, a subsidiary of Associated Manganese Mines of South Africa that produces low-carbon ferrochromium, reported operating at only 35% of annual capacity.[31]

Chromecorp Technology (CCT) operated one ferrochromium plant at Rustenburg with an annual ferrochromium production capacity of about 185,000 tons from three electric furnaces. CCT started operation in 1988 with two furnaces of 30-megavolt-ampere electrical power capacity. A third furnace of 33-megavolt-ampere electrical power capacity was added in 1990. CCT acquired the Chroombronne Mine in 1987 and the Cashan Mine in 1992. The mines are about 18 kilometers from the plant. CCT reported consumption of about 3 to 3.2 tons of chromite ore and 4,200 kilowatt-hours per ton of ferrochromium product. CCT can recover about 20,000 tons per year of ferrochromium from slag.[32]

Samancor, South Africa's largest chromite ore and ferrochromium producer, found it necessary to make major reorganizations owing to weak market conditions. Samancor sold a share of Columbus Joint Venture to the parastatal Industrial Development Corp., reducing Samancor to an equal joint partner with Highveld Vanadium and Industrial Development Corp.[33]

Samancor operated five ferrochromium plants: Batlhako, with an annual production capacity of about 20,000 tons; Ferrometals at Witbank, with an annual production capacity of about 300,000 tons; Tubatse at Steelpoort, with an annual production capacity of about 300,000 tons; Middelburg plant at Middelburg, with an annual production capacity of about 280,000 tons (including the yet-to-go-into-commercial-production kiln process); and Krugersdorp plant at Krugersdorp, with an annual production capacity of about 100,000 tons. Samancor has a total ferrochromium production capacity of about 1 million tons. Owing to weak demand, Samancor reduced its production in 1993 by closing some furnaces to reach from 40% to 60% of production capacity. Samancor closed all except one of its ferrochromium furnaces in the first half of the year, restarted one furnace at each plant in the second half of the year, and was operating at near 50% of capacity at yearend. Samancor planned to lay off about 2,000 of its 7,000 employees as a result of production cutbacks.

Stainless Steel.—Columbus Joint Venture (CJV) was organized and scheduled for formal recognition as a new company in January 1993. CJV was planned to be co-owned by Highveld Steel & Vanadium, Samancor, and Industrial Development Corp. (a state-owned corporation), each with one-third ownership. CJV planned to develop Southern Cross Stainless from its current annual production capacity of 120,000 tons to 500,000 tons in 1995. CJV reported that all major contracts had been left for the project and that construction was underway as follows: Davy International for the hot and cold mills, Voest Alpine for the steel plant, and Danelli for the slab grinding equipment. The new plant will produce liquid steel from a 100-ton electric furnace, after which the liquid steel will be refined in an Argon-Oxygen-Decarburization vessel before being continuously cast into slabs.[34]

Taiwan.—Taiwan reported ferrochromium production and consumption for 1991. No ferrochromium was produced, compared with 1990 production of 5,952 tons. Ferrochromium consumption was 45,017 tons, up from 1990 consumption of 34,905 tons.

Thailand.—Chromite mineralization was found to occur in strongly serpentinized ultramafic rocks along the Nan-Uttaradit mafic-ultramafic belt. Chromite was found to occur in massive, banded, disseminated, and a few centimeters thick veins in serpentinized-pyroxenite sometimes transformed to amphibolite, lherzolite, and harzburgite. Cr_2O_3 contents were found to range from 50% to 66%.[35]

Turkey.—Etibank, a state-owned company, is Turkey's major chromite ore producer and only ferrochromium producer. The other major chromite ore producers include Hayri Ögelman Madencilik and Bilfer Madencilik AŞ. Etibank operated a low-carbon smelter at Antalya and a high-carbon ferrochromium plant at Elazığ. High-carbon ferrochromium production started at Elazığ in 1977 from two 17-megavolt-ampere furnaces. Production capacity was increased by 100,000 tons per year when two additional 30-megavolt-ampere furnaces were completed in 1989. Chromite ore exports have declined in value from 1991 to 1993 by more than 50%. Chromite ore is one of Turkey's major primary mineral export income sources. Turkish chromite ore exports were effected by the change in status of the former U.S.S.R. previously described. (See South Africa in this section.)

United Kingdom.—Harcros Chemical is the primary chromium chemical producer in the United Kingdom and one of the largest producers worldwide. (Bayer, based in Germany, and Oxychem in the United States are the other major world producers with Chinese and C.I.S. producers also reportedly active in world markets.) Harcros produced under the name British Chrome and Chemicals in the United Kingdom and American Chrome and Chemicals in the United States with an annual sodium bichromate production capacity of 200,000 tons and operated distribution terminals in Canada, the United Kingdom, and the United States. Harcros production capacity was distributed as follows: United Kingdom, 150,000 tons of sodium bichromate per year from two equal-sized kilns; and United States, 50,000 tons of sodium bichromate per year. It was estimated that 40% of Harcros' sodium bichromate goes into leather tanning and that 90% of the leather is tanned with chromium chemicals. Chromic acid used for plating and for wood treatment is the second largest outlet for Harcros' chromium chemicals followed by chromic oxide, which is used for chromium metal or pigment production.

Zimbabwe.—The Government of Zimbabwe granted Midlands Distributors the right to export chromite ore. The Minerals Marketing Corp. (Government owned) also sought to export chromite ore. Government policy has been to export only ferrochromium.

Two ferrochromium producers operated in Zimbabwe—Zimbabwe Mining and Smelting and Zimbabwe Alloys. Zimbabwe Mining and Smelting is a subsidiary of Union Carbide (United States). It produces high-carbon ferrochromium at Kwekwe with an annual capacity of about 178,000 tons from six electric furnaces. Zimbabwe Alloys is a subsidiary of Anglo American (South Africa). It produces low-carbon ferrochromium with an annual capacity of about 22,000 tons and ferrochromium-silicon at Gweru. Both companies experienced reduced demand and increased production costs because of increased electrical power cost in Zimbabwe. The Chamber of Mines sought power rate reduction from the Ministry of Transport and Energy on behalf of the country's ferrochromium producers.

Current Research

Mineral Processing and Industrial Applications.—U.S. Bureau of Mines research provides fundamental scientific and technical information essential for advancing mineral science, processing technology, and conserving and developing domestic mineral resources.

This research is conducted in support of the Strategic and Critical Materials Stock Piling Act of 1946 as amended, the Defense Production Act of 1950 as amended, the Mining and Minerals Policy Act of 1970, and the National Materials and Minerals Policy, Research and Development Act of 1980. Recent research related to chromium the study of chromium-containing corrosion and wear-resistant steels.

The Council for Mineral Technology (Mintek) of the Republic of South Africa conducts Government-sponsored and commercially sponsored and cosponsored research and development on chromite ore and ferrochromium. Recent Mintek research has included chromite beneficiation, agglomeration, smelting, recovery from slag, and stainless steel alloying. Mintek reported development of its Enviroplas process for the recovery of fine chromium-containing dusts resulting from stainless steel production.[36] A historical study of ferritic stainless steels found that their use increased substantially in the 1950-60 time period as a result of automotive demand for trim. Since then, the primary use of ferritic stainless steels for automotive applications has been in automotive exhaust systems.[37]

Environmental.—Environmental concerns about chromium have resulted in a wide variety of studies to determine chemical characteristics, the natural background levels, sources of environmental emissions, movement of chromium in the environment, interaction of chromium with plants and animals, effect of chromium on plants and animals, measurement methods, and recovery technology.

The EPA reported on the potential carcinogenicity of chromium compounds[38] and on the atmospheric release of hexavalent chromium from hard chromium plating operations.[39]

OUTLOOK

On average (from 1983 through 1992), U.S. chromium consumption by end-use industry has been: 87%, metallurgical; 10%, chemical; and 3%, refractory. Stainless steel, by definition, contains at least 11% chromium but may contain up to 36% chromium. Stainless steel production accounts for about 79% of the reported metallurgical chromium consumed in the United States. The remaining 2% of metallurgical industry consumption is for the production of other ferrous and nonferrous alloys. Some of the chemical and refractory products are consumed in the steel production process.[40]

On average internationally, about 79% of chromium is consumed by the metallurgical industry, 13% by the chemical industry, and 8% by the refractory industry. Of the chromium consumed in the metallurgical industry, about 60% is consumed in stainless steel. Thus, stainless steel production accounts for about one-half of the chromium consumed internationally.[41]

The outlook for chromium consumption in the United States and internationally is the same as that for stainless steel. Stainless steel is estimated to be the major end use for chromium worldwide. Thus, stainless steel industry performance determines chromium industry demand worldwide. *(See next section and table 24.)*

The trend to supply chromium in the form of ferrochromium by chromite mining countries is expected to continue. The rate at which new ferrochromium plants come into production is expected to diminish now that all major chromite producers have such facilities. With new, efficient ferrochromium production facilities and excess capacity in chromite-producing countries, both production and capacity are expected to diminish in traditional ferrochromium-producing countries, except where domestic industries are protected by quotas and tariffs. Further upward integration of the chromium industry is expected as chromite-producing countries expand current capacity or develop new stainless steel production capacity.

Since the dissolution of the U.S.S.R. in 1991, the industries of the former U.S.S.R. have been reorganizing and integrating into the rest of the world economy. This process is expected to continue, at different rates for different C.I.S. republics depending on the rate of political, legal, and economic structure within those countries and the conditions of the world economy to accommodate changes. The first impact of this integration has been on the globalized minerals markets. The low cost of chromite ore and ferrochromium from the former U.S.S.R. has resulted in that material displacing former suppliers to Western markets. New stable relationships are expected to develop as cost-based pricing is introduced in former U.S.S.R. countries and as those countries complete the process of legal, political, and economic reform that they have begun. It is anticipated that industrial renovation and unfulfilled consumer demand in the former U.S.S.R. could stimulate recovery in those countries and add to world demand for chromium-containing products.

China is emerging as a potential major factor in the world chromium market. China is primarily a chromium processing and consuming country. Chromite ore production in China is minor. Continued industrial growth in China could result in increased demand for stainless steel because stainless steel use is characteristic of the larger and more technologically developed economies.

Stainless Steel

As pointed out before, chromium demand is driven by stainless steel demand. Stainless steel demand is price sensitive, and an important part of stainless steel cost is nickel cost (about 70% of stainless steel requires nickel). One factor that could affect chromium demand is the availability of inexpensive nickel. Nickel availability is adequate to meet current demand and anticipated stainless steel demand until about 1995, at which time new nickel production capacity may be needed to meet demand. (Projected cost of production from new nickel production capacity could be substantially higher than that of currently available material.)[42] After 1995, possible increasing cost of nickel may result in increased stainless steel cost, which could result in reduced demand for stainless steel. Thus, just when stainless steel demand for chromium is anticipated to come into equilibrium with ferrochromium production capacity, demand may decline, reducing chromium industry growth after 1995.

Several factors could modify this scenario. Nickel supply and stainless steel demand from the previously centrally planned economy countries is uncertain. Reduction in cost of stainless steel, owing to greater production rates, may offset some nickel cost increases. Stainless steel producers could substitute manganese for nickel in some cases, thereby reducing the impact of nickel cost increases. Short-term fluctuations in demand could exceed these longer term average projections.

Chromium Chemicals[43]

Chromium chemical markets were reviewed in 1991. U.S. demand for sodium bichromate was reported to have been 130,200 tons in 1990 and was projected to be 130,800 tons in 1991 and 133,400 tons in 1995. The domestic chromium chemicals market showed -0.7% growth from 1981 through 1990 and was expected to show a positive 1% growth from 1991 through 1995. Reported price in 1991 for sodium bichromate crystals was $0.60 per pound of sodium bichromate dihydrate equivalent content (for pricing purposes, sodium bichromate dihydrate equivalent content of crystals is 100%) and for sodium bichromate liquor was $0.55 per pound of sodium bichromate dihydrate equivalent content (typically the sodium bichromate dihydrate equivalent content of liquor ranges from 69% to 70%). Sodium bichromate was used as follows: chromic acid, 55%; chromium oxide, 10%; leather tanning, 8%; pigments, 7%; wood preservatives, 2%; drilling mud additives, 2%; other uses (including metal finishing, water treatment, textiles, and catalysts), 3%; and export, 13%. Environmental concerns were seen as driving the chromium chemicals markets.

Demand for chromic acid was expected to continue to grow at an annual rate of about 2% to 3% through 1995. Domestic chromic acid producers, American Chrome and Chemicals and Occidental Chemicals, increased their chromic acid production capacity to the current annual rate of 71,000 tons to meet increasing demand. Chromic acid prices were about $1.10 to $1.15 per pound in 400-pound drums. Chromic acid was consumed for the production of wood preservatives, metal finishing, and chromium dioxide. Wood preservation currently accounts for about 70% of chromic acid demand and was expected to increase even though chromium chemicals account for about 70% of the U.S. wood treatment market. Environmental restrictions on the use of creosote (in marine pilings) and pentachlorophenol (in utility poles) are expected to result in greater use of chromic acid for wood preservation. The most widely used chromium-containing wood preservative is chromium copper arsenate (CCA). CCA-treated wood is resistant to decay and termite attack, and wood treated with CCA is easier to paint than wood treated with oil-based formulations. CCA-treated wood thus finds use in roofing, outdoor decks, and house foundations. Metal finishing accounts for about 27% of chromium oxide demand. Metal finishing includes chromium plating, aluminum anodizing, and other metal treatments. No growth was anticipated for metal finishing. The remaining 3% of chromic acid consumption included the production of chromium dioxide, a growth market that included the production of magnetic particles for use in magnetic recording media (audiotapes and videotapes and computer disks).

EPA regulations limiting chromium releases have encouraged recycling of chromium chemicals and the use of substitutes to reduce releases. As a result, demand is expected to be reduced for many end uses.

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TABLE 1
PRINCIPAL WORLD CHROMITE PRODUCERS, 1993

Country[1]	Company
Albania	Government owned.
Brazil	Bayer AG (Germany)
	Coitezeiro Mineraçao S.A.
	Cia. de Ferro-Ligas da Bahia S.A.
	Cia. de Mineraçao Serra de Jacobina S.A.
	Mineraçao Vale do Jacurici S.A.
	Industria e Comércio de Minérios S.A.
	Vila Nova Mine.
	Magnesita S.A.
Finland	Outokumpu Oy (Government owned).
India	Ferro Alloys Corp. Ltd.
	Mysore Mineral Ltd.
	Orissa Mining Corp. Ltd. (Government owned).
	Tata Iron and Steel Co. Ltd.
Kazakhstan	Donskoy Ore Dressing Complex.
Philippines	Acoje Mining Co. Inc.
	Benguet Corp.
	Philchrome Mining Corp.
Russia	Saranov Complex.
South Africa, Republic of[2]	Anglovaal Ltd.
	Lavino (Pty.) Ltd.
	African Mining and Trust Co. Ltd.
	Zeerust Chrome Mine Ltd.
	Rustenburg Minerals Development Co. (Pty.) Ltd.
	Bayer (Germany).
	Chrome Chemicals SA (Pty.) Ltd.
	Canadian Gold S.A. (Pty.) Ltd.
	Goudini Chrome (Pty.) Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Chroombronne (Pty.) Ltd.
	Genmin Ltd.
	Samancor Chrome Ltd.
	Batlhako Mining Ltd.
	Henry Gould (Pty.) Ltd.
	Millsell Chrome Mines (Pty.) Ltd.
	Montrose Mine.
	Groothoek Section.
	Jagdlust Section.
	Montrose Section.
	Mooinooi Mine.
	Tweefontein Mine.
	Waterkloof Mine.
	Winterveld Chrome Mines Ltd.
	Hernic Chrome
	Hernic Mining (Pty.) Ltd.
	Johannesburg Consolidated Investment Co.
	Consolidated Metallurgical Industries Ltd.
	Purity Chrome (Pty.) Ltd.
	Lebowa Development Corp. Ltd.
	Dilokong Chrome Mine (Pty.) Ltd.

See footnotes at end of table.

TABLE 1—Continued

PRINCIPAL WORLD CHROMITE PRODUCERS, 1993

Country[1]	Company
South Africa, Republic of[2]—Continued	National Manganese Mines (Pty.) Ltd. Buffelsfontein Chrome Mine.
	Tolgate Group Holding (Pty.) Ltd.
	Pilanesberg Chrome (Pty.) Ltd.
	Vereeniging Refractories Ltd.
	Marico Chrome Corp. Ltd.
	Bophuthatswana Chrome Co. (Pty.) Ltd.
Turkey	Etibank (Government owned).
	Bursa Toros Kromlari AS.
	Egemetal Madencilik AS.
	Sitki Kocman Mines.
	Turk Maadin Sirketi AS.
	Hayri Ogelman Madencilik AS.
Zimbabwe	Zimbabwe Alloys Ltd.
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

[1] Other chromite-producing countries included Burma, China, Cuba, Egypt, Indonesia, Iran, Japan, Macedonia, Madagascar, Morocco, Oman, Pakistan, and Sudan.

[2] Includes Bophuthatswana.

TABLE 2

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1993

Country[1]	Company
Brazil	Cia. de Ferro-Ligas da Bahia S.A.
China	Government owned.
Croatia	Tvornica Karbida i Ferolegura Dalmacija.
Finland	Outokumpu Oy (Government owned).
Germany	Gesellschaft für Elektrometallurgie mbH Elektrowerk Weisweiler GmbH.
India	Deepak Ferro-Alloys Ltd.
	Ferro-Alloys Corp. Ltd.
	Indian Metals and Ferroalloys Ltd.
	Indian Charge Chrome Ltd.
	Industrial Development Corp.
	Tata Iron and Steel Co.
	OMC Alloys Ltd.
	Visvesvaraya Iron and Steel Ltd. (State owned)
Italy	Acciaierie e Ferriere Lombarde Falck SpA.
	Ferroleghe SpA.
Japan	Japan Metals and Chemicals Co. Ltd.
	Nippon Denko Co. Ltd.
	NKK Corp.
	Pacific Metals Co. Ltd.
	Showa Denko K.K.
Kazakhstan	Aktubinsk Ferroalloy Works.
	Yermakovsky Ferroalloy Works.
Norway	Elkem Rana.
Philippines	Ferro Chemicals Inc.
	Ferrochrome Philippines Inc.
	Integrated Chrome Corp.
Russia	Chelyabinsk Electrometallurgical Works.
	Klyuchevsk Ferroalloy Works.
	Serovsk Ferroalloy Works.
Slovenia	Tovarna Dusika Ruse.
South Africa, Republic of	Anglovaal Ltd.
	Ferralloys Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Johannesburg Consolidated Investment Co. Ltd.
	Consolidated Metallurgical Industries Inc.
	Lydenburg Works.
	Rustenburg Works.
	Purity Ferrochrome (Pty.) Ltd.
	Genmin Ltd.
	Samancor Ltd.
	Batlhako Ferrochrome Ltd.
	Ferrometals Ltd.
	Middelburg Ferrochrome (Pty.) Ltd.
	Pamiet Ferrochrom (Pty.) Ltd.
	Tubatse Ferrochrome Division
Sweden	Vargön Alloy AB.
Turkey	Etibank (Government owned).
United States	Elkem Metals Co.
	Macalloy Corp.

See footnotes at end of table.

TABLE 2—Continued

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1993

Country[1]	Company
Zimbabwe	Zimbabwe Alloys Ltd.
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

[1] Other ferrochromium-producing countries include Albania, Chile, Poland, Mexico, Romania, Spain, and Taiwan.

TABLE 3

TIME-VALUE[1] RELATIONSHIPS FOR CHROMITE ORE

(Average annual value, dollars per metric ton of contained chromium)

Year	Not more than 40% chromic oxide		More than 40% but less than 46% chromic oxide		46% or more chromic oxide		Total, all grades	
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar
1963	86	315	40	146	63	232	54	197
1964	84	302	44	157	59	212	57	205
1965	88	309	48	169	59	208	59	209
1966	82	279	45	154	62	211	58	198
1967	87	289	48	159	66	218	62	205
1968	81	256	45	142	60	191	59	185
1969	75	226	51	153	66	198	64	192
1970	85	243	53	151	90	256	79	226
1971	98	265	58	157	98	264	87	235
1972	99	254	62	159	94	242	89	230
1973	104	252	55	132	93	225	82	199
1974	109	244	67	150	104	231	96	213
1975	178	362	101	206	209	425	175	355
1976	222	425	146	279	262	501	212	405
1977	235	421	166	296	254	454	206	368
1978	230	381	177	293	185	307	200	331
1979	240	367	187	285	232	354	215	329
1980	288	402	195	272	189	263	222	310
1981	266	337	192	244	184	234	219	277
1982	293	350	201	239	213	254	229	273
1983	359	412	172	198	166	190	194	223
1984	403	443	141	154	156	172	186	204
1985	261	277	160	170	160	169	184	195
1986	218	225	145	149	146	151	163	169
1987	185	185	160	160	155	155	168	168
1988	241	232	269	259	187	180	229	220
1989	292	269	290	267	247	228	271	250
1990	313	276	228	^{r}201	237	209	242	214
1991	562	477	209	^{r}178	263	223	232	197
1992	368	304	214	177	213	176	226	187
1993	506	^{p}407	204	^{p}164	190	^{p}153	196	^{p}158

^{p}Preliminary. ^{r}Revised.

[1] Customs value per ton of chromium contained in imported material.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is 1987 GDP divided by annual GDP index. GDP ratio calculated as the ratio of GDP indices reported in Economic Report of the President, U.S. Government, Feb. 1992, available from Superintendent of Documents, U.S. Government Printing Office.

TABLE 4

TIME-VALUE[1] RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL

(Average annual value)

Year	Ferrochromium (dollars per metric ton of contained chromium)						Chromium metal (dollars per metric ton gross weight)	
	Low-carbon[2]		High-carbon[3]		Total, all grades			
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar
1963	397	1,461	290	1,067	376	1,383	1,677	6,165
1964	380	1,371	304	1,098	360	1,300	1,670	6,029
1965	408	1,437	268	942	395	1,390	1,661	5,849
1966	410	1,394	232	789	367	1,249	NA	NA
1967	417	1,375	264	870	394	1,301	NA	NA
1968	399	1,260	261	824	382	1,204	1,656	5,224
1969	426	1,279	236	710	370	1,112	1,800	5,405
1970	453	1,290	272	775	401	1,142	NA	NA
1971	585	1,582	342	925	464	1,254	2,003	5,414
1972	556	1,433	282	727	422	1,089	2,206	5,686
1973	617	1,493	289	700	392	948	2,491	6,031
1974	797	1,776	512	1,141	600	1,335	3,030	6,748
1975	1,534	3,119	942	1,914	1,061	2,157	4,486	9,118
1976	1,406	2,688	719	1,376	916	1,751	4,350	8,317
1977	1,385	2,478	702	1,255	826	1,477	4,938	8,834
1978	1,405	2,329	640	1,061	686	1,138	NA	NA
1979	1,737	2,652	853	1,303	945	1,443	NA	NA
1980	1,826	2,546	890	1,241	972	1,355	7,682	10,714
1981	1,609	2,040	870	1,102	952	1,206	7,662	9,711
1982	1,551	1,851	887	1,058	1,008	1,202	6,018	7,181
1983	1,437	1,648	683	783	737	845	4,491	5,150
1984	1,496	1,644	782	860	833	916	5,674	6,235
1985	1,571	1,664	847	897	914	968	5,468	5,792
1986	1,409	1,454	779	804	851	878	5,320	5,490
1987	1,543	1,543	783	783	893	893	6,097	6,097
1988	1,988	1,914	1,317	1,268	1,403	1,351	7,231	6,960
1989	1,909	1,759	1,524	1,404	1,609	1,483	6,598	6,081
1990	1,619	[r]1,429	883	[r]779	1,017	[r]897	6,459	[r]5,701
1991	1,991	[r]1,692	874	742	997	[r]847	7,584	[r]6,444
1992	1,871	[r]1,545	875	[r]723	966	[r]798	6,671	[r]5,509
1993	1,307	[p]1,052	679	[p]547	790	[p]636	6,136	[p]4,940

[p] Preliminary. [r] Revised. NA Not available.

[1] Customs value per ton of chromium contained in imported material.

[2] Carbon not more than 4%.

[3] More than 4% carbon.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is 1987 GDP divided by annual GDP index. GDP ratio is calculated as the ratio of GDP indices reported in Economic Report of the President, U.S. Government, Feb. 1992, available from Superintendent of Documents, U.S. Government Printing Office.

TABLE 5
AVAILABILITY OF CHROMITE AND CHROMIUM FERROALLOYS FROM 10 MARKET ECONOMY COUNTRIES

Chromium materials	Quantity available (million metric tons, gross weight)	Cost[1] (dollars per metric ton)	
		Weighted average	Range
Chromite:			
Chemical grade	64.3	53	$35- $174
Foundry sand grade	16.4	49	39- 83
Metallurgical grade:			
Primary product	145.4	101	42- 705
Secondary product	35.6	54	33- 117
Subtotal	181.0	92	33- 705
Refractory grade	26.8	87	54- 180
Total	288.5		
Chromium ferroalloys:			
Ferrochromium:			
High-carbon ferrochromium	74.3	473	417- 1,286
Low-carbon ferrochromium	3.9	937	635- 1,309
Ferrochromium-silicon	2.0	737	578- 814
Total	80.2		

[1] Cost of production for zero percent discounted cash-flow rate of return in Jan. 1989 dollars per metric ton, gross weight, of product f.o.b. at port of export.

Source: U.S. Bureau of Mines, Minerals Availability system cost analysis.

TABLE 6
SALIENT CHROMIUM STATISTICS

(Thousand metric tons, gross weight)

	1989	1990	1991	1992	1993
			CHROMITE		
United States:					
Exports	40	6	9	7	10
Reexports	2	4	—	(1)	2
Imports for consumption	525	306	212	219	255
Consumption	561	405	375	362	337
Stocks, December 31: Consumer	392	355	321	321	275
World production	[r]14,006	[r]12,959	[r]13,320	[r]10,993	[e]10,001
			CHROMIUM FERROALLOYS[2]		
United States:					
Net production[3]	147	109	68	61	63
Exports	9	9	11	11	15
Reexports	2	2	2	2	2
Imports for consumption	351	420	460	420	396
Consumption	354	382	356	[r]355	341
Stocks, December 31: Consumer	19	18	19	18	17
World production	[r]3,894	[r]3,619	[r]3,619	[r]3,425	[e]3,129

[e] Estimated. [r] Revised.

[1] Less than 1/2 unit.

[2] High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.

[3] Includes chromium metal, exothermic chromium additives, and other miscellaneous alloys.

TABLE 7

HISTORICAL AND PROJECTED PERFORMANCE OF THE NATIONAL DEFENSE STOCKPILE CHROMITE ORE TO FERROCHROMIUM CONVERSION PROGRAM

Contract year	Ore converted (metric tons)	High-carbon ferrochromium produced (metric tons)		Cost (millions)
		Gross	Content	
HISTORICAL PERFORMANCE				
1984	113,968	45,590	30,180	$22.3
1985	124,298	44,872	29,630	22.5
1986	85,301	31,944	20,898	17.6
1987	125,739	52,414	34,415	28.8
1988	111,105	41,511	26,727	26.7
1989	120,651	46,940	30,392	31.5
1990	113,453	42,881	28,082	30.9
1991	111,531	42,577	28,181	31.0
1992	113,944	41,120	27,511	32.8
1993	170,221	63,712	42,623	40.0
PROJECTED PERFORMANCE[e]				
1994	99,026	16,574	NA	10.5

[e] Estimated. NA Not available.

Source: Defense Logistics Agency.

TABLE 8

HISTORICAL AND PROJECTED PERFORMANCE OF THE NATIONAL DEFENSE STOCKPILE LOW-CARBON FERROCHROMIUM TO CHROMIUM METAL CONVERSION PROGRAM

Time period	Low-carbon ferrochromium[1] (metric tons)	Chromium metal (metric tons)	Cost (millions)
HISTORICAL PERFORMANCE			
October 1989 - September 1990	2,129	1,048	$7.3
October 1990 - September 1991	1,090	780	7.0
October 1991 - September 1992	2,049	1,022	10.1
October 1992 - September 1993	2,892	1,452	13.5
PROJECTED PERFORMANCE[e]			
October 1993 - September 1994	NA	NA	NA

[e] Estimated. NA Not available.

[1] Nonspecification grade.

Source: Defense Logistics Agency.

TABLE 9
U.S. GOVERNMENT STOCKPILE YEAREND INVENTORIES AND ANNUAL DISPOSALS FOR CHROMIUM IN 1993

(Thousand metric tons, gross weight)

Material	Inventory[1]	Disposals
Chromite, metallurgical	1,062	192
Chromite, chemical	220	—
Chromite, refractory	355	—
High-carbon ferrochromium	740	59
Low-carbon ferrochromium	285	—
Ferrochromium-silicon	53	—
Chromium metal	7	—

[1] Includes specification- and nonspecification-grade material.

Source: Defense Logistics Agency.

TABLE 10
PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1993, BY INDUSTRY

Industry and company	Plant
Metallurgical:	
Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
Macalloy Corp.	Charleston, SC.
Satra Concentrates Inc.	Steubenville, OH.
Refractory:	
General Refractories Co.	Lehi, UT.
Harbison-Walker Refractories, a division of Dresser Industries Inc.	Hammond, IN.
National Refractories & Mining Corp.	Moss Landing, CA and Columbiana, OH.
North American Refractories Co. Ltd.	Womelsdorf, PA.
Chemical:	
American Chrome & Chemicals Inc.	Corpus Christi, TX.
Occidental Chemicals Corp.	Castle Hayne, NC.

TABLE 11
PRODUCTION, SHIPMENTS, AND STOCKS OF CHROMIUM FERROALLOYS AND METAL, AND OTHER CHROMIUM MATERIALS IN THE UNITED STATES

(Metric tons)

Year	Net production		Net shipments	Producer stocks, Dec. 31
	Gross weight	Chromium content		
1989	146,844	90,073	135,361	20,475
1990	108,932	67,701	91,735	14,935
1991	68,327	43,061	75,286	11,832
1992	60,945	40,272	68,346	5,723
1993	63,018	44,453	61,154	5,612

TABLE 12
CONSUMPTION OF CHROMITE AND TENOR OF ORE USED BY PRIMARY CONSUMER GROUPS IN THE UNITED STATES

Year	Chemical and metallurgical industry		Refractory industry		Total	
	Gross weight (metric tons)	Average Cr_2O_3 (percentage)	Gross weight (metric tons)	Average Cr_2O_3 (percentage)	Gross weight (metric tons)	Average Cr_2O_3 (percentage)
1989	516,931	42.8	43,780	39.5	560,711	42.6
1990	361,176	43.8	44,237	39.8	405,413	43.3
1991	339,068	45.4	36,016	40.1	375,084	44.9
1992	334,624	47.4	27,431	41.1	362,055	46.9
1993	313,708	47.8	22,874	39.1	336,582	47.2

TABLE 13
U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL, BY END USE

(Metric tons, gross weight)

End use	Ferrochromium		Ferrochromium-silicon	Other	Total[3]
	Low-carbon[1]	High-carbon[2]			
1991:					
Steel:					
Carbon	3,751	6,478	249	195	10,673
Stainless and heat-resisting	8,283	278,108	7,010	136	293,536
Full-alloy	4,174	19,916	1,228	38	25,356
High-strength, low-alloy and electric	1,815	2,480	6,612	—	10,908
Tool	334	2,922	W	5	3,261
Cast irons	W	4,447	24	16	4,487
Superalloys	3,155	3,377	—	3,741	10,273
Welding materials[4]	339	627	2	161	1,129
Other alloys[5]	140	247	—	111	500
Miscellaneous and unspecified	160	—	(6)	319	479
Total[3] [7]	22,151	318,604	15,125	[8]4,721	360,602
Chromium content	[r]15,013	183,105	5,595	4,451	208,164
Stocks, December 31, 1991	2,455	15,355	367	[9]623	18,800
1992:					
Steel:					
Carbon	4,618	6,786	209	W	11,613
Stainless and heat-resisting	8,534	275,984	W	89	284,607
Full-alloy	3,005	32,329	W	40	35,374
High-strength, low-alloy and electric	1,865	2,615	6,723	—	11,203
Tool	W	3,317	W	—	3,317
Cast irons	[r]895	[r]5,160	15	19	[r]6,088
Superalloys	2,753	W	—	3,005	5,758
Welding materials[4]	W	W	W	[r]276	[r]276
Other alloys[5]	W	W	—	[r]120	[r]120

See footnotes at end of table.

TABLE 13—Continued

U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL, BY END USE

(Metric tons, gross weight)

End use	Ferrochromium		Ferro-chromium-silicon	Other	Total[3]
	Low-carbon[1]	High-carbon[2]			
1992—Continued:					
Miscellaneous and unspecified	([6])	[r]4,160	7,372	[r]511	[r]12,043
Total[7]	[r]21,670	[r]330,351	[r]14,319	[r] [10]4,060	[r]370,399
Chromium content[r]	15,910	192,844	5,166	3,733	217,653
Stocks, December 31, 1992	[r]2,520	14,218	276	[11]614	[r]17,628
1993:					
Steel:					
Carbon	4,803	7,439	185	W	12,427
Stainless and heat-resisting	8,447	270,944	W	100	279,491
Full-alloy	3,400	22,882	1,188	44	27,514
High-strength, low-alloy and electric	1,807	2,903	6,403	—	11,113
Tool	W	2,910	W	W	2,910
Cast irons	1,027	4,064	W	19	5,110
Superalloys	2,552	W	—	3,138	5,690
Welding materials[4]	W	W	W	298	298
Other alloys[5]	W	229	—	150	379
Miscellaneous and unspecified	([6])	4,406	7,707	569	12,682
Total[3] [7]	22,036	315,777	15,484	[12]4,318	357,614
Chromium content	16,109	191,110	5,621	3,993	216,833
Stocks, December 31, 1993	3,175	12,412	391	[13]707	16,685

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1]Low-carbon ferrochromium contains less than 3% carbon.

[2]High-carbon ferrochromium contains 3% or more carbon.

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

[4]Includes structural and hard-facing welding material.

[5]Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

[6]Withheld to avoid disclosing company proprietary data; included with "Other."

[7]Includes estimates.

[8]Includes 3,585 tons of chromium metal.

[9]Includes 433 tons of chromium metal.

[10]Includes 3,819 tons of chromium metal.

[11]Includes 438 tons of chromium metal.

[12]Includes 4,120 tons of chromium metal.

[13]Includes 524 tons of chromium metal.

TABLE 14
U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1989	1990	1991	1992	1993
Chromite:					
Chemical and metallurgical	368,482	333,224	310,111	307,829	259,267
Refractory	23,791	21,437	11,114	13,144	15,489
Total	392,273	354,661	321,225	320,973	274,756
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	4,397	3,276	2,455	[r]2,520	3,175
High-carbon ferrochromium	14,141	12,929	15,355	14,218	12,412
Ferrochromium-silicon	425	455	367	276	391
Other[1]	523	938	623	614	707
Total	19,486	17,598	18,800	[r]17,628	16,685

[r] Revised.

[1] Includes chromium briquets, chromium metal, exothermic chromium additives, and other miscellaneous chromium alloys.

TABLE 15
PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 1993

Material	January	December
	Dollars per metric ton of product	
Chromite ore:		
South Africa, Republic of	50 - 60	50 - 60
Turkey	105 - 110	105 - 110
	Cents per pound of chromium	
High-carbon ferrochromium:		
Domestic: 50% to 55% chromium	52	52
Imported:		
50% to 55% chromium	36 - 39	35.5 - 38
60% to 65% chromium	33.5 - 34.5	35 - 36
Low-carbon:		
Domestic:		
0.05% carbon	95	95
0.015% carbon (Simplex)	166	166
Imported:		
0.05% carbon	71.5 - 74	71 - 73
0.10% carbon	70 - 72	53 - 55
	Cents per pound of product	
Chromium metal (domestic):		
Electrolytic	370.0	370.0
Elchrome	450.0	450.0

Source: Metals Week.

TABLE 16
U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1990	1991	1992	1993		Principal destinations, 1993
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
Chromite ore and concentrate	6,321	8,759	7,042	10,011	$2,136	Canada (77%); Mexico (21%).
Metal and alloys:						
Chromium metal[1]	338	424	299	472	4,476	Canada (52%); Japan (32%); Venezuela (3%).
Chromium ferroalloys:						
High-carbon ferrochromium[2]	[3]5,795	[4]7,820	[5]8,292	[6]10,071	7,804	Canada (69%); Mexico(28%).
Low-carbon ferrochromium[7]	[8]2,521	[9]2,084	[10]1,860	[11]4,391	5,374	Canada (39%); Mexico (28%); Japan (15%); Netherlands (5%); Venezuela (4%).
Ferrochromium-silicon	[12]802	[13]745	[14]671	[15]800	759	Canada (90%); Mexico (8%).
Total ferroalloys	[16]9,118	[17]10,649	[18]10,823	[19]15,262	13,937	
Chemicals:						
Chromium oxides:						
Chromium trioxide	4,082	3,967	5,269	5,014	9,350	Canada (28%); Japan (12%); Mexico (11%); Republic of Korea (10%); Taiwan (8%); Australia (6%).
Other	1,226	1,500	1,640	2,043	11,464	Canada (37%); Japan (14%); Netherlands (9%).
Chromium sulfates	44	48	6	31	71	Argentina (53%); Mexico (35%); Canada (12%).
Salts of oxometallic or peroxometallic acids:						
Zinc and lead chromate	209	627	477	501	4,303	Canada (59%); Germany (17%); Singapore (11%).
Sodium dichromate	16,663	16,860	15,241	11,743	7,799	Mexico (38%); China (15%); Colombia (9%); Taiwan (6%).
Potassium dichromate	48	42	48	34	88	Canada (75%); Hong Kong (10%); Japan (4%).
Other chromates, dichromates, and peroxochromates	228	193	139	635	1,844	Australia (45%); Canada (24%); United Kingdom (9%); Mexico (8%).
Pigments and preparations	2,643	1,969	2,554	2,312	9,403	Canada (32%); Philippines (17%); Thailand (8%).

[1] Articles thereof and waste and scrap.
[2] More than 4% carbon.
[3] Contained 3,477 tons of chromium.
[4] Contained 4,617 tons of chromium.
[5] Contained 4,907 tons of chromium.
[6] Contained 5,992 tons of chromium.
[7] Not more than 4% carbon.
[8] Contained 1,517 tons of chromium.
[9] Contained 1,263 tons of chromium.
[10] Contained 1,085 tons of chromium.
[11] Contained 2,673 tons of chromium.
[12] Contained 333 tons of chromium.
[13] Contained 261 tons of chromium.
[14] Contained 235 tons of chromium.
[15] Contained 280 tons of chromium.
[16] Contained 5,327 tons of chromium.
[17] Contained 6,141 tons of chromium.
[18] Contained 6,227 tons of chromium.
[19] Contained 8,945 tons of chromium.

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF CHROMITE ORE, BY 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)
1992:												
Germany	1,251	230	$14	—	—	—	—	—	—	1,251	230	$14
Philippines	9,067	2,702	1,052	22	10	$5	161	96	$35	9,250	2,808	1,092
South Africa, Republic of	—	—	—	61,937	27,870	3,991	128,736	61,039	8,871	190,673	88,909	12,865
Turkey	14,000	5,197	981	4,300	1,749	350	—	—	—	18,300	6,946	1,331
Total[1]	24,318	8,129	2,047	66,259	29,629	4,347	128,897	61,135	8,905	219,474	98,893	15,299
1993:												
Philippines	6,415	2,131	737	—	—	—	—	—	—	6,415	2,131	737
South Africa, Republic of	—	—	—	2,308	1,058	148	246,079	120,092	15,623	248,387	121,150	15,769
Total	6,415	2,131	737	2,308	1,058	148	246,079	120,092	15,623	254,802	123,281	16,506

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

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total[1] (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)
1992:												
Albania	—	—	—	—	—	—	2,200	1,320	$956	2,200	1,320	$956
China	503	329	$631	—	—	—	17,115	10,084	8,282	17,615	10,412	8,913
Croatia	—	—	—	—	—	—	13,975	8,823	7,448	13,975	8,823	7,448
Czechoslovakia	—	—	—	—	—	—	393	277	450	393	277	450
Finland	—	—	—	—	—	—	20,897	11,108	10,339	20,897	11,108	10,339
France	—	—	—	—	—	—	1,227	759	615	1,227	759	615
Germany	10,225	7,262	18,202	—	—	—	59	38	54	10,285	7,300	18,257
India	—	—	—	—	—	—	31,048	18,974	16,183	31,048	18,974	16,183
Japan	290	211	885	—	—	—	5,609	3,593	3,743	5,899	3,804	4,629
Kazakhstan	686	237	456	—	—	—	3,127	2,046	1,308	3,813	2,284	1,763
Norway	—	—	—	—	—	—	28,471	17,921	15,707	28,471	17,921	15,707
Poland	—	—	—	—	—	—	1,192	790	627	1,192	790	627
Russia	850	250	469	—	—	—	4,882	3,162	2,593	5,732	3,412	3,062
Slovenia	—	—	—	—	—	—	1,250	821	641	1,250	821	641

See footnotes at end of table.

TABLE 18—Continued

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

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total[1] (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)
1992—Continued:												
South Africa, Republic of	4,539	2,546	$3,412	—	—	—	110,523	57,147	$48,429	115,062	59,693	$51,841
Sweden	35	26	97	—	—	—	5,461	3,194	2,959	5,495	3,220	3,056
Turkey	9,290	6,446	9,677	—	—	—	66,603	40,680	32,996	75,893	47,126	42,673
Ukraine	60	46	122	—	—	—	—	—	—	60	46	122
U.S.S.R.[2]	39	20	30	—	—	—	235	127	126	274	146	155
United Kingdom	376	281	920	—	—	—	155	86	85	531	367	1,005
Yugoslavia	—	—	—	—	—	—	30,900	19,477	16,630	30,900	19,477	16,630
Zimbabwe	6,978	4,628	6,783	—	—	—	31,604	20,623	23,286	38,582	25,251	30,068
Total[1]	33,871	22,281	41,684	—	—	—	376,926	221,052	193,456	410,798	243,333	235,140
1993:												
Albania	—	—	—	—	—	—	7,178	4,319	2,962	7,178	4,319	2,962
China	—	—	—	—	—	—	3,713	2,310	1,826	3,713	2,310	1,826
Croatia	—	—	—	—	—	—	21,275	13,353	8,735	21,275	13,353	8,735
Finland	—	—	—	—	—	—	38,156	20,430	15,397	38,156	20,430	15,397
France	—	—	—	—	—	—	6	4	6	6	4	6
Germany	10,195	7,371	18,378	—	—	—	210	140	172	10,405	7,510	18,550
India	—	—	—	—	—	—	13,632	7,967	5,636	13,632	7,967	5,636
Japan	288	208	866	—	—	—	124	83	243	412	291	1,108
Kazakhstan	5,347	2,751	3,284	—	—	—	30,360	18,906	11,620	35,707	21,657	14,904
Netherlands	—	—	—	—	—	—	25	17	25	25	17	25
Poland	—	—	—	—	—	—	32	22	20	32	22	20
Russia	22,568	13,233	15,316	—	—	—	16,732	10,877	7,225	39,300	24,110	22,541
South Africa, Republic of	5,220	2,887	3,663	—	—	—	74,779	37,396	25,785	79,999	40,284	29,448
Turkey	5,952	4,180	4,924	—	—	—	84,706	52,268	32,920	90,657	56,448	37,844
Ukraine	4,071	2,768	2,040	3,257	2,264	1,242	10,800	7,444	3,496	18,128	12,476	6,778
United Kingdom	38	26	51	123	83	84	410	249	277	570	358	412
Zimbabwe	5,731	3,559	4,851	—	—	—	22,089	14,351	12,772	27,820	17,910	17,623
Total[1]	59,410	36,983	53,373	3,380	2,347	1,326	324,225	190,136	129,117	387,015	229,466	183,816

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

[2] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF CHROMIUM MATERIALS, BY TYPE

Type	1990	1991	1992	1993		Principal sources, 1993
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
METALS AND ALLOYS						
Chromium metal:						
Waste and scrap	85	18	192	437	$2,000	China (91%); Canada (4%).
Other than waste and scrap	6,579	5,747	5,259	5,733	35,902	China (39%); United Kingdom (18%); Japan (17%); France (16%).
Ferrochromium-silicon	[1]3,801	[2]5,301	[3]9,379	[4]8,751	6,180	Zimbabwe (88%); China (6%).
CHEMICALS						
Chromium oxides and hydroxides:						
Chromium trioxide	1,677	1,196	390	362	1,284	Japan (47%); Mexico (29%); Germany (6%); Netherlands (4%).
Other	3,512	3,976	3,309	3,094	10,253	Germany (34%); Japan (23%); Kazakhstan (17%); Netherlands (7%).
Sulfates of chromium	192	186	122	162	97	Turkey (75%); Mexico (24%).
Salts of oxometallic or peroxometallic acids:						
Chromates of lead and zinc	425	334	283	252	772	Japan (53%); France (18%); Norway (16%); Poland (12%).
Sodium dichromate	1,661	4,895	4,372	10,280	5,857	United Kingdom (88%); Argentina (4%); Canada (4%).
Potassium dichromate	680	464	587	522	754	Russia (31%); Brazil (20%); Mexico (15%); United Kingdom (15%).
Other chromates and dichromates; peroxochromates	1,860	859	782	668	1,593	United Kingdom (63%); France (29%).
Chromium carbide	123	77	103	124	1,123	United Kingdom (75%); Japan (19%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM						
Chrome yellow	3,643	3,468	3,507	3,609	8,003	Canada (74%); Mexico (10%); Hungary (9%).
Molybdenum orange	916	812	894	680	2,023	Canada (99%).
Zinc yellow	436	218	220	246	554	Norway (59%); France (23%); Germany (9%).
Other	657	441	2,322	446	2,113	Germany (59%); Poland (13%); France (7%).

[1] Contained 1,459 tons of chromium.
[2] Contained 2,046 tons of chromium.
[3] Contained 3,643 tons of chromium.
[4] Contained 3,307 tons of chromium.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1993

Item	Harmonized Tarriff Schedule No.	Most favored nation (MFN)	Non-MFN[1]	Special	
				CA[2]	A, E, IL, J[3]
Chromite ores and concentrates therefrom:					
Not more than 40% Cr_2O_3	2610.00.0020	Free	Free	NA	NA.
More than 40% and less than 46% Cr_2O_3	2610.00.0040	do.	do.	NA	NA.
Not less than 46% Cr_2O_3	2610.00.0060	do.	do.	NA	NA.
Chromium oxides and hydroxides:					
Chromium trioxide	2819.10.0000	3.7% ad valorem	25% ad valorem	Free	Free.
Other	2819.90.0000	do.	do.	do.	Do.
Sulfates; alums; peroxosulfates (persulfates):					
Other sulfates: of chromium	2833.23.0000	do.	do.	do.	Do.
Salts of oxometallic or peroxometallic acids:					
Chromates of zinc and of lead	2841.20.0000	do.	do.	do.	Do.
Sodium dichromate	2841.30.0000	2.4% ad valorem	8.5% ad valorem	do.	Do.
Potassium dichromate	2841.40.0000	1.5% ad valorem	3.5% ad valorem	do.	Do.
Other chromates and dichromates; peroxochromates	2841.50.0000	3.1% ad valorem	25% ad valorem	do.	Do.
Carbides, whether or not chemically defined:					
Other: of chromium	2849.90.2000	4.2% ad valorem	do.	do.	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad valorem	do.	do.	Do.
Molybdenum orange	3206.20.0020	do.	do.	do.	Do.
Zinc yellow	3206.20.0030	do.	do.	do.	Do.
Other	3206.20.0050	do.	do.	do.	Do.
Metal and alloys: Ferroalloys:					
Ferrochromium:					
More than 4% carbon	7202.41.0000	1.9% ad valorem	7.5% ad valorem	Do.	Do.
More than 3% and not more than 4% carbon	7202.49.1000	do.	do.	do.	Do.
Other (i.e., not more than 3% carbon)	7202.49.5000	3.1% ad valorem	30% ad valorem	do.	Do.
Ferrosilicon chromium	7202.50.0000	10% ad valorem	25% ad valorem	do.	Do.
Other base metals; cermets; articles thereof:					
Chromium:					
Waste and scrap	8112.20.3000	Free	Free	NA	NA.
Other	8112.20.6000	3.7% ad valorem	30% ad valorem	Free	Free.

NA Not available.

[1] The following countries were non-MFN in 1993; Afghanistan, Albania, Cuba, Kampuchea, Laos, North Korea, Romania, and Vietnam.

[2] United States-Canada Free-Trade Agreement.

[3] A-Generalized System of Preferences, E-Caribbean Basin Economic Recovery Act, IL-United States-Israel Free Trade Area Implementation Act of 1985, J-Andean Trade Preference Act.

Source: U.S. International Trade Commission.

TABLE 21

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, CHROMIUM CHEMICALS, AND STAINLESS STEEL IN 1993

(Thousand metric tons, contained chromium)

Country	Resources[2]			Annual production capacity				
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chemicals	Stainless steel
Albania	1,900	1,900	6,300	150	32	—	—	—
Argentina	—	—	—	—	—	—	6	NA
Australia	—	500	500	—	—	—	—	NA
Austria	—	—	—	—	—	—	—	12
Bangladesh	—	—	—	—	—	—	—	3
Belgium	—	—	—	—	—	—	—	75
Brazil	2,900	5,600	9,000	135	89	(4)	12	165
Burma	NA	NA	NA	(4)	—	—	—	—
Canada	—	1,600	3,800	—	—	—	—	28
Chile	—	—	—	—	2	—	—	—
China	NA	NA	NA	13	125	2	16	43
Croatia	—	—	—	—	42	—	—	—
Cuba	700	700	2,000	14	—	—	—	11
Czech Republic	—	—	—	—	—	—	—	NA
Egypt	NA	NA	NA	1	—	—	—	—
Finland	11,600	14,200	14,200	190	115	—	—	54
France	—	—	—	—	—	3	—	136
Germany	—	—	—	—	76	—	20	200
Greece	400	400	800	21	—	—	—	—
Greenland	—	—	26,000	—	—	—	—	—
India	18,100	23,800	23,800	309	167	(4)	5	45
Indonesia	200	200	200	20	—	—	—	—
Iran	700	700	17,700	34	—	—	2	—
Italy	—	—	—	—	64	—	—	107
Japan	(5)	60	70	3	218	5	21	495
Kazakhstan	99,300	99,300	301,000	1,100	330	—	42	—
Korea, North	—	—	—	—	32	—	—	—
Korea, Republic of	—	—	—	—	—	—	—	83
Macedonia	NA	NA	NA	3	7	—	5	—
Madagascar	2,100	2,100	2,100	21	—	—	—	—
Mexico	—	—	—	—	2	—	—	NA
Norway	—	—	—	—	88	—	—	—
Oman	NA	300	600	4	—	—	—	—
Pakistan	NA	NA	NA	10	—	—	3	—
Papua New Guinea	—	—	2,900	—	—	—	—	—
Philippines	2,300	2,300	2,300	60	45	—	—	—
Poland	—	—	—	—	35	—	7	NA
Romania	—	—	—	—	26	—	5	—
Russia	300	300	1,200	40	233	7	63	330
Slovakia	—	—	—	—	30	—	—	—
Slovenia	—	—	—	—	8	—	—	NA
South Africa, Republic of	295,200	1,704,400	2,973,700	1,600	794	—	—	25
Spain	—	—	—	—	—	—	—	83
Sudan	500	500	500	8	—	—	—	—

See footnotes at end of table.

TABLE 21—Continued

WORLD CHROMIUM RESOURCES[1] AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, CHROMIUM CHEMICALS, AND STAINLESS STEEL IN 1993

(Thousand metric tons, contained chromium)

Country	Resources[2]			Annual production capacity				
	Reserves	Reserve base[3]	Identified resources	Ore	Ferro-chromium	Metal	Chemicals	Stainless steel
Sweden	—	—	—	—	97	—	—	83
Taiwan	—	—	—	—	1	—	—	28
Thailand	NA	NA	NA	(4)	—	—	—	—
Turkey	2,500	6,000	6,800	300	103	—	10	NA
Ukraine	—	—	—	—	—	—	—	33
United Kingdom	—	—	—	—	—	2	52	74
United States	—	3,100	35,000	—	83	3	55	330
Zimbabwe	43,500	285,400	285,400	169	125	—	—	—
Total	482,000	2,154,000	3,716,000	4,205	2,977	22	324	2,443

NA Not available.

[1] World resources derived in consultation with the U.S. Geological Survey.

[2] Data and total rounded to nearest 100,000 metric tons.

[3] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[4] Less than 1/2 unit.

[5] Less than 50,000 metric tons.

TABLE 22
CHROMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1989	1990	1991	1992	1993[e]
Albania[e]	[r]900,000	[3]910,000	[r]500,000	150,000	90,000
Brazil[4]	475,949	267,000	340,000	[r]460,044	430,000
Burma[e]	5,000	1,000	1,000	6,200	6,000
China[e]	25,000	25,000	25,000	25,000	25,000
Cuba[e]	[3]50,600	50,000	50,000	50,000	50,000
Egypt	2,448	399	649	[e]600	600
Finland[e]	[r]513,000	[r]504,000	[r]473,000	[r]499,000	500,000
Greece[5]	[r]62,324	[r]35,400	[r]37,169	—	—
India	1,002,659	939,000	[r]1,087,000	[r]1,312,000	1,070,000
Indonesia	7,635	[e]8,000	1,950	[e]2,000	2,500
Iran[6]	72,628	77,189	90,119	[r]130,265	150,000
Japan	11,674	8,075	[e]8,000	[e]8,000	7,000
Kazakhstan	—	—	—	3,600,000	2,900,000
Macedonia[7]	—	—	—	[r] [e]6,000	5,000
Madagascar[6]	62,540	[e]73,000	[e]63,000	[r]69,123	69,000
Morocco	1,000	300	500	500	500
New Caledonia	60,281	6,223	—	[r]7	—
Oman	12,810	—	—	[r]1,764	10,000
Pakistan	27,105	18,191	31,474	[r]22,852	20,000
Philippines	216,562	185,595	[r]191,484	[r]101,690	[3]105,000
Russia	—	—	—	121,400	120,000
South Africa, Republic of [8]	4,950,854	4,618,310	[r]5,100,299	[r]3,363,000	2,840,000
Sudan	25,000	12,500	[e]10,000	[e]10,000	10,000
Thailand	416	—	—	—	—
Turkey[9]	[r]1,076,834	[r]835,704	[r] [e]940,000	[r]531,112	490,000
U.S.S.R.[10]	3,800,000	3,800,000	[e]3,800,000	—	—
Vietnam[e]	[r]4,000	[r]—	[r]—	[r]—	—
Yugoslavia[7] [11]	12,721	10,843	[r] [e]6,000	—	—
Zimbabwe	627,424	[r]573,103	563,634	[r]522,013	400,000
Total	[r]14,006,464	[r]12,958,832	[r]13,320,278	[r]10,992,570	9,300,600

[e] Estimated. [r] Revised.

[1] Table includes data through June 14, 1994.

[2] Figures for all countries represent marketable output unless otherwise noted.

[3] Reported figure.

[4] Average Cr_2O_3 content was as follows: 1989—39.5%; 1990—38.9%; 1991—42.0%; 1992—43.0% (revised); and 1993—43.0% (estimated).

[5] Direct-shipping ore plus concentrate.

[6] Concentrate.

[7] All production in Yugoslavia from 1989-91 came from Macedonia.

[8] Includes production by Bophuthatswana.

[9] Salable product: direct-shipping lump ore plus concentrate.

[10] Dissolved in Dec. 1991.

[11] Dissolved in Apr. 1992.

TABLE 23
FERROCHROMIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Albania	38,800	24,000	[r]25,000	[e]15,000	10,000
Brazil[2]	113,267	[r]83,753	[r]82,225	[r]91,829	[3]85,000
Chile	2,840	1,868	[r]2,509	[r]2,100	2,140
China[e]	[r]180,000	[r]200,000	[r]160,000	[r]280,000	190,000
Croatia	—	—	—	56,456	[3]27,336
Czechoslovakia[2] [4]	29,844	31,866	[r]33,860	37,756	—
Finland	169,000	157,000	190,000	[r]187,100	[3]218,370
France[e]	[r]18,100	25,000	23,100	[3]6,694	—
Germany:[e]					
Eastern states	22,000	21,000	—	—	—
Western states	[r]33,350	[r]37,500	—	—	—
Total	[r]55,350	[r]58,500	[r]33,650	[3]26,520	[3]16,400
Greece	43,579	30,300	[e]10,500	—	—
India[5]	[r]151,167	[r]168,511	[r]219,477	[r]256,831	[3]244,370
Italy	[r]87,331	[r]53,000	[r]47,192	[r]60,315	[3]53,504
Japan[2]	[r]333,978	[r]303,838	[r]278,522	[r]275,615	[3]215,000
Kazakhstan[e]	—	—	—	[r]400,000	400,000
Macedonia[e]	—	—	—	[r] [3]3,958	[3]4,376
Mexico	2,569	275	72	[e]70	70
Norway	—	60,000	83,000	102,000	[3]80,000
Philippines[e]	82,000	56,000	[3]23,730	27,400	[3]12,000
Poland	[r]28,222	[r]13,679	[r]1,928	[r]35,322	[3]38,449
Romania	26,849	20,633	20,380	6,977	[3]3,907
Russia	—	—	—	[r] [3]400,000	400,000
Slovakia[2] [4] [6]	—	—	—	—	[3]45,793
Slovenia	—	—	—	[r]17,104	[3]9,000
South Africa, Republic of[7] [8]	1,049,900	1,022,000	[r]1,126,700	[r]664,856	650,000
Spain[e]	29,000	15,000	6,000	—	[3]2,390
Sweden	153,800	117,680	120,884	[r]133,000	[3]127,543
Turkey	59,715	[r]62,360	[r]84,651	85,755	[3]90,030
U.S.S.R.[e] [9]	[r] [3]828,000	[r]700,000	[r]700,000	—	—
United States[10]	146,844	108,932	68,327	60,945	[3]63,018
Yugoslavia[11]	90,428	82,687	[r]91,000	—	—
Zimbabwe[2]	[r]173,000	[r]222,102	[r]186,774	[r]190,994	140,000
Total	[r]3,893,583	[r]3,618,984	[r]3,619,481	[r]3,424,597	3,128,696

[e] Estimated. [r] Revised.

[1] Table includes data available through June 14, 1994.

[2] Includes high- and low-carbon ferrochromium.

[3] Reported figure.

[4] Czechoslovakia was dissolved on Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from Slovakia.

[5] Includes ferrochrome and charge chrome.

[6] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[7] Includes high- and low-carbon ferrochromium and ferrochromium silicon.

[8] Includes production from Bophuthatswana.

[9] Dissolved in Dec. 1991.

[10] Includes high- and low-carbon ferrochromium, ferrochromium silicon, chromium metal, and other chromium materials.

[11] Dissolved in Apr. 1992.

TABLE 24
CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WORLD PRODUCTION													
Chromite ore (mine)[1]	2,736	2,553	2,472	2,943	3,292	3,552	3,588	3,882	[r]4,219	[r]3,901	[r]4,010	[r]3,309	[e]3,011
Ferrochromium (smelter)[2]	1,760	1,512	1,554	1,862	1,947	1,893	[r]1,885	2,166	[r]2,219	[r]2,063	[r]2,063	[r]1,952	[e]1,783
Stainless steel[3]	1,084	[r]1,345	[r]1,563	[r]1,764	[r]1,761	[r]1,876	[r]2,053	[r]2,324	[r]2,260	[r]2,248	[r]2,259	[r]2,169	[e]2,240
U.S. SUPPLY													
Components of U.S. supply:													
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	65	61	75	79	85	84	95	119	[r]100	[r]104	[r]99	[r]108	103
Imports:													
Chromite ore	228	130	53	83	109	133	133	185	162	92	65	68	84
Chromium ferroalloy	228	79	148	223	173	206	171	255	208	244	234	247	233
Chromium metal	3	2	3	4	4	4	4	4	4	7	6	6	6
Chromium chemicals	1	2	4	3	5	4	3	2	5	4	5	4	5
Chromium pigments	2	1	2	2	2	2	2	4	NA	NA	NA	NA	NA
Stocks, Jan. 1:													
Government	1,051	1,051	1,051	1,051	1,051	[4]1,080	[4]1,110	[4]1,079	[4]1,057	[4]1,097	[4]1,099	[4] [5]1,166	[4] [5]1,197
Industry	219	232	181	164	114	106	102	119	137	139	[r]125	[r]118	118
Total U.S. supply[6]	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	[r]1,674	[r]1,686	[r]1,634	[r]1,717	1,746
Distribution of U.S. supply:													
Exports:													
Chromite ore	18	2	3	15	27	25	([7])	1	12	2	3	2	3
Chromium ferroalloy	7	3	2	9	6	3	2	5	6	5	6	6	9
Chromium metal	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([7])	([8])
Chromium chemicals	6	5	5	7	4	7	6	8	6	7	[r]9	7	7
Stocks, Dec. 31:													
Government	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099	1,166	1,197	1,129
Industry	232	181	164	114	106	102	119	137	139	[r]125	[r]118	[r]118	104
Total U.S. distribution[6]	1,314	1,243	1,226	1,197	1,223	1,247	1,207	1,208	1,260	[r]1,239	[r]1,315	[r]1,331	1,252
Apparent industry demand	483	315	292	412	349	402	382	537	[r]453	[r]450	[r]399	[r]429	523

[e] Estimated. [r] Revised. NA Not available.

[1] Calculated assuming chromite ore to average 44% Cr_2O_3 that is 68.42% chromium.

[2] Calculated assuming chromium content of ferrochromium to average 57%.

[3] Calculated from World Stainless Steel Statistics, 1992 ed. reported production, assuming chromium content of stainless steel to average 17%. Western world only in 1991.

[4] Variation in stockpile quantity does not contribute to apparent industry demand because variation resulted from upgrading programs.

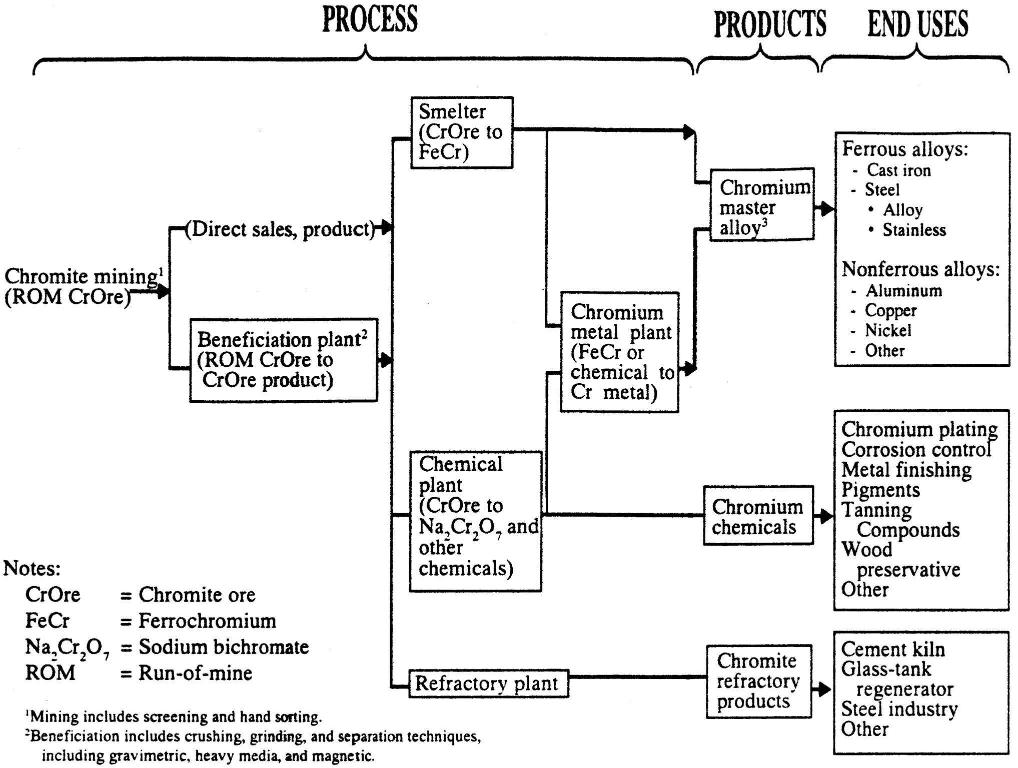
[5] Goverment releases of chromium materials that contributed to apparent industry demand were as follows: 1992, 13; 1993, 97.

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

[7] Less than 1/2 unit.

[8] Included with "Chromium ferroalloy."

FIGURE 1
CHROMIUM MATERIAL FLOW



Notes:
CrOre = Chromite ore
FeCr = Ferrochromium
$Na_2Cr_2O_7$ = Sodium bichromate
ROM = Run-of-mine

[1] Mining includes screening and hand sorting.
[2] Beneficiation includes crushing, grinding, and separation techniques, including gravimetric, heavy media, and magnetic.
[3] Master alloy is an alloy used as a feedstock to produce other alloys.

FIGURE 2
GENERAL RECYCLING CHROMIUM MATERIAL FLOW INDUSTRY STRUCTURE

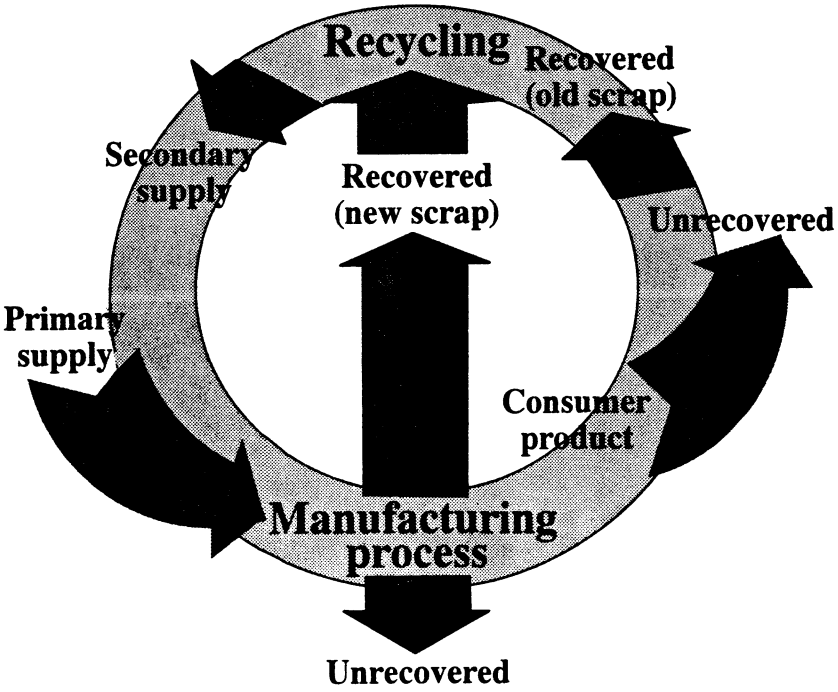


FIGURE 3

COST OF LOW-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCRES

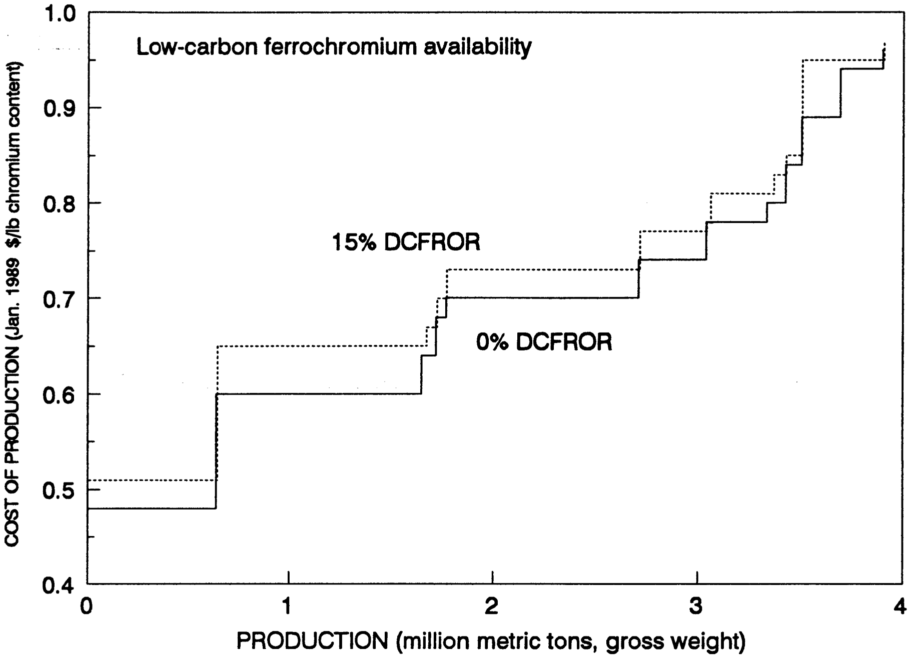
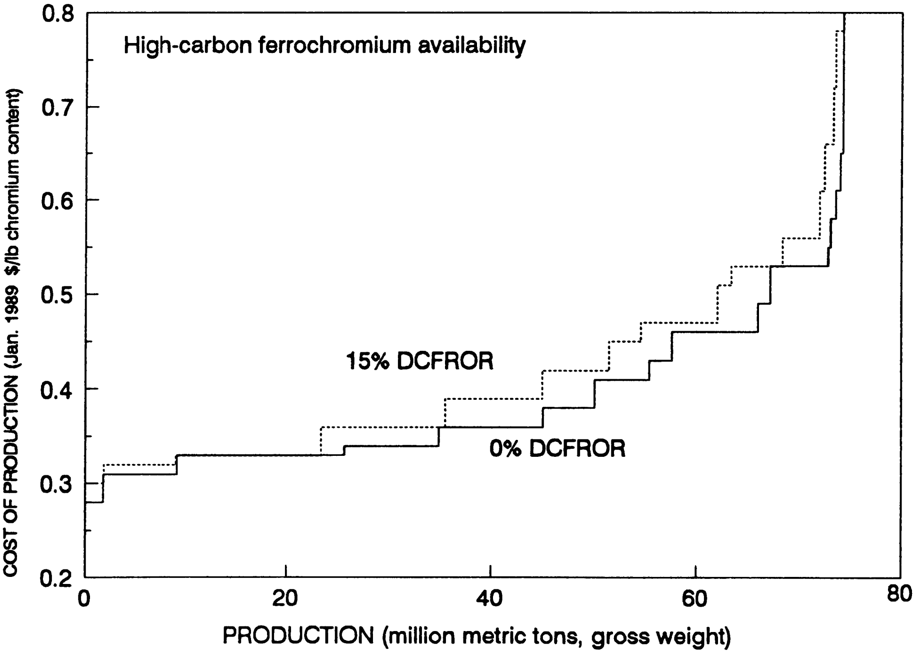


FIGURE 4

COST OF HIGH-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFROR) FOR SELECTED MARKET ECONOMY PRODUCERS



NOTE.--DCFROR is discounted cash-flow rate of return.

Source: U. S. Bureau of Mines, Minerals Availability system cost analysis.

FIGURE 5
IMPORTED HIGH-CARBON FERROCHROMIUM WEEKLY PRICE RANGE AND TIME-AVERAGED ANNUAL PRICE IN 1993

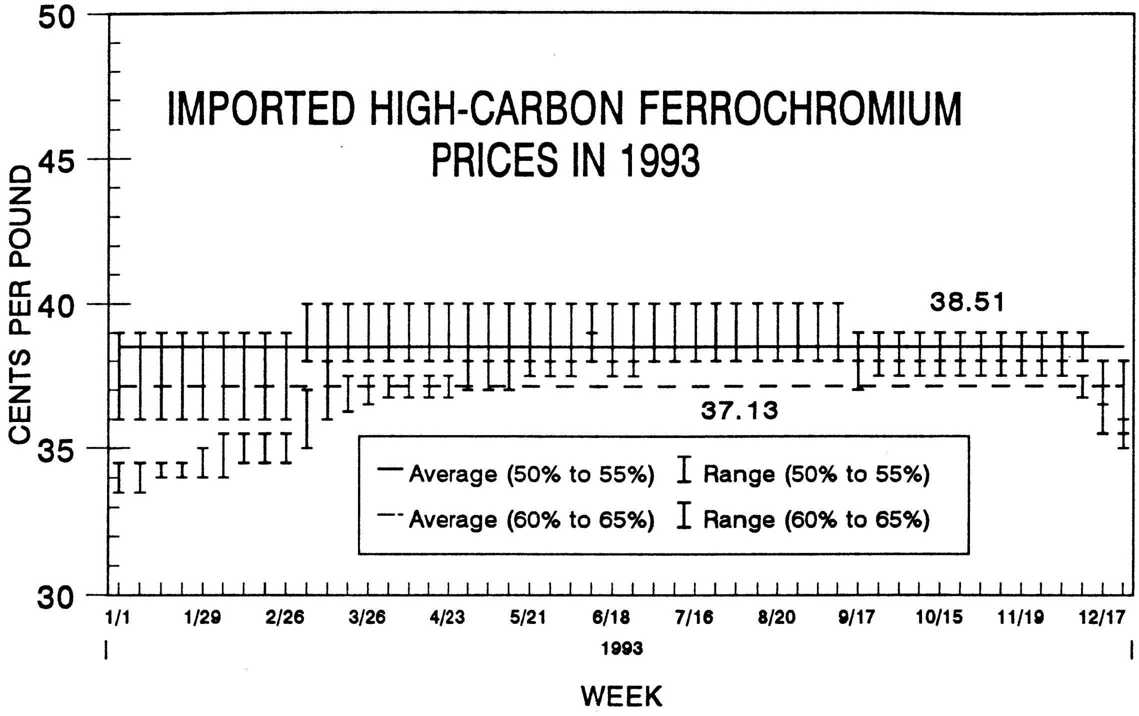
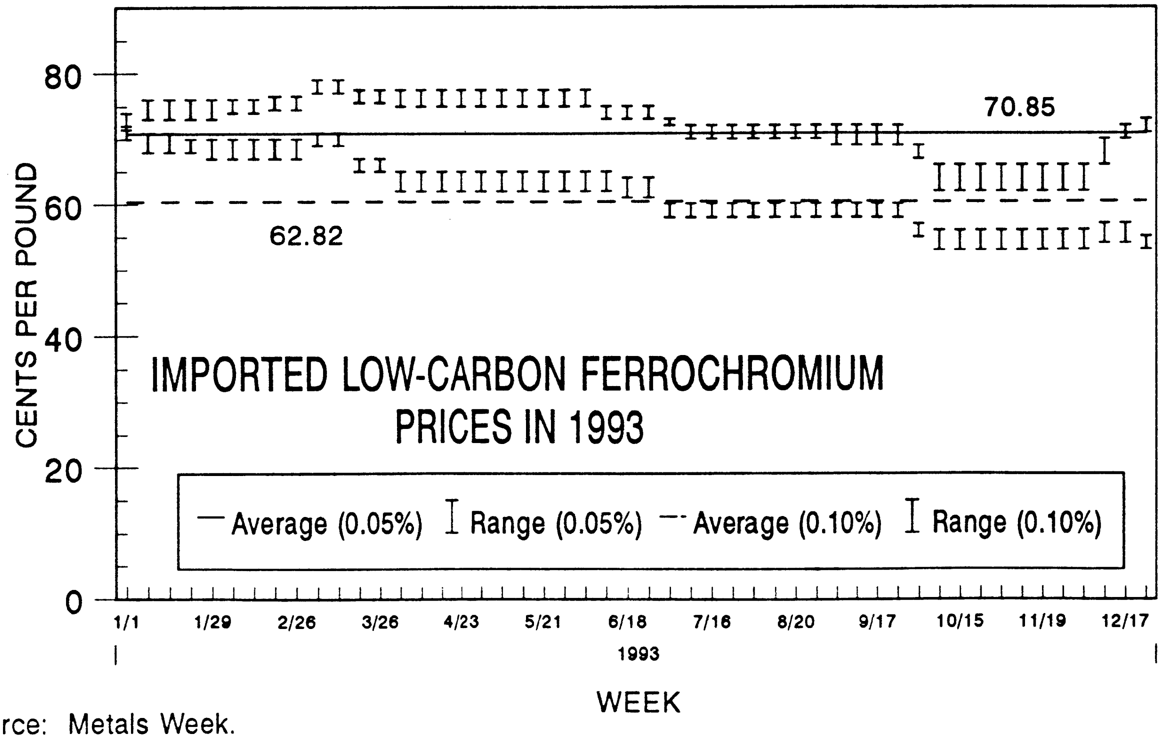


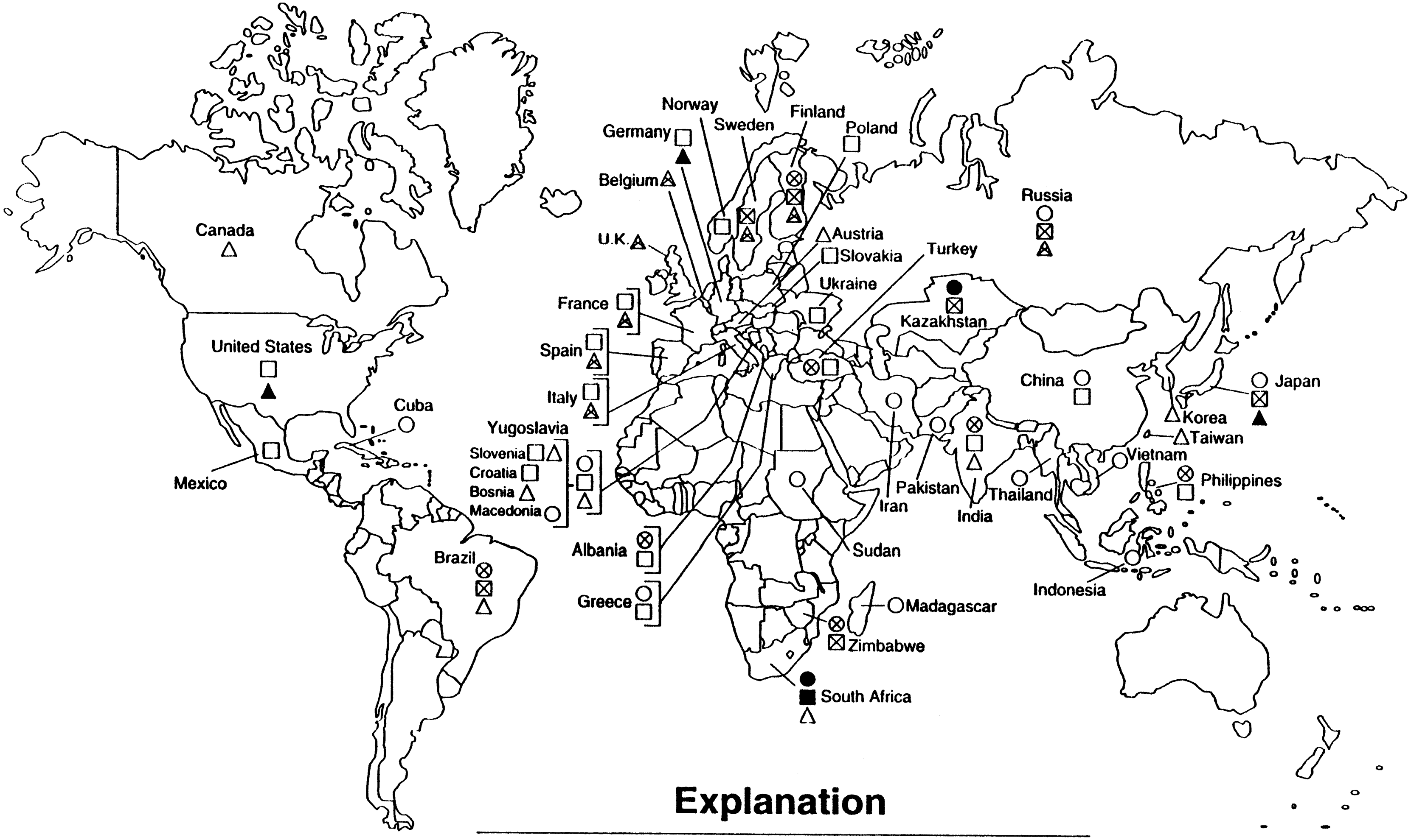
FIGURE 6
IMPORTED LOW-CARBON FERROCHROMIUM WEEKLY PRICE RANGE AND TIME-AVERAGE PRICE IN 1993



Source: Metals Week.

FIGURE 7

WORLD GEOGRAPHIC LOCATION AND SIZE OF CHROMITE ORE, FERROCHROMIUM, AND STAINLESS STEEL PRODUCERS



Explanation

Material	Producer size Major	 Intermediate	 Minor
Chromite ore	●	⊗	○
Ferrochromium	■	⊠	□
Stainless steel	▲	◬	△

CLAYS

By Robert L. Virta

Mr. Virta, a physical scientist with 18 years of U.S. Bureau of Mines experience, has been the commodity specialist for clays since 1991. Domestic survey data were prepared by Maria Arguelles, statistical assistant; and international tables were prepared by Virginia Woodson, Amy Durham, and Amy Burke, international data coordinators.

The amount of clay sold or used by domestic producers increased slightly in tonnage to 41.1 million metric tons, valued at $1.5 billion. Production of all types of clay increased in 1993. Common clays accounted for 61% of the tonnage. Kaolin accounted for 64% of the value of clays produced in 1993. Imports decreased 5% in tonnage to 39,430 tons and increased 13% in value to $17.6 million. Exports were essentially unchanged in tonnage at 4.2 million tons although they increased slightly in value to $669.5 million. (*See table 1.*)

Clays were produced in 44 States and Puerto Rico. The 10 leading producer States, in descending order, were Georgia, Alabama, Wyoming, North Carolina, Texas, Ohio, California, South Carolina, Missouri, and Michigan. (*See table 2.*)

DOMESTIC DATA COVERAGE

Domestic production data for clays are developed by the U.S. Bureau of Mines (USBM) from one voluntary survey of U.S. operations. Of the 649 operations covered by the survey, 480 responded, representing 73% of the total clay and shale production sold or used shown in table 1.

BACKGROUND

Definitions, Grades, and Specifications

Clays are categorized into six groups by the USBM. The categories are ball clay, bentonite, common clay and shale, fire clay, fuller's earth, and kaolin. The definitions listed in this work for ball clay, fire clay, high-alumina clays, and kaolin are similar to those in USBM Information Circular 8335.[1]

Ball clay is a plastic, white-firing clay used mainly for bonding in ceramicware. The clays are sedimentary in origin and consist mainly of kaolinite, sericite mica, and organic matter. Ball clays usually are much finer grained than kaolins and are renowned for their plasticity. They are classified according to the method of preparation (crude, shredded, air-floated, water-washed, or slurry) and specific physical and chemical properties.

Bentonite is a clay composed predominately of smectite minerals. The primary smectite mineral is montmorillonite. Swelling-type bentonite has a high-sodium ion concentration. Its volume increases 15 to 20 times its dry volume when wetted with water. Nonswelling bentonites usually are high in calcium. Bentonite is classified according to its physical and chemical properties, with particular emphasis on particle size and swelling index.

Common clay is defined as a clay or claylike material that is plastic enough to mold easily. Its vitrification point is usually below 1,100° C. Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. The common clays and shales are composed mainly of illite or chlorite. They also may contain kaolin and montmorillonite. Common clays and shales usually contain more alkali, alkaline earth, and ferruginous minerals and less aluminum than high-quality kaolins, fire clays, and ball clays. Iron present in the clay usually imparts a reddish color to the final product after firing. There is no formal classification of common clays and shales, although a clay may sometimes be referred to as common, brick, sewer pipe, or tile clay. Clay and shale are used in the manufacture of structural clay products such as brick, drain tile, and roofing tile as well as portland cement clinker and expanded lightweight aggregates.

Fire clay is defined as detrital material, either plastic or rocklike, that commonly occurs as underclay below coal seams. Low concentrations of iron oxide, lime, magnesia, and alkalies in fire clay enable the material to withstand temperatures of 1,500° C or higher. It is composed mainly of kaolinite. Fire clays also contain other clays such as ball clay, bauxitic clay and shale, burley, burley-flint, and diaspore. Fire clays generally are used for refractories or to raise vitrification temperatures in structural clay products. The fired colors of fire clays range from buffs to grays. Fire clays are classified according to their physical and chemical properties and the characteristics of the products made from them.

The term "fuller's earth" is derived from the first major use of the material, which was for cleaning textiles by fullers. Fuller's earth does not refer to a clay with a specific composition or mineralogy. It is defined as a nonplastic clay or claylike material, usually high in magnesia, that is suitable for decolorizing and purifying mineral and vegetable oils. They are composed mainly of the needle- and/or lath-shaped clay mineral attapulgite or varieties of montmorillonite. Fuller's earths containing opal or other forms of colloidal silica also are produced. Fuller's earths are classified according to their physical and chemical properties. Sepiolite-type clays are grouped with fuller's earths under the USBM classification system.

Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite and other kaolin-group minerals, such as halloysite and dickite. Kaolin has a specific gravity of 2.6 and a fusion point of 1,785° C. Kaolin is classified according to the method of preparation (crude, air-separated, water-washed, delaminated, air-dried, calcined, slip, pulp, slurry, or water suspension) and on specific physical and chemical properties.

The American Society for Testing and Materials, American Foundrymen's Association, American Oil Chemist's Society, American Petroleum Institute, Technical Association of the Pulp and Paper Industry, and other national organizations have developed tests and set standards for some applications. Many producers and consumers, however, use nonstandardized tests that are applicable to their specific needs. Individual companies often set the acceptable limits of mineralogical composition, particle size, and other physical and chemical properties. Detailed data on specifications have been published by the USBM.[2]

Products for Trade and Industry

Because of the many types of clay and different qualities within each type, the consumption pattern and the products for trade and industry are constantly changing. Consumption of kaolin in refractories has been growing since 1970 because of the increasing popularity of castable, ramming, gunning, and plastic mixes that use calcined kaolin aggregates (grog) in their formulations.[3] The consumption of calcined kaolin grogs also has increased in refractory brick manufacturing, replacing imported calcined refractory-grade bauxite grogs. Bentonite used for waterproofing and sealing in construction and disposal sites and in pet waste absorbents has grown significantly in the past few years.

Industry Structure

An estimated 330 companies operating 989 clay pits or mines reported production in 1993; of these, 90 companies, most with multiple operations, accounted for approximately 68% of the tonnage and 77% of the value for all types of clay produced and sold or used. Clay production was reported in all States and Puerto Rico except Alaska, Delaware, Hawaii, Rhode Island, Vermont, Wisconsin, and the District of Columbia.

The leading clay-producing States were Georgia, 9.8 million tons; Alabama, 2.5 million tons; Wyoming, 2.4 million tons; North Carolina, 2.4 million tons; Texas, 2.2 million tons; Ohio, 2.2 million tons; California, 2 million tons; South Carolina, 1.5 million tons; Missouri, 1.2 million tons; and Michigan, 1.2 million tons. (*See table 2.*) Most of the clay is mined by open pit methods. Less than 1% of U.S. clay output was from underground mines in 1993. Most of the underground production was in Pennsylvania, Ohio, and West Virginia, where the clays are mainly underclays associated with coal and suitable for refractory uses.

The ball clay industry was small, with 7 producers operating 27 mines in 6 States in 1993. Three of the producers were large, diversified firms with widespread foreign and domestic mineral interests. Tennessee ball clay production represented about 76% of the total output.

Firms producing bentonite operated 141 mines in 13 States. Four producers were large, diversified firms with international mineral operations; three of the firms had interests in other types of clay in the United States. Wyoming was the leading State, accounting for 78% of the total output. Swelling-type bentonite was produced mainly in Montana and Wyoming and nonswelling-type bentonite was produced mainly in Alabama, California, and Mississippi. The United States was the world's largest producer and exporter of bentonitic clays.

Firms producing common clay and shale in 1993 were manufacturers of structural clay products such as clay pipe, sewer pipe, lightweight aggregates, and cement. Most companies mined the clays used in making their products. Less than 10% of the total output usually is sold. Private mining contractors and haulers were employed in many of the operations. Some producers were diversified firms having interests in metals and other nonclay products. Some companies owned and operated several clay pits and plants to cover a large market area. The economic radius for shipment of common clay or shale products was usually 320 kilometers or less. The high cost of transport promotes the development of local ownership companies, or in the case of a large firm, the ownership and operation of several strategically located pits and associated fabricating plants.

Fireclay producers were mostly refractories manufacturers that used the clays in firebrick and other refractories. Seventy-eight mines were operated in 1993 by 22 firms in 10 States.

Nineteen companies produced fuller's earth from 33 mines in 12 States. Seven of the mines were in the attapulgite-fuller's earth areas of Florida and Georgia; these two States accounted for most of the domestic attapulgite production. Most producers were small, independent firms, but three were large, diversified corporations with international mineral interests. The United States is the world's largest producer and user of fuller's earth.

Thirty-nine firms operated 136 kaolin mines in 12 States. In 1993, three large, diversified firms accounted for about 60% of total domestic kaolin output. Most large kaolin producers have operations in Georgia, which accounted for 83% of the kaolin production.

Geology-Resources

Clay is formed by the mechanical and chemical breakdown (weathering) of rocks. The weathering products consist of mineral grains and rock fragments of different size and different physical and chemical properties. The nonplastic portion consists of altered and unaltered rock fragments (grit), which are usually feldspar, iron oxides, micas, and quartz. The plastic portion usually is composed of clays and is low in grit.

Clays may be classified as residual or sedimentary. Residual clays are deposited in the same location in which they were formed. Sedimentary clays are those that have been transported, usually by water, and deposited elsewhere.[4] Sedimentary clays often undergo further alteration and classification during transport. Kaolin deposits in Georgia and South Carolina are sedimentary. Kaolin deposits in North Carolina and English china or kaolin clay deposits are residual.[5] The Kentucky and Tennessee ball clays and the Missouri fire clays are sedimentary deposits. Most bentonites, montmorillonites, and fuller's earths were formed in place through the weathering of volcanic ash or tuff. The attapulgite-type fuller's earth deposits of Florida and Georgia were probably not formed from volcanic ash or tuff. Geologists have never found any evidence of volcanic materials associated with these deposits.[6]

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals." Reserves are the part of an ore body that can be economically extracted at the time of evaluation. Reserve base is the part of an ore body that meets specified minimum physical and chemical criteria related to current mining and production practices. Reserve base includes reserves, marginal reserves, and subeconomic resources.

Common clay and shale deposits are found throughout the United States and domestic resources are almost unlimited. Not all deposits, however, are near potential markets, and most deposits are not suitable for all applications. For example, most common clay or shale deposits can be used to manufacture common brick, but the color or strength of the final product may not meet the requirements of the local market. Relatively few deposits are suitable for manufacture of lightweight aggregate. Even with these limitations of location and use, resources of common clay and shale are "virtually unlimited."

U.S. reserves of other types of clays that are owned or controlled by domestic producers are estimated to be about 700 million tons. U.S. reserves of kaolin are estimated to be 400 million tons; ball clay, 30 million tons; fire clay, 100 million tons; bentonite, 120 million tons; and fuller's earth, 60 million tons.

Large quantities of high-quality kaolin suitable for paper-coating and paper-filler applications are found in Georgia. A small area in Florida and Georgia contains sizable reserves of attapulgite-type fuller's earth. Most bentonite for iron ore pelletizing and oil-well-drilling muds is mined in Wyoming. Fire clay deposits, such as those found in Missouri, are widespread. Kentucky and Tennessee are two of only a few States that have sizable deposits of ball clay.

Technology

Exploration.—Exploration begins with an understanding of the geological occurrence of the clays of interest. With this knowledge, potential economic deposits can be located. Auger or core drills are then made to delineate the size and shape of the deposit and to obtain material for testing.

Kaolins usually are evaluated for filler and ceramic applications. The grit, particle size, brightness, and leachability are determined. Air-floated clays normally require only grit and brightness determinations. Kaolin, ball clay, and fire clay for ceramic and/or refractory applications are analyzed for grit, brightness, green and dry strengths, fired color, and iron and alumina contents. The common clays and shales usually are tested according to the intended end use, such as brick, drain tile, or lightweight aggregate. Usually, prepared specimens are tested for plasticity, green strength, shrinkage, vitrification temperature range, etc. For lightweight aggregates, the bloating range is determined. Bentonites and fuller's earth clays are difficult to evaluate because there are no standard testing procedures or specifications. Generally, they are processed to meet the purchaser's specifications.

Mining.—Most clays are mined from open pits using modern surface mining equipment such as draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. Some kaolin is extracted by hydraulic mining and dredging. A few clay pits are operated using crude hand-mining methods. A small number of clay mines, principally in underclays in coal mining areas, are mined underground using room-and-pillar methods. Clays usually are transported by truck from the pit or blending areas to the processing plants. Rail, conveyor belt, and in the case of kaolin, pipelines also are used.

About 100% of the clay is recovered from the minable beds in most open pit operations. Approximately 75% is recovered in underground operations. The waste-to-clay ratio is highest for kaolin, about 7:1, and lowest for common clay and shale, about 0.25:1.

Processing.—Clays are used in a large number of products, so they must be treated in different ways. Processing can consist of very simple and inexpensive grinding or shredding and screening for some common clays. Very complex and expensive grinding or shredding, sizing, leaching, delamination, etc., may be required for paper-coating clays and high-quality filler clays for use in rubber, paint, plastic, and other products. In general, processing does not appreciably alter the chemical or mineralogical characteristics of the clays. The two exceptions are calcining and cation exchange.

Significant processing losses occur with kaolin and fuller's earth. About 40% of the kaolin and 30% of the fuller's earth delivered to the processing plants is discarded. Waste material from processing consists mostly of off-grade clays and small quantities of feldspar, iron-bearing minerals, mica, and quartz.

Ball Clay.—Processing involves drying, shredding, pulverizing, air floating, and slurrying.

Bentonite.—Processing involves weathering, drying, grinding, sizing, granulation, and the use of additives for cation exchange.

Common Clay and Shale.—Processing involves shredding, blunging, extruding, and drying. Common bricks, tile, lightweight aggregate, etc., require firing in a kiln. The kiln firing or drying operation produces a finished manufactured product.

Fire Clay.—Processing involves shredding, calcining, and blending.

Fuller's Earth.—Processing involves blunging, extruding, drying, crushing, grinding, sizing, and dispersing.

Kaolin.—Processing involves one or more of the following: shredding, blunging with dispersant, degritting, water fractionation, magnetic separation, ultraflotation, acid treatment, calcination, air floating, attrition grinding, slurrying, and delaminating. Kaolins used for paper-coating applications may be leached and further delaminated by grinding, deflocculation, and centrifugation to special sizes. Ultraflotation or wet magnetic separation treatment may be used to remove iron- or titanium-bearing minerals to obtain a whiter product.

Processing costs for clays range from a few cents per ton for some common clays to more than $400 per ton for some special paper-coating clays and high-quality clays that require very elaborate and expensive treatments.

Price schedules, although not complete, are available and are published regularly in trade journals such as the American Paint and Coatings Journal, Chemical Marketing Reporter, and Industrial Minerals (London).

Federal tax laws allow clay producers a depletion allowance on 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; and clay used for extraction of alumina or aluminum compounds, 22% domestic; clay used or sold for use in manufacturing drainage and roofing tile, flower pots, and kindred products, 5% domestic and 5% foreign; and clay and shale used for making brick, tile, and lightweight aggregate, 7.5% domestic and 7.5% foreign. Severance taxes are levied by some producing States.

Byproducts and Coproducts

Firms in California, Florida, and Texas produce silica glass sand as a coproduct of its kaolin production. Flake mica is a byproduct in one kaolin operation in North Carolina. Bauxite is a coproduct in clay operations in Alabama and Georgia. Clay and limestone for cement manufacture commonly are produced from the same property and reported as coproducts or byproducts even though they are usually mined separately from different formations or beds. Sand, gravel, and stone aggregates are occasionally produced together with common clays.

Economic Factors

Economic factors affecting clays vary in importance with type, quality, and intended end use. The cost of transportation is an important factor for the common clay and fire clay industries; mines must be close to consumers to be cost competitive. Other types of clays are less abundant and have higher unit values. They can be shipped greater distances from the mines and still be cost competitive. For example, paper-coating clay from Georgia and attapulgite-type fuller's earth from Florida and Georgia can be shipped nationwide. Bentonite for iron ore pelletizing from Montana and Wyoming can be shipped a considerable distance to the iron ore centers. In some of these cases, the shipping costs exceed the value of the clays at the mine or processing plant. Other important factors to consider are associated with land acquisition, severance taxes, land rehabilitation, energy requirements, and environmental factors.

Because most clays are relatively low-cost materials in the crude state, mining costs must be kept as low as possible. Cost of the crude clays ranges from less than $3 per ton for some common clays to more than $20 per ton for some of the higher quality materials.

Very little clay is imported because transportation costs would make the clays noncompetitive in price. Consequently, import duties have little impact on the amount of clays imported.

Operating Factors

To manufacture finished clay products, producers require equipment to mine the clay; crushers, blungers, centrifuges, settling tanks, rotary vacuum filters, spray dryers, etc., to process the clay and kilns to prepare fired clay products. These require high initial capital outlays and constant maintenance and/or replacement for proper operation. Additionally, customer needs vary so suppliers must produce a multitude of products. This greatly increases the complexity (and cost) of the milling process.

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%. Producers attempt to maximize the efficiency of the recovery process in an effort to reduce costs associated with the handling and processing of waste material.

Clay mining lacks many of the hazards associated with other types of mining because only a few deposits require the use of explosives and most mines are open pit earth-moving operations. Domestic mine employment in 1993 was estimated to be 2,000 workers. Domestic mill employment was estimated to be 9,100 workers.

ANNUAL REVIEW

Issues

Clay mining has an environmental impact because of the disturbance to the land. Overburden is moved and clays are removed, leaving a depression or pit. State laws usually require leveling or recontouring of the disturbed area and planting trees or grasses to prevent or minimize erosion. For processing, the impoundment of slimes and dust control are usually required. The rules for disposal of coarse tailings are similar to or included with those laws governing reclamation of the mined area.

Production

Ball Clay.—Production of domestic ball clay increased 11% to 949,250 tons valued at $39.8 million. Tennessee supplied 64% of the Nation's output, followed by, in descending order of production, Kentucky, Texas, Indiana, Mississippi, and Ohio. Production increased in Indiana, Kentucky, Tennessee, and Texas and was unchanged in Mississippi. Water-slurried ball clay was produced in Tennessee and air-float ball clay was produced in Indiana, Kentucky, Mississippi, and Tennessee. (*See table 3.*)

Bentonite.—The quantity and value of bentonite sold or used increased slightly to 3.09 million tons and $112.3 million, respectively. Wyoming was the largest bentonite producer, accounting for 78% of the total bentonite production and 92% of the swelling bentonite production. Wyoming was followed by Montana, California, Utah, Oregon, Texas, Nevada, Virginia, and Tennessee, in decreasing order of production. Production of swelling bentonites increased in California, Nevada, Oregon, and Wyoming.

Mines in Alabama and Mississippi accounted for more than 47% of the nonswelling or calcium bentonite production. Mississippi was followed by Alabama, California, Texas, Arizona, Nevada, Oregon, Utah, Colorado, and Montana, in decreasing order of production. Increases in production of nonswelling bentonite were reported in Alabama, California, and Nevada. Decreases were reported in other producing States. *(See table 5.)*

Tremont Corp. announced plans to sell its subsidiary, Bentonite Corp., to Baroid Corp. for $20 million. Major markets for Bentonite Corp.'s bentonite are foundry use, civil engineering applications, and oil drilling muds.[7]

Common Clay and Shale.—Domestic sales or use of common clay and shale increased slightly in tonnage to 25.3 million tons and value to $136.9 million. The 10 major producing States were North Carolina, Texas, Alabama, Ohio, California, Georgia, Michigan, South Carolina, Missouri, and Arkansas, in descending order of tonnage. Of these States, production increased in Alabama, California, Georgia, and North Carolina. Common clay and shale represented about 61% of the quantity but only 9% of the value of total domestic clay production. *(See table 7.)*

Fire Clay.—Fire clay sold or used by domestic producers increased 20% in tonnage to 459,000 tons and 11% in value to $11.5 million. Missouri, was the leading producing State, followed by Ohio, Alabama, Georgia, Arkansas, New Mexico, Montana, New Jersey, Washington, and Colorado. Production increased in Arkansas, Georgia, Missouri, Montana, Ohio, and Washington. *(See table 9.)*

Fuller's Earth.—Production of fuller's earth increased 3% to 2.5 million tons valued at $230 million. Production from the region that includes Attapulgus, Decatur County, GA, and Quincy, Gadsden County, FL, was composed predominantly of the lath-shaped amphibolelike clay mineral attapulgite. Georgia accounted for most of the domestic attapulgite production followed by Florida and Nevada, in decreasing order of production.

Most of the fuller's earth produced in other areas of the United States contains varieties of montmorillonite and/or other clays. Illinois, Mississippi, and Missouri accounted for most of the production, followed by California, Florida, Tennessee, Georgia, Kansas, Virginia, Texas, and Utah, in decreasing order of production. Production increased in California and Florida. *(See table 11.)*

J. M. Huber Corp. announced an agreement to market sepiolite for Tolsa SA in North America. Tolsa SA mines sepiolite in Spain primarily for cat litter. J. M. Huber will market the sepiolite in North America to the paint, ink, and adhesives industries.[8]

Kaolin.—Domestic production of kaolin increased 3% in tonnage to 9 million tons, valued at $957.9 million. Georgia was the largest kaolin producer with 83% of U.S. production, followed by South Carolina with 6% of production. Other producing States were Alabama, Arkansas, California, Minnesota, Nevada, North Carolina, Florida, Texas, Pennsylvania, and Colorado, in decreasing order of production. Production increased in all States except Pennsylvania. *(See table 13.)*

Approximately 47% of the kaolin produced was water-washed; followed by calcined, 18%; delaminated, 14%; air-floated, 13%; and unprocessed, 9%. *(See table 14.)* Delaminated kaolin was produced exclusively in Georgia. Georgia also accounted for 99% of the production of water-washed kaolin and 69% of the calcined kaolin. Georgia and South Carolina accounted for 94% of the air-floated kaolin. Production/sales of air float and calcined and unprocessed kaolin increased in 1993. *(See tables 14, 15, 16, and 18.)* Some of the unprocessed kaolin was used in bricks, pottery, roofing granules, etc. The low value of the clay used in these applications suggests that some of the clay should be classified as common clay rather than kaolin.

Kentucky-Tennessee Clay Co. increased the capacity of its Sandersville, GA, slurry facilities by approximately

50%. The company installed an automated system for batch processing, increased screening capacity, and enlarged its storage facilities.[9]

Engelhard Corp. announced plans to increase its facilities for producing calcined kaolin. Capacity will be increased by approximately 40,000 tons. Calcined kaolin will be marketed to the paper industry.[10]

Kemira Inc. announced its intention to acquire 20% of Nord Kaolin Co. Kemira is a major supplier of TiO_2 for the paper industry. Nord Kaolin produces kaolin for the paper industry, with one product being a kaolin-extended TiO_2 product.[11]

Consumption and Uses

Ball Clay.—Ball clays are extremely refractory, and their use, largely in whitewares, imparts a high green strength as well as plasticity to the bodies. Although white-firing ball clays are preferable, fired products that range to cream or buff colors do not generally impair the quality of the whiteware products.

The principal ball clay markets were pottery, floor and wall tile, fillers and extenders, and sanitaryware with 14%, 25%, 21%, and 22%, respectively, of the domestic consumption. No major changes were observed in domestic consumption patterns except in fillers and extenders where animal feed applications increased significantly. Producers reported increased exports in 1993. *(See table 4.)*

Bentonite.—The swelling sodium bentonites were used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. The nonswelling or calcium bentonites were used mostly in conjunction with the swelling bentonites in foundry sand mixes in which the sodium bentonites provide dry strength and the calcium bentonites provide high green strength.

Bentonite also was used for foundry casting by the steel, iron, and nonferrous casting. The bentonite provided good green strength and desirable dry strength characteristics. Sodium bentonites were used in steel casting. Ion-exchanged bentonites were used for iron and nonferrous casting. There has been an increased use of mixtures of ion-exchanged and sodium bentonites to meet the more stringent demands of the casting industry. Calcium bentonite produced in Alabama and Mississippi was suitable for the production of absorbent, acid-activated, and foundry products.

The major end uses were drilling mud, foundry sand, iron ore pelletizing, and pet waste absorbents with 20%, 30%, 18%, and 11%, respectively, of total domestic sales. Sales of swelling bentonite for pet waste absorbents increased in 1993 largely due to the marketing success of clumping kitty litters. Similarly, sales of swelling bentonite for foundry sand applications also increased. The increase was not as great as shown in table 16 because some of the 1992 data was concealed to avoid disclosing company proprietary data. Based on the trend over the past 5 years, sales of 700,000 tons to 750,000 tons would be expected rather than the 803,420 tons reported by producers. A large decrease in sales for filtering and clarifying was reported. Much of this decrease was attributed to a large one-time sale of bentonite for clarification of acids in 1992. Increased sales of bentonite for drilling muds correspond to increased drilling activity. Again, producers that sold bentonite for pelletizing iron ore did not separate domestic and foreign shipments. An estimated 100,000 tons was exported for pelletizing. *(See table 6.)*

Bentonite Corp. completed construction of a new processing plant in Wyoming. The plant produces premixes, consisting of bentonite, coal, and proprietary additives, for the metal casting industry. The plant has a capacity of 127,000 tons.[12]

Common Clay and Shale.—Common clay was used most frequently in the manufacture of heavy clay products, including (1) building brick; flue linings, sewer pipe, drain tile, structural tile, and terra cotta; (2) portland cement clinker; and (3) lightweight aggregate, accounting for 52%, 30%, and 14%, respectively, of total domestic consumption. Consumption increased 4% for heavy clay products and lightweight aggregates and decreased 4% for portland cement clinker. *(See table 8.)*

Fire Clay.—Fire clays were used mostly in commercial refractory products such as firebrick and block, grogs and calcines, high-alumina brick and specialties, saggers, refractory mortars and mixes, and ramming and gunning mixes. Fire clays also were used to produce lightweight aggregates, portland cement, pottery, and common brick.

Consumption of fire clay increased 20% in 1993. Firebrick accounted for 28% of fire clay use followed by heavy clay products, 10%; and ceramics and glass, 4%. The large increase in sales for firebrick is contrary to industry trends. Based on previous trends, sales of approximately 200,000 tons would be expected. *(See table 10.)*

Fuller's Earth.—Fuller's earth and calcium bentonite were used for decolorizing and purifying mineral, vegetable, and animal oils. Clays activated by acid treatment were used to process animal or vegetable oils. Acid treatment produced a highly absorbent sievelike structure. Attapulgite is used in drilling muds instead of sodium bentonites for drilling saltwater formations. Sodium bentonite flocculates in brine, thereby destroying the gel-like colloidal suspension required for drilling. The major uses for attapulgite and montmorillonite types of the fuller's earths were in pet waste and oil and grease absorbents because of their absorbent properties.

Attapulgite, a fuller's earth-type clay, found wide application in absorbent and gelling and/or thickening areas. The thixotropic properties of attapulgite clays provided important thickening and viscosity controls necessary for suspending solids. Mineral thickeners were used in such diverse markets as paint, joint compound cement, and saltwater drilling mud.

Overall consumption of all types of fuller's earth increased 3% in 1993. The major use was in pet waste absorbents, which accounted for 63% of the fuller's earth consumption. Other major domestic uses were oil and grease absorbents (11%) and pesticide carriers (8%). Consumption of fuller's earth in oil and gas absorbents declined. Sales of attapulgite and montmorillonite-type fuller's earth increased for animal feed and pesticide carrier applications. *(See table 12.)*

The major use for montmorillonite-type fuller's earth was in pet waste absorbents. The next largest use was in pesticides, followed by oil and gas absorbents, animal feed additives, fertilizer carriers, and clarifying animal and mineral oils. There was a 46% decrease in the use of montmorillonite-type fuller's earth for oil and grease absorbent applications and a 13% increase in sales of montmorillonite-type fuller's earth for pet waste absorbents. Montmorillonite-type fuller's earth was the dominant clay used in pet waste absorbents (74%). The largest use of attapulgite was in pet waste absorbents (292,000 tons). Sales of attapulgite for pet waste absorbents decreased 21% in 1993. Other major markets for attapulgite were oil and grease absorbents (20%) and fertilizer carriers (8%). No other significant changes in consumption patterns were reported for fuller's earth.

Kaolin.—Kaolin had many industrial applications, and many grades were specifically designed for use as a filler in paper, paint, rubber, plastics,[13] and ceramics.[14] New uses are constantly being developed. Kaolin is a unique industrial mineral because it is chemically inert over a relatively wide pH range, is white in color, and has good covering or hiding power when used as a pigment or extender in coated films and filling applications. It also is relatively nonabrasive, has low conductivity of heat and electricity, and costs less than most materials with which it competes. Fillers and extenders must meet very rigid specifications such as particle size, color, brightness, and viscosity.[15]

Kaolin producers reported major domestic end uses as paper coating, 37%; grogs and calcines, 14%; paper filling, 14%; fiberglass, 5%; paint, 4%; rubber, 4%; brick, 3%; portland cements, 3%; and catalysts, 3%. *(See table 20.)* The largest decline in tonnage was in paper applications where coatings and filler declined 6% and 17%, respectively. Besides facing a slumping paper industry, kaolin sales have been affected slightly by the increased use of ground and precipitated calcium carbonate in the alkaline papermaking process. Despite the decline domestically, producers reported increased exports of kaolin for the paper industry. The increase in catalyst applications was not as great as shown in table 20 because some of the 1992 data were concealed to avoid disclosing company proprietary data. No other major changes were observed in the domestic consumption patterns.

There were distinct differences in markets for kaolin from Georgia and South Carolina. Major domestic markets for kaolin from Georgia were paper coating (48%), paper filling (18%), fiberglass (5%), and paint (4%). Major markets for kaolin from South Carolina were rubber, fiber glass, catalyst, and adhesives, in decreasing order of consumption. No significant changes were observed in markets for South Carolina kaolin. Changes in consumption patterns for Georgia were mentioned in the preceding paragraph concerning paper. *(See tables 17 and 19.)*

Absorbent Uses.—Absorbent uses for clays accounted for about 2.1 million tons or 5% of total clay consumption. Consumption was for oil and grease absorbents, 15%; pet waste absorbents, 84%; and miscellaneous absorbent applications, 1%. Demand for absorbents decreased slightly in 1993. Fuller's earth was the principal clay used for absorbent purposes, followed by bentonite. *(See tables 6 and 12.)* Small amounts of ball clay and kaolin also were used for absorbent applications.

Ceramics.—Pottery and related products required good ceramic qualities, including plastic formation, desirable firing temperatures, color, etc. The principal clays meeting these and other specifications were ball clay, common clay, and kaolin. Total demand for clay in the manufacture of pottery, sanitaryware, china and dinnerware, and related products (excluding clay flower pots) exceeded 750,000 tons. Common clay and shale, ball clay, and kaolin, in order of volume, were used in manufacturing floor, wall, and quarry tile. Demand in floor, wall, and quarry tile applications was 603,000 tons in 1993. *(See tables 4, 8, 10, and 20.)*

Construction.—Common clays and shales were used to manufacture a wide variety of construction materials such as expanded aggregates, hydraulic cement, and structural clay products.

Expanded Clay and Shale.—Materials with specific bloating properties and strength are required for this use. Lightweight concrete blocks, floors, walls, and other products made from expanded clay and shale have a lower overall weight and better insulating qualities than equivalent products made with sand and gravel and crushed stone aggregates.

Consumption of common clay and shale in the production of lightweight aggregate increased slightly to 3.5 million tons. Concrete block accounted for 63% of total lightweight aggregate production. Structural concrete accounted for 22% of the market. Highway surfacing accounted for 7% of lightweight aggregate production. *(See tables 8, 10, and 21.)*

Hydraulic Cement.—Clays provide the alumina and silica required to manufacture hydraulic cements. Common clays, kaolin, fuller's earth, fire clay, and bentonite, in decreasing order of consumption, were used in cement products. Approximately 97% of the clay consumed by the cement industry was common clay. *(See tables 8, 12, and*

20.)

Structural Clay Products.—Structural clay products include such items as building brick, drain tile, flue linings, roofing tile, sewer pipe, and terra cotta. Clays for structural applications must be plastic and easily shaped, must not warp during firing, and must produce a product with adequate strength. Common clay is most commonly used in these applications. Other clays, such as ball clay, bentonite, fire clay, and kaolin, are not used in large tonnages because of their higher cost.

Slightly more than 13.5 million tons of clay was consumed for structural clay products. Common and face brick accounted for 93% of this total or 12.6 million tons. Other markets, in decreasing order of consumption, were sewer pipe, flue linings, terra cotta, flower pots, structural tile, drain tile, and roofing tile. *(See tables 8, 10, 20, and 22.)*

The value reported by the Bureau of the Census for shipments of building and face brick was 6.6 billion bricks valued at $985 million, an increase from that of 1992. Shipments of clay floor and wall tile increased to almost 49 million square meters valued at $678 million. Shipments of vitrified clay and sewer pipe fittings decreased to 129,839 tons valued at $33 million.

Drilling Mud.—Drilling mud is a scientifically designed mixture of several items. The clays are used to adjust the viscosity and gel strength of the drilling fluid and to coat the drill-hole walls to prevent fluid loss. Drilling muds contain, in addition to bentonite or attapulgite, ground barite for its high specific gravity.[16] Demand for clays in rotary-drilling muds decreased to approximately 559,000 tons. Swelling-type bentonite remained the principal clay used in drilling mud mixes, although fuller's earth, used mostly in saltwater drilling techniques, and nonswelling sodium-activated bentonites also were used to a limited extent. *(See tables 6 and 12.)*

Filler.—Clays are used as binders, extenders, and fillers in a wide variety of products, ranging from adhesives to flooring products to paint to rubber. They are added to products for widely varying reasons. For example, clays displace more expensive product components in paint, paper, and plastics; improve the ink retention and opacity in paper; prevent pigment settling in paints; act as carriers for fertilizers and pesticides; and increase the strength of plastics.

More than 5 million tons of clays was used as fillers and extenders. Kaolin accounted for approximately 82% of this amount, followed by fuller's earth, bentonite, ball clay, and common clay, in decreasing order of consumption. *(See tables 4, 6, 8, 12, and 20.)* Approximately 84% of the kaolin was used for paper-coating and paper-filling applications. Kaolin also was used in the manufacture of products such as adhesives, cosmetics, fertilizer, ink, linoleum, paint, pesticides, plastics, and rubber. *(See table 20.)* Fuller's earth was used mainly in pesticides, fertilizers, and animal feed. Smaller amounts were used in adhesives, paint, and asphalt emulsion, in decreasing order of consumption. *(See table 12.)* Bentonite was used mainly in animal feed with smaller amounts used for the manufacture of paint, adhesives, asphalt emulsions, cosmetics, and pesticides. *(See table 6.)* Major ball clay uses were in animal feed, asphalt emulsion, wallboard, asphalt tile, paper, and plastic. Common clay was used mainly in asphalt emulsions and wallboard. Small amounts of fire clay were used in animal feeds.

Glass.—Exacting chemical and physical specifications are required for clay used in glass manufacturing. Approximately 347,000 tons of kaolin was used in fiberglass. A small amount of bentonite was used as a raw material feed for manufacturing mineral wool. *(See table 20.)*

Iron Ore Pelletizing.—Demand for bentonite in iron and steel production is based on its ability to form strong iron ore pellets from fine-grained taconite concentrates. Easily handled hard pellets are essential for efficient blast furnace operation. Demand decreased to 487,000 tons in 1993. *(See table 6.)* Small amounts of common clay also were used for iron ore pelletizing. *(See table 8.)*

Paper Products.—Kaolin serves to provide a smooth coating to paper, improves its ink retention and brightness, increases the paper density, fills interstices in the paper, and improves opacity. Kaolin accounted for essentially all of the clay used for paper coating (2.5 million tons) and 99% of the clay used for paper filling (947 thousand tons). *(See table 20.)* Small amounts of ball clay were used in paper-filling applications and a small amount of bentonite was used for paper coating. Growth in consumption rates declined in recent years in response to poor paper markets. Also affecting consumption was the increased use of calcium carbonate as paper manufacturers converted to the alkaline process.

One new area of interest involved the use of positively charged kaolin particles for removing pitch during the papermaking process. Traditionally, pitch is controlled using chemical means or adsorbing the pitch onto talc platelets. Favorable results were obtained by applying a high positive charge density onto kaolin platelets. The pitch was negatively charged by adding organic fatty acids to the solution. The negatively charged pitch was bound to the kaolin through a cationic exchange mechanism. The kaolin was most effective at pH levels below 6.[17]

In situ production of iron hydrosulfite, as opposed to the use of commercial sodium hydrosulfite, was investigated as a means of bleaching kaolin. Iron powder and sulfite in the form of sodium sulfite, sodium bisulfite, sodium metabisulfite, and sulfur dioxide were mixed in a kaolin slurry. These reacted to form iron hydrosulfite. The brightness of kaolin bleached with iron hydrosulfite was equivalent or better than that bleached with sodium hydrosulfite and costs for bleaching were lower.[18]

Refractories.—Refractories require strength at high temperatures, resistance to corrosion, low coefficient of expansion, and many other physical and chemical properties, depending on application. The current trend is for refractories designed for a specific use and castable mixes containing refractory aggregates and calcium aluminate cements.[19] Bentonite, both swelling and nonswelling, was used as a bonding agent in proprietary foundry formulations imparting both hot and green strength to the sand.

More than 2.5 million tons of clays was used for the manufacture of refractories. Ball clay, bentonite, common clay, fire clay, and kaolin accounted for 2%, 35%, 6%, 14%, and 43%, respectively, of the refractories markets. Ball clay, common clay, and fire clay were the most commonly used clays for firebrick; bentonite for foundry sand for bentonite; and kaolin for grogs and calcines. *(See tables 6, 10, and 20.)*

Markets and Prices

Ball Clay.—The average unit value for ball clay reported by domestic producers was $41.89 per ton. The unit value of imported ball clay was $190.39. The unit value of exported ball clay was $53.28 per ton.

Bentonite.—The unit value reported by domestic producers for nonswelling bentonite was $48.51 per ton. The unit value for swelling bentonite was $34.12 per ton. The unit value for all bentonite was $36.31 per ton. The unit value of imported bentonite was $289.36 per ton. The unit value of exported bentonite was $91.41 per ton.

Common Clay and Shale.—The average unit value for all common clay and shale produced in the United States and Puerto Rico was $5.41 per ton. The unit value of clay and shale used in lightweight aggregate was $8.34 per ton.

Fire Clay.—The unit value for fire clay reported by domestic producers was $25.13 per ton. The unit of imported fire clay was $217.27 per ton. The unit value of exported fire clay was $100.28 per ton.

Fuller's Earth.—The unit value of attapulgite-fuller's earth reported by domestic producers was $125.75 per ton. The unit value of montmorillonite-fuller's earth was $68.18 per ton. The average unit value of all types of fuller's earth was $92.48 per ton. The unit value of imported fuller's earth was $206.78 per ton. The unit value of exported fuller's earth decreased to $121.14 per ton.

Kaolin.—The unit value of kaolin was $106.94 per ton for all kaolin grades. The unit value for air-float kaolin was $56.98 per ton; for high-temperature calcined kaolin, $148.29; for low-temperature calcined kaolin, $334.39; for all types of calcined kaolin, $158.13 per ton; for delaminated kaolin, $114.44 per ton; for water-washed kaolin, $116.34 per ton; and for unprocessed kaolin, $17.12 per ton. The unit value of the imported kaolin was $347.28 per ton. The unit value of exported kaolin was $163.56 per ton.

Foreign Trade

Ball Clay.—Ball clay exports increased 22% to 60,000 tons valued at $3.2 million, according to the Bureau of the Census. Shipments were made to 25 countries. The major importer was Mexico, with 66% of the exports. *(See table 23.)* Domestic ball clay producers reported that 116,085 tons of ball clay was exported in 1993. The exports were used mainly for floor and wall tile production and sanitaryware production. Other major uses are asphalt emulsions and filler and extender applications. *(See table 4.)*

The discrepancy between the Bureau of the Census and the tonnage producers reported as exports probably resulted because some shipments of clays may be classified under a nonspecific mineral category by the Bureau of the Census. Shipments classified under the nonspecific mineral category would not appear in the Bureau of the Census' ball clay export statistics.

Approximately 93% of the ball clay imported was from the United Kingdom. Imports decreased slightly to 687 tons valued at $228,000. *(See table 24.)*

Bentonite.—Bentonite exports increased slightly to 606,000 tons valued at $55.4 million. Bentonite was exported to 60 countries with Japan and Canada accounting for 55% of the exports. Domestic bentonite producers reported exports of 431,241 tons, 175,000 tons less than that reported by the Bureau of the Census. This discrepancy is partially explained by the inclusion of an estimated 100,000 tons of bentonite for Canadian iron ore pelletizing under domestic sales. The largest markets for exported bentonite were foundry sand (61%) and drilling mud (21%). Other major export markets were absorbent, decolorizing and clarifying animal oils, desiccant, paint, and refractories. *(See tables 6 and 23.)*

Bentonite imports consisted mainly of untreated bentonite clay and chemically or artificially activated materials. Imports of untreated bentonite decreased 21% to 1,994 tons valued at $664,000. Most of this material was imported from Canada (47%). Imports of chemically activated material decreased 14% to 12,922 tons valued at $10.7 million. Mexico supplied 77% of the chemically activated bentonite imported into the United States. *(See table 24.)*

Fire Clay.—Exports of fire clay decreased 35% to 148,000 tons valued at $14.8 million. Fire clay was exported to 30 countries. The major importers were Japan, Mexico, and the Netherlands. These countries accounted for 68% of the exports. According to the Bureau of the Census, 1,096 tons of fire clay valued at $282,000 was imported in 1993. Most of the fire clay was imported from the Philippines (48%). *(See tables 23 and 24.)*

Fuller's Earth.—Exports of fuller's earth were 63,000 tons valued at $7.6 million. Fuller's earth was exported to 44 countries. The major importers were Canada (14%) and the Netherlands (25%). Domestic producers reported more than 137,818 tons exports in 1993. *(See table 12.)* As with ball clay, the discrepancy between the producers' and the Bureau of the Census' statistics is probably one of clay classification (see discussion under Ball Clay). The major market for exported fuller's earth was pet waste absorbents. Other markets were ceramic tile, foundry sand, cosmetics, oil and grease absorbents, paint, and pesticide carriers. Small amounts of decolorizing fuller's earth (101 tons) were imported from Canada and Germany. *(See tables 12, 23, and 24.)*

Kaolin.—Exports of kaolin reported by the Bureau of the Census were essentially unchanged at 3 million tons valued at $488 million. Kaolin was exported to 69 countries. Major importers were Japan, Canada, Finland, Italy, and the Netherlands. Major end-use markets reported by producers were paper coating (76%) and paper filling (13%). *(See tables 20 and 23.)* Other major markets included paint and rubber.

Kaolin imports for consumption increased 81% to 7,622 tons valued at $3.5 million. The United Kingdom supplied 78% of the kaolin imports. *(See table 24.)*

World Review

World production of kaolin increased 8%, bentonite production decreased 4%, and fuller's earth production increased slightly from productions of 1993. *(See tables 25, 26, and 27, respectively.)*

Australia.—Browns Creek Gold NL continued evaluating a sodium bentonite deposit in New South Wales. The deposit consists of flat to gently dipping beds that are 2 to 10 meters in thickness, extending over an area of at least 6 kilometers by 1 kilometer. Additional drilling is proposed to further delineate the deposit.[20]

Venture Exploration NL began evaluating a kaolin deposit in northern Queensland. The deposit has proven resources of 27 million tons.[21]

Brazil.—The proposed kaolin mine in Rio Capim Quimica remained under study. The mine, which was proposed as a joint venture by Rio Capim Quimica Companhia Vale do Rio Doce and Caemi Mineracao e Metalurgia SA, is in northern Brazil. The kaolin deposit has measured reserves of 40 million tons and estimated reserves of 150 million tons. The companies will focus sales on the papermaking markets in Europe and Asia. The major focus of concern is the environmental impact that the mine and slurry pipeline could have on what is considered to be an environmentally sensitive jungle region.

Canada.—Lang Bay Resources continued its evaluation of a kaolin deposit near Powell River, British Columbia. The company has produced paper-grade kaolin in pilot studies and is looking into local paper markets.[22]

OUTLOOK

U.S. clay demand between 1982 and 1993 has rebounded slowly from 32 million tons to 44 millon tons. This is well below the levels of the early 1970's. In general, there has been a decrease in construction activity in the public, private, and commercial sectors due to a slow economy. Demand for common clay and shale, which are strongly tied to the construction industry, has declined over the past 10 years. Kaolin, ball clay, and fuller's earth have fared better than their common clay and shale counterparts because they are used in more diversified applications and industries. Domestic demand for specialty clays should remain strong in the near future.

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TABLE 1
SALIENT U.S. CLAY STATISTICS[1]

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
Domestic clays sold or used by producers:					
Quantity	42,254	42,904	41,017	[r]40,237	41,074
Value	$1,515,300	$1,619,824	$1,455,816	[r]$1,470,050	$1,487,474
Exports:					
Quantity	3,755	4,123	3,997	4,158	4,154
Value	$550,343	$584,404	$590,174	$663,478	$669,520
Imports for consumption:					
Quantity	28	30	35	41	39
Value	$10,928	$11,988	$13,249	$15,503	$17,564

[r] Revised.

[1] Excludes Puerto Rico.

TABLE 2

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay•	Bent-onite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total	Total value
Alabama	—	W	2,105	71	—	316	2,492	23,195
Arizona	—	W	97	—	—	—	97	451
Arkansas	—	—	796	W	—	230	1,026	2,357
California	—	140	1,690	—	W	131	1,961	26,482
Colorado	—	(2)	280	(2)	—	1	281	2,158
Connecticut	—	—	W	—	—	—	W	W
Florida	—	—	W	—	407	W	407	52,699
Georgia	—	—	1,675	W	641	7,443	9,759	995,013
Idaho	—	—	W	—	—	—	W	W
Illinois	—	—	477	—	W	—	477	1,086
Indiana	W	—	600	—	—	—	600	2,540
Iowa	—	—	358	—	—	—	358	1,667
Kansas	—	—	513	—	W	—	513	1,965
Kentucky	W	—	768	—	—	—	768	3,057
Louisiana	—	—	375	—	—	—	375	496
Maine	—	—	W	—	—	—	W	W
Maryland	—	—	294	—	—	—	294	705
Massachusetts	—	—	W	—	—	—	W	W
Michigan	—	—	1,234	—	—	—	1,234	4,848
Minnesota	—	—	W	—	—	W	W	W
Mississippi	67	152	537	—	344	—	1,100	38,228
Missouri	—	—	976	208	W	—	1,184	7,737
Montana	—	W	W	W	—	—	W	W
Nebraska	—	—	192	—	—	—	192	932
Nevada	—	16	—	—	W	W	16	3,434
New Hampshire	—	—	3	—	—	—	3	16
New Jersey	—	—	W	W	—	—	W	W
New Mexico	—	—	32	1	—	—	33	101
New York	—	—	508	—	—	—	508	9,250
North Carolina	—	—	2,381	—	—	W	2,381	11,165
North Dakota	—	—	W	—	—	—	W	W
Ohio	W	—	2,019	142	—	—	2,161	12,023
Oklahoma	—	—	613	—	—	—	613	2,938
Oregon	—	24	197	—	—	—	221	1,410
Pennsylvania	—	—	754	—	—	11	765	3,777
South Carolina	—	—	1,005	—	—	534	1,539	31,304
South Dakota	—	—	W	—	—	—	W	W
Tennessee	607	W	W	—	W	—	607	25,703
Texas	W	W	2,183	—	W	W	2,183	17,441
Utah	—	W	216	—	W	—	216	3,129
Virginia	—	W	775	—	W	—	775	2,950
Washington	—	—	238	W	—	—	238	1,373

See footnotes at end of table.

TABLE 2—Continued

CLAYS SOLD OR USED BY PRODUCERS IN THE UNITED STATES[1] IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Ball clay[e]	Bent-onite	Common clay and shale	Fire clay	Fuller's earth	Kaolin	Total	Total value
West Virginia	—	—	115	—	—	—	115	334
Wyoming	—	2,407	W	—	—	—	2,407	73,399
Undistributed	275	354	1,127	37	1,091	291	3,175	122,111
Total	949	3,093	25,133	459	2,483	8,957	41,074	1,487,474

[e] Estimated. W Withheld to avoid disclosing company proprietary data; included with "Undistributed."

[1] Excludes Puerto Rico.

[2] Less than 1/2 unit.

TABLE 3

BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Airfloat		Water-slurried		Unprocessed		Total[1]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1992								
Tennessee	307	13,813	103	5,101	164	5,183	574	24,097
Other[2]	128	6,857	—	—	152	5,277	280	12,133
Total	435	20,670	103	5,101	316	10,460	854	36,230
1993[e]								
Tennessee	232	12,179	138	5,862	236	7,662	607	25,703
Other[2]	167	8,106	—	—	176	5,946	342	14,052
Total	399	20,285	138	5,862	412	13,608	949	39,755

[e] Estimated.

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

[2] Includes Indiana, Kentucky, Mississippi, Ohio (1993), and Texas.

TABLE 4
BALL CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Filler, extenders, and binders[1]	133,137	172,865
Floor and wall tile	202,029	204,676
Miscellaneous ceramics[2]	33,275	39,798
Pottery	113,944	115,825
Refractories[3]	36,075	41,974
Sanitaryware	173,823	185,237
Miscellaneous[4]	61,868	72,790
Exports[5]	99,678	116,085
Total	853,829	949,250

[1] Includes adhesives, animal feed, asphalt tile, paint, paper filling, plastics, rubber, asphalt emulsions, wallboard, and other filler, extenders, and binders.

[2] Includes electrical procelain, fine china/dinnerware, and miscellaneous ceramics.

[3] Includes firebrick, blocks, and shape, high-alumina brick and specialties, kiln furniture, and other uses unknown.

[4] Includes heavy clay products, absorbents, waterproofing seals, brick (common), flue lining, and other uses unknown.

[5] Includes ceramics and glass, fillers, extenders and binders, floor and wall tile, refractories, and other uses unknown.

TABLE 5
BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Nonswelling		Swelling		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1992						
Alabama and Mississippi	330	10,669	—	—	330	10,669
California	W	W	W	W	143	13,069
Colorado	(1)	9	—	—	(1)	9
Nevada	W	W	W	W	14	3,442
Oregon	W	W	W	W	19	873
Wyoming	—	—	[r]2,134	[r]71,450	[r]2,134	[r]71,450
Other[2]	207	15,029	[r]283	[r]16,586	[r]314	14,231
Total	537	25,707	[r]2,417	[r]88,036	[r]2,954	[r]113,743
1993						
Alabama and Mississippi	152	5,310	—	—	152	5,310
California	W	W	W	W	140	13,099
Colorado	(1)	6	—	—	(1)	6
Nevada	W	W	W	W	16	3,434
Oregon	W	W	W	W	24	1,112
Wyoming	—	—	2,407	73,399	2,407	73,399
Other[2]	321	17,634	212	15,975	354	15,952
Total[3]	473	22,944	2,619	89,374	3,093	112,312

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Less than 1/2 unit.

[2] Includes Alabama (1993), Arizona, Montana, Tennessee, Texas, Utah, Virginia, and items indicated by symbol W.

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

TABLE 6
BENTONITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Domestic:		
Absorbents:		
Pet waste absorbents	[r]148,349	302,055
Other absorbents[1]	[r]145,801	66,436
Adhesives	8,804	5,835
Animal feed	[r]112,478	94,333
Ceramics (except refractories)[2]	31,324	25,805
Drilling mud	[r]481,874	528,424
Filler and extender applications[3]	30,259	28,441
Filtering, clarifying, decolorizing:		
Animal oils, minerals oils and greases, and vegetable oils	116,157	13,678
Foundry sand	[r]487,287	803,420
Pelletizing (iron ore)	[r]505,506	486,716
Miscellaneous refractories and kiln furniture[4]	47,001	69,485
Miscellaneous[1]	243,638	46,038
Waterproofing and sealing	[r]176,224	191,050
Total	[r]2,534,702	2,661,716
Exports:		
Drilling mud	[r]71,994	90,440
Foundry sand	[r]276,549	264,354
Other[5]	[r]70,909	76,447
Total	[r] [6]419,451	431,241
Grand total	[r] [6]2,954,154	3,092,957

[r] Revised.

[1] Includes data that was withheld in 1992, by kind.

[2] Includes catalysts (oil-refinings), glazes, glass, and enamels, mineral wools and insulation, and pottery.

[3] Includes fertilizers, medical, pharmaceutical, cosmetics, paint, paper coating, pesticides and related products, plastics, rubber, asphalt emulsions, and miscellaneous filler and extender applications.

[4] Includes firebrick, blocks, and shapes, plugs, taps, wads, and miscellaneous refractories.

[5] Includes absorbents, ceramics and glass, waterproofing seals, fillers, extenders and binders, animal oils, desiccants, and other uses unknown.

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

TABLE 7
COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Alabama	2,007	15,292	2,105	15,659
Arizona	102	463	97	451
Arkansas	837	2,972	796	2,357
California	1,635	8,146	1,690	8,431
Colorado	242	1,787	280	2,146
Connecticut and New Jersey	155	1,944	198	2,267
Georgia	1,484	15,312	1,675	11,559
Illinois	535	2,362	477	1,086
Indiana	842	3,016	600	2,540
Iowa	[r]331	[r]1,530	358	1,667
Kansas	544	3,921	513	1,965
Kentucky	760	3,777	768	3,057
Louisiana	384	3,589	375	496
Maine and Massachusetts	48	248	54	296
Maryland	227	980	294	705
Michigan	1,265	4,345	1,234	4,848
Mississippi	575	6,170	537	4,475
Missouri	1,018	4,449	976	3,820
Montana	35	101	W	W
Nebraska	183	879	192	932
New Mexico	33	79	32	101
New York	415	2,412	508	9,250
North Carolina	2,120	9,775	2,381	11,165
Ohio	2,180	8,804	2,019	7,887
Oklahoma	622	3,296	613	2,938
Oregon	203	326	197	298
Pennsylvania	633	2,531	754	3,119
Puerto Rico	W	527	155	508
South Carolina	[r]1,068	[r]3,030	1,005	4,499
South Dakota and Wyoming	129	634	165	767
Texas	2,237	[r]12,610	2,183	17,441
Utah	243	2,714	216	3,129
Virginia	753	3,367	775	2,950
Washington	306	1,889	238	1,373
West Virginia	80	221	115	334
Other[1]	[r]830	[r]3,011	713	2,357
Total[2]	[r]25,062	[r]136,510	25,286	136,873

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Includes Florida, Idaho, Minnesota, Montana (1993), New Hampshire, North Dakota, and Tennessee.

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

TABLE 8

COMMON CLAY AND SHALE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Ceramics and glass[1]	[r]173,251	159,470
Civil engineering and sealing	84,064	84,246
Floor and wall tile:		
Ceramic	[r]404,277	274,218
Other[2]	[r]63,476	100,415
Heavy clay products:		
Brick, extruded	[r]10,251,543	10,909,565
Brick, other	1,603,858	1,453,597
Drain tile and sewer pipe	[r]138,146	142,207
Flowerpots	44,568	35,667
Flue linings	52,113	55,277
Structural tile	36,108	35,005
Other[3]	[r]561,828	581,596
Lightweight aggregate:		
Concrete block	2,113,910	2,214,950
Highway surfacing	252,503	243,277
Structural concrete	[r]723,352	786,786
Miscellaneous[4]	309,868	286,220
Portland and other cements	[r]7,862,445	7,539,952
Refractories[5]	99,518	152,790
Miscellaneous[6]	[r]287,149	230,799
Total	[r]25,061,977	25,286,037

[r] Revised.

[1] Includes crockery/earthenware, pottery, roofing granules, and abrasives.

[2] Includes quarry tile and miscellaneous floor and wall tiles.

[3] Includes roofing tile, terra cotta, and miscellaneous clay products.

[4] Includes miscellaneous lightweight aggregates.

[5] Includes firebrick, blocks and shapes, and miscellaneous refractories.

[6] Includes manufacturing, pelletizing (iron ore), exports, and other uses unknown.

TABLE 9

FIRE CLAY[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Alabama	[r]71	[r]2,962	71	2,861
Missouri	178	3,878	208	3,917
Ohio	108	3,258	142	4,136
Other[2]	[r]25	[r]340	37	621
Total[3]	[r]383	[r]10,438	459	11,536

[r] Revised.

[1] Refractory uses only.

[2] Includes Arkansas, Colorado, Georgia, Montana, New Jersey, New Mexico, and Washington.

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

TABLE 10

FIRE CLAY SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Ceramics and glass[1]	16,285	19,146
Heavy clay products and lighweight aggregates[2]	[r]71,329	43,711
Refractories:		
Firebrick, block and shapes	169,873	235,766
Other refractories[3]	[r]103,079	129,706
Miscellaneous	[r]22,804	31,090
Exports	W	W
Total	[r]383,370	459,419

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous."

[1] Includes glazes, glass and enamels, and pottery.

[2] Includes brick (common), portland cement, terra cotta, highway surfacing, and other uses unknown.

[3] Includes foundry sand, grogs and calcines, high-alumina brick and specialties, and other uses unknown.

TABLE 11

FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Attapulgite		Montmorillonite		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1992						
Florida	332	33,767	(1)	(1)	332	33,767
Georgia	591	76,665	(1)	(1)	591	76,665
Southern States[2]	—	—	575	41,747	575	41,747
Western States[3]	(4)	(4)	[r]906	89,448	[r]906	89,448
Total[5]	[r]932	[r]110,432	[r]1,481	[r]131,195	2,413	241,627
1993						
Florida	407	52,699	(1)	(1)	407	52,699
Georgia	641	79,082	(1)	(1)	641	79,082
Southern States[2]	—	—	472	34,154	472	34,154
Western States[3]	(4)	(4)	963	63,685	963	63,685
Total	1,048	131,781	1,435	97,839	2,483	229,620

[r] Revised.

[1] Included under attapulgite.

[2] Includes Mississippi, Tennessee, and Virginia.

[3] Includes California, Illinois, Kansas, Missouri, Nevada, Texas, and Utah.

[4] Included under montmorillonite.

[5] Data may not add to totals shown because of independent rounding and/or proprietary coverage of individual kinds.

TABLE 12
FULLER'S EARTH SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Absorbents:		
Oil and grease absorbent	407,051	259,091
Pet waste absorbent	1,414,895	1,469,035
Miscellaneous absorbent	41,185	42,738
Animal feed	37,772	90,510
Drilling mud	30,862	30,117
Fertilizers	74,424	89,702
Fillers, extenders, binders[1]	59,797	70,784
Filtering, clarifing, decolorizing:		
Animal, mineral, and vegetable oils, and greases	36,754	35,147
Pesticides and related products	172,954	190,908
Miscellaneous[2]	55,826	67,971
Exports[3]	81,933	137,818
Total	2,413,453	2,483,821

[1] Includes adhesives, asphalt tiles, gypsum products, medical, pharmaceutical and cosmetics, paint, plastics, asphalt emulsions, and other uses unknown.

[2] Includes catalysts (oil-refining), electrical porcelain, roofing granules, chemical manufacturing, heavy clay products, lightweight aggregates, refractories, and other uses unknown.

[3] Includes absorbents, fillers, extenders and binders, floor and wall tiles, refractories, and other uses unknown.

TABLE 13
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Arkansas	W	W	230	W
California	128	4,958	131	4,952
Florida	35	3,434	W	W
Georgia	[r]7,387	[r]881,678	7,443	904,372
South Carolina	523	24,547	534	26,805
Other[1]	[r]662	[r]17,411	619	21,757
Total	[r]8,735	[r]932,028	8,957	957,886

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

[1] Includes Alabama, Colorado (1993), Minnesota, Nevada, North Carolina, Pennsylvania, Texas, and items indicated by symbol W.

TABLE 14
KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1992		1993	
	Quantity	Value	Quantity	Value
Airfloat	1,120	59,472	1,177	67,060
Calcined[1]	[r]1,426	[r]242,109	1,570	248,270
Delaminated	1,257	143,031	1,226	140,301
Unprocessed	720	14,082	782	13,390
Water-washed	4,212	473,334	4,202	488,864
Total	[r]8,735	[r]932,028	8,957	957,886

[r] Revised.

[1] Includes both low-temperature filler and high-temperature refractory grades.

TABLE 15
CALCINED KAOLIN SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	High-temperature		Low-temperature	
	Quantity	Value	Quantity	Value
1992				
Alabama and Georgia	W	W	W	W
Other[1]	[r]1,230	[r]162,420	[r]196	[r]79,689
Total	[r]1,230	[r]162,420	[r]196	[r]79,689
1993				
Alabama and Georgia	1,249	214,836	W	W
Other	238	5,680	83	27,754
Total	1,487	220,516	83	27,754

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

[1] Includes Alabama, Arkansas, California, Georgia, Pennsylvania, and South Carolina.

TABLE 16
GEORGIA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1992		1993	
	Quantity	Value	Quantity	Value
Airfloat	685	30,001	720	35,370
Calcined[1]	[r]1,086	[r]229,685	1,091	233,517
Delaminated	1,257	143,031	1,226	140,301
Unprocessed	190	6,953	249	7,842
Water-washed	4,169	472,008	4,157	487,343
Total	[r]7,387	[r]881,678	7,443	[2]904,372

[r] Revised.

[1] Includes low-temperature filler and high-temperature refractory grades.

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

TABLE 17
GEORGIA KAOLIN[1] SOLD OR USED BY PRODUCERS, BY USE

(Metric tons)

Use	1992	1993
Domestic:		
Ceramics and glass:		
Catalysts (oil-refining)	44,591	155,789
Electrical porcelain	11,636	10,562
Fiber glass	259,179	255,590
Roofing granules	W	11,812
Sanitaryware	W	46,504
Other[2]	165,539	80,274
Fillers, extenders, and binder:		
Adhesives	58,943	56,607
Paint	199,123	211,210
Paper coating	2,675,276	2,512,890
Paper filling	[r]1,157,105	941,390
Plastic	29,505	28,154
Rubber	51,117	77,958
Other[3] [4]	165,915	53,215
Heavy clay products[5]	52,989	58,151
Refractories[6]	580,043	570,435
Undistributed[7]	176,707	203,063
Total	[r]5,627,668	5,273,604
Exports:		
Paint	26,764	74,959
Paper coating	1,357,724	1,683,235
Paper filling	200,639	279,888
Rubber	17,250	4,497
Undistributed[8]	156,562	127,017
Total	1,758,939	2,169,596
Grand total	[r]7,386,607	[9]7,443,201

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Undistributed."

[1] Includes high-temperature calcined, low-temperature calcined, and delaminated.

[2] Includes crockery/earthenware, fine china/dinnerware, glazes, glass, and enamels, pottery, roofing granules (1992), sanitaryware (1992), and miscellaneous ceramics.

[3] Includes asphalt tile, fertilizers, gypsum products, medical, pharmaceutical and cosmetics, pesticides and related products, textiles and miscellaneous fillers, extenders, and binders.

[4] Includes data withheld in 1992 for paint and plastic.

[5] Includes brick (common and face), flue lining, portland cement, and miscellaneous clay products.

[6] Includes firebrick, blocks and shapes, grogs and calcines, high-alumina, kiln furniture, and miscellaneous refractories.

[7] Includes chemical manufacturing, civil engineering and sealings, drilling mud, filtering, clarifying, and decolorizing, floor and wall tiles, and other uses unknown.

[8] Includes fiber glass, sanitaryware, ink, miscellaneous fillers, extenders and binders, and other uses unknown.

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

TABLE 18
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND

(Thousand metric tons and thousand dollars)

Kind	1992		1993	
	Quantity	Value	Quantity	Value
Airfloat	370	23,728	391	25,903
Unprocessed	154	819	143	902
Total	[r] [1]523	24,547	534	26,805

[r] Revised.

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

TABLE 19
SOUTH CAROLINA KAOLIN SOLD OR USED BY PRODUCERS, BY KIND AND USE

(Metric tons)

Kind and use	1992	1993
Airfloat:		
Adhesives	W	W
Animal feed and pet waste absorbent	W	W
Ceramics[1]	2,939	3,435
Fertilizers, pesticides and related products	8,018	6,821
Fiber glass	W	W
Paint	W	W
Paper coating and filling	4,473	W
Plastics	W	W
Rubber	164,728	165,182
Refractories[2]	W	W
Other uses[3]	159,435	185,393
Exports[4]	30,111	30,627
Total	369,704	391,458
Unprocessed: Face brick and other uses	153,672	142,697
Grand total	523,376	534,155

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

[1] Includes crockery and earthenware, electrical porcelain, fine china/dinnerware, floor and wall tile, pottery, and roofing granules.

[2] Includes refractory calcines and grogs, firebrick, blocks and shapes, refractory mortar and cement, and high-alumina refractories.

[3] Includes animal oil, catalysts (oil refining), chemical manufacturing, ink, medical, sewer pipe, and unknown uses.

[4] Includes ceramics, adhesives, paper filling, pesticides and related products, and rubber.

TABLE 20
KAOLIN[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Metric tons)

Use	1992	1993
Domestic:		
Ceramics:		
Catalyst (oil and gas refining)	[r]46,809	224,359
Electrical porcelain	11,636	16,767
Fine china and dinnerware	15,194	10,393
Floor and wall tile	45,054	11,824
Pottery	23,756	24,123
Roofing granules	10,914	12,234
Sanitaryware	41,321	48,316
Miscellaneous	179,735	157,823
Chemical manufacture	167,484	145,694
Civil engineering	W	20,497
Glass fiber, mineral wool	379,176	346,829
Filler, extender, and binder:		
Adhesive	[r]69,538	69,167
Fertilizer	6,206	W
Medical, pharmaceutical cosmetic	1	1
Paint	242,000	242,192
Paper coating	2,674,908	2,512,890
Paper filling	1,144,302	947,212
Pesticide	12,310	15,839
Plastic	49,061	28,181
Rubber	215,849	243,144
Miscellaneous	169,947	62,736
Heavy clay products:		
Brick, common and face	218,810	223,148
Miscellaneous	18,314	6,532
Portland cement	179,320	207,232
Refractories:		
Firebrick, block and shapes	21,178	48,605
Grogs	[r]859,450	938,304
High alumina brick, specialties, and kiln furniture	31,390	34,496
Foundry sand, mortar, cement, and miscellaneous refractories	62,153	67,504
Miscellaneous applications	32,571	72,111
Total	[r]6,928,387	6,738,153
Exports:		
Ceramics	103,279	63,922
Foundry sand, grogs and calcines; other refractories	W	W
Paint	26,764	75,060
Paper coating	1,402,484	1,683,235
Paper filling	200,874	279,903
Rubber	47,361	35,123
Miscellaneous	26,055	82,169
Total	1,806,817	2,219,412
Grand total	[r]8,735,204	8,957,565

[r] Revised. W Withheld to avoid disclosing proprietary data; included with "Miscellaneous applications" or "Miscellaneous."

[1] Includes high-temperature calcined, low-temperature calcined, and delaminated kaolin.

TABLE 21

COMMON CLAY AND SHALE USED IN LIGHTWEIGHT AGGREGATE PRODUCTION IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	Concrete block	Structural concrete	Highway surfacing	Other	Total[1]	Total value
1992						
Alabama and Arkansas	670	88	14	13	785	10,427
California	87	75	—	7	169	696
Florida and Indiana	132	36	—	38	206	1,619
Kansas, Kentucky, Louisiana	295	128	—	55	478	1,078
Mississippi and Missouri	15	1	2	103	121	1,387
New York and Montana	179	92	—	—	271	1,683
North Carolina	245	82	—	—	327	3,696
Ohio, Oklahoma, Pennsylvania	173	36	5	19	233	1,808
Texas	49	157	222	31	459	2,518
Utah and Virginia	269	29	9	43	350	3,434
Total[1]	2,114	724	253	310	3,400	28,348
1993						
Alabama and Arkansas	751	77	17	1	846	11,284
California	76	102	—	45	223	755
Florida and Indiana	125	34	—	—	159	1,495
Kansas, Kentucky, and Louisiana	295	128	—	70	493	1,115
Mississippi and Missouri	15	1	2	90	109	1,218
New York and Montana	192	182	—	—	374	8,484
North Carolina	301	52	—	8	360	4,045
Ohio, Oklahoma, and Pennsylvania	162	31	—	—	193	1,347
Texas	49	157	222	31	459	2,518
Utah and Virginia	251	22	2	42	316	3,834
Total[1]	2,215	787	243	286	3,531	36,095

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

TABLE 22
COMMON CLAY AND SHALE USED IN BUILDING BRICK PRODUCTION IN THE UNITED STATES, BY STATE[1]

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Alabama	825	3,548	798	2,720
Arizona[2] and New Mexico[2]	[r]69	192	69	200
Arkansas	395	894	423	888
California	323	1,389	313	1,492
Colorado	215	[r]1,749	260	2,059
Connecticut, New Jersey,[2] New York[2]	299	2,652	329	3,009
Georgia	1,041	12,857	1,201	8,997
Idaho, Washington, Wyoming[2]	236	[r]1,887	168	1,372
Illinois	454	1,687	437	546
Indiana and Iowa	[r]268	[r]1,533	263	1,483
Kansas	125	[r]513	106	357
Kentucky[2] and Tennessee[2]	738	3,508	790	1,923
Louisiana	89	3,165	80	72
Maine, Massachusetts,[2] New Hampshire[2]	54	288	W	W
Maryland and West Virginia[3]	205	828	289	612
Michigan[2] and Minnesota[2]	119	415	120	420
Mississippi and Missouri	504	[r]2,644	486	1,863
Nebraska and North Dakota[2]	144	438	138	462
North Carolina	1,776	6,017	1,933	6,026
Ohio	978	[r]5,168	911	4,369
Oklahoma	273	1,403	290	1,460
Oregon	28	95	28	95
Pennsylvannia	523	1,947	637	2,459
South Carolina	[r]668	[r]1,770	599	3,408
Texas	896	[r]6,220	1,038	7,448
Utah[2]	70	376	70	376
Virginia	541	2,185	562	1,768
Total[4]	[r]11,855	[r]65,369	12,339	55,880

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

[1] Includes extruded and other brick.

[2] Extruded brick only.

[3] Other brick only.

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

TABLE 23
U.S. EXPORTS OF CLAYS IN 1993, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	Ball clay		Bentonite		Fire clay		Fuller's earth		Kaolin		Clays, n.e.c.[1]		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Argentina	4	177	(2)	58	(2)	23	—	—	8	1,663	1	155	13	2,076
Australia	(2)	4	29	2,147	15	1,200	—	—	12	4,567	2	2,213	58	10,131
Belgium	—	—	5	1,609	—	—	(2)	43	43	10,191	1	2,165	49	14,008
Bolivia	—	—	(2)	9	—	—	—	—	(2)	10	(2)	354	(2)	373
Brazil	(2)	19	16	1,302	(2)	11	(2)	19	2	893	2	3,054	20	5,298
Canada	—	—	143	11,881	7	1,110	9	1,000	537	71,343	148	26,814	844	112,148
Chile	(2)	87	1	206	—	—	(2)	4	11	3,466	(2)	498	12	4,261
China	—	—	2	339	(2)	59	—	—	8	2,342	3	2,881	13	5,621
Colombia	—	—	1	220	—	—	(2)	41	12	3,307	(2)	431	13	3,999
Costa Rica	1	144	—	—	(2)	9	(2)	12	1	205	1	408	3	778
Denmark	—	—	1	198	—	—	(2)	21	(2)	35	—	—	1	254
Dominican Republic	(2)	38	(2)	94	—	—	(2)	4	1	180	1	165	2	481
Ecuador	(2)	14	2	203	—	—	(2)	55	4	440	1	345	7	1,057
Egypt	—	—	(2)	193	(2)	27	(2)	17	—	—	1	285	1	522
El Salvador	—	—	1	79	—	—	5	364	1	89	1	286	8	818
Finland	(2)	3	(2)	86	—	—	(2)	22	419	61,065	6	505	425	61,681
France	—	—	39	2,279	1	163	(2)	50	8	1,759	2	793	50	5,044
Germany	3	70	19	1,554	1	177	(2)	42	61	11,494	3	3,092	87	16,429
Greece	—	—	—	—	—	—	1	144	2	735	(2)	138	3	1,017
Guatemala	3	361	1	114	(2)	37	(2)	44	2	228	(2)	95	6	879
Hong Kong	—	—	1	360	(2)	44	—	—	9	1,899	2	813	12	3,116
India	(2)	3	(2)	46	—	—	1	268	(2)	78	(2)	19	1	414
Indonesia	—	—	2	340	(2)	103	(2)	8	43	7,759	1	1,113	46	9,323
Israel	(2)	3	(2)	101	—	—	(2)	49	(2)	42	(2)	207	(2)	402
Italy	—	—	2	809	(2)	44	(2)	130	169	24,119	2	707	173	25,809
Japan	4	253	191	13,259	30	3,095	(2)	7	775	135,030	6	5,861	1,006	157,505
Korea, Republic of	(2)	21	6	1,473	2	584	(2)	9	127	26,963	6	3,148	141	32,198
Malaysia	—	—	7	432	(2)	7	13	1,886	3	616	3	998	26	3,939
Mexico	40	1,706	5	748	42	3,014	1	132	117	14,043	8	1,540	213	21,183
Netherlands	(2)	22	15	1,405	28	3,420	16	1,252	163	23,207	28	11,119	250	40,425
New Zealand	(2)	5	1	240	5	306	(2)	13	1	372	(2)	433	7	1,369
Norway	—	—	8	489	(2)	7	(2)	3	(2)	95	(2)	116	8	710
Pakistan	(2)	12	(2)	93	—	—	1	113	1	143	4	358	6	719
Peru	—	—	1	77	—	—	—	—	(2)	84	1	276	2	437
Philippines	—	—	2	468	—	—	(2)	51	10	2,155	6	1,278	18	3,952
Saudi Arabia	(2)	3	(2)	9	—	—	(2)	76	(2)	133	(2)	256	(2)	477
Singapore	1	28	12	1,218	—	—	1	251	3	798	1	1,671	18	3,966
South Africa, Republic of	(2)	16	(2)	101	—	—	1	227	22	4,631	1	930	24	5,905
Spain	—	—	(2)	220	3	—	—	—	4	1,396	(2)	110	7	1,726
Sweden	—	—	(2)	212	(2)	12	—	—	109	21,428	11	2,440	120	24,092
Syria	—	—	—	—	—	—	—	—	—	—	(2)	6	(2)	6
Taiwan	(2)	22	33	4,217	13	880	—	—	117	19,643	4	2,129	167	26,891
Thailand	—	—	13	1,334	(2)	93	(2)	3	14	3,852	1	946	28	6,228
United Kingdom	—	—	20	2,738	1	121	7	623	130	15,916	13	12,058	171	31,456
Venezuela	3	147	18	1,397	(2)	41	(2)	56	18	3,271	14	3,938	53	8,850
Other	1	39	9	1,035	—	255	7	593	17	6,368	8	3,257	40	11,547
Total[3]	60	3,197	606	55,392	148	14,842	63	7,632	2,984	488,053	293	100,404	4,154	669,520

[1] Also includes chamotte or dinas earth, activated clays and earths, and artifically activated clays.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 24

U.S. IMPORTS FOR CONSUMPTION OF CLAY IN 1993, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
China clay or kaolin:		
Belgium	18	$7
Canada	124	141
China	172	78
Germany	93	62
Italy	50	41
Japan	39	28
Netherlands	19	6
New Zealand	1,179	674
Norway	3	2
United Kingdom	5,925	2,422
Total	7,622	3,461
Fire clay:		
Canada	165	35
Dominican Republic	5	3
Germany	180	117
Mexico	9	14
Philippines	524	7
United Kingdom	213	106
Total	1,096	282
Decolorizing earths and fuller's earth:		
Canada	46	10
Germany	54	16
Japan	1	3
Total	101	29
Bentonite:		
Canada	935	338
France	3	8
Germany	51	36
Japan	323	37
Mexico	273	48
Morocco	18	10
Netherlands	9	4
Switzerland	2	7
United Kingdom	340	171
Venezuela	40	5
Total	1,994	664
Common blue clay and other ball clay:		
Canada	6	9
China	1	2
Germany	19	7
Netherlands	21	7
United Kingdom	640	203
Total	687	228
Other clay:		
Belgium	22	10
Canada	172	132
China	52	17

See footnotes at end of table.

TABLE 24—Continued

U.S. IMPORTS FOR CONSUMPTION OF CLAY IN 1993, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
Other clay—Continued:		
Dominican Republic	3	2
France	3	12
Germany	120	90
Italy	203	80
Japan	7	18
Korea, Republic of	1	2
Netherlands	20	2
South Africa, Republic of	59	53
Taiwan	10	5
Thailand	25	16
United Kingdom	1,775	1,070
Venezuela	22	5
Total	2,494	1,514
Chamotte or dina's earth:		
Canada	5	2
China	12,486	706
France	1	3
Germany	22	18
Total	12,514	729
Artificially activated clay and activated earth:		
Austria	12	16
Belgium	19	20
Canada	450	281
France	7	12
Germany	2,206	6,365
India	1	2
Italy	5	7
Japan	42	210
Korea, Republic of	1	8
Mexico	9,947	3,582
Netherlands	167	50
Switzerland	1	5
United Kingdom	18	91
Venezuela	46	8
Total	12,922	10,657
Grand total	39,430	17,564

Source: Bureau of the Census.

TABLE 25

BENTONITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Algeria[3]	39,200	33,700	25,803	[r] [e]30,000	30,000
Argentina	[r]89,189	[r]123,254	[r]135,569	[r]81,534	90,000
Australia[e] [3]	35,000	35,000	35,000	35,000	35,000
Bosnia and Herzegovina	—	—	—	[r] [e]1,000	800
Brazil (beneficiated)	[r]188,260	[r]179,646	[r]130,000	[r] [e]130,000	130,000
Burma	711	416	[e]600	[e]500	300
Chile	2,005	[r]1,207	1,054	[r]1,008	950
Croatia	—	—	—	[r] [e]10,000	10,000
Cyprus	59,744	82,000	58,500	[r]58,840	60,000
Egypt	3,512	4,904	[e]4,900	[e]4,900	4,900
France[e]	[r]5,000	10,000	10,000	[r] [4]6,000	5,000
Germany: Western states	[r]584,898	[r]576,947	[r]582,618	[r]581,169	575,000
Greece	1,096,177	592,864	600,286	[e]600,000	600,000
Guatemala[e]	[4]8,236	[r]9,000	12,000	[r]12,600	12,300
Hungary	59,973	[r]36,600	[r]18,097	[r]23,000	25,000
Indonesia	3,863	5,914	21,512	[r]17,960	20,000
Iran[5]	31,547	51,096	40,452	[r]47,659	50,000
Italy	234,212	228,153	385,000	[e]360,000	300,000
Japan	526,131	549,414	554,145	534,445	518,700
Macedonia	—	—	—	[r] [e]40,000	35,000
Mexico	123,927	144,895	[r]145,347	[r]135,993	[4]127,289
Morocco	3,970	[e]4,000	9,228	[r]8,137	8,100
Mozambique	126	—	[r]664	[r]20	100
New Zealand (processed)	1,342	1,393	—	—	—
Pakistan	5,466	3,235	5,106	[r]6,057	10,000
Peru	[e]40,000	[e]45,000	55,300	[r]14,500	14,500
Philippines	5,961	16,484	[r]42,066	[r]31,896	30,000
Poland	[r]93,000	[r]69,000	[r]38,000	[r] [e]40,000	40,000
Romania[e]	[r]175,000	150,000	[r]150,000	120,000	120,000
Serbia and Montenegro	—	—	—	[r] [e]5,000	5,000
South Africa, Republic of[6]	62,987	66,059	64,600	[r]43,977	40,000
Spain	[r]143,389	151,226	[r] [e]150,000	[e]150,000	150,000
Tanzania[e]	75	75	75	70	70
Turkey	93,256	[r]97,464	[r]123,928	[r]123,516	125,000
U.S.S.R.[e] [7]	2,900,000	2,700,000	2,400,000	2,000,000	1,600,000
United States	3,112,365	3,473,595	[r]3,431,601	[r]2,954,152	[4]3,092,956
Yugoslavia[8]	128,593	102,681	[e]85,000	—	—
Zimbabwe[6]	104,865	99,854	[r] [e]99,900	[r]82,956	83,000
Total	[r]9,961,980	[r]9,645,076	[r]9,416,351	[r]8,291,889	7,948,965

[e] Estimated. [r] Revised.

[1] Table includes data available through July 26, 1994.

[2] In addition to the countries listed, Canada and China are believed to produce bentonite, but output is not reported, and available information is inadequate to make reliable estimates of ouput levels.

[3] Includes bentonitic clays.

[4] Reported figure.

[5] Year beginning Mar. 21 of that stated.

[6] May include other clays.

[7] Dissolved in Dec. 1991; however, information if inadequate to formulate reliable estimates for individual countries.

[8] Dissolved in Apr. 1992.

TABLE 26
FULLER'S EARTH: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Algeria[e]	3,500	4,000	[3]4,526	[r]4,550	4,550
Argentina[e]	2,000	2,000	2,000	1,500	1,600
Australia (attapulgite)[e]	15,000	20,000	15,000	15,000	15,000
Germany: Western states (unprocessed)	636,000	653,000	708,000	[r]673,000	670,000
Italy	43,550	45,800	[r,e]23,000	[r,e]28,000	30,000
Mexico	24,603	29,865	[r]41,078	[r]41,111	[3]41,152
Morocco (smectite)	48,820	45,230	37,552	[e]38,000	38,000
Pakistan	15,436	16,489	22,075	[r]22,042	19,000
Senegal (attapulgite)	98,882	114,610	129,403	[r]112,336	112,000
South Africa, Republic of (attapulgite)	6,609	7,628	8,109	8,235	7,600
Spain (attapulgite)[e]	[3]23,990	[r]30,000	25,000	25,000	20,000
United Kingdom[4]	[e]210,000	[r]204,000	189,000	[e]190,000	200,000
United States[5]	1,881,511	2,307,475	[r]2,740,346	2,413,453	[3]2,453,821
Total	3,009,901	[r]3,480,097	[r]3,945,089	[r]3,572,227	3,612,723

[e]Estimated. [r]Revised.

[1]Excludes centrally planned economy countries and former such countries, some of which presumably produce fuller's earth, but for which no information is available. Table includes data available through July 26, 1994.

[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]Salable product.

[5]Sold or used by producers.

TABLE 27

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993•
Algeria	18,000	18,000	21,460	21,500	21,500
Argentina	45,598	[r]72,421	[r]145,098	[r]90,545	90,600
Australia• (includes ball clay)	185,000	200,000	190,000	180,000	180,000
Austria (marketable)	85,312	81,265	•80,000	[r]•65,000	65,000
Bangladesh[3]	7,092	7,223	7,338	•7,300	7,500
Belgium	[r]165,520	[r]•175,000	[r]260,000	[r]•325,000	300,000
Bosnia and Herzegovina	—	—	—	[r]3,000	3,000
Brazil (beneficiated)	714,647	658,927	746,000	[r]750,000	750,000
Bulgaria	[r]203,000	186,467	[r]106,000	[r]110,000	110,000
Burundi	4,305	5,281	6,682	[r]9,688	5,000
Chile	58,512	32,416	[r]63,063	[r]58,937	60,000
Colombia•	540,000	540,000	900,000	900,000	900,000
Czech Republic[4]	—	—	—	—	2,500,000
Czechoslovakia[5] (marketable)	698,000	872,000	705,000	•700,000	—
Denmark (sales)	[r]•15,900	17,423	[r]17,057	[r]3,503	3,500
Ecuador	[r]14,660	[r]7,883	[r]16,217	[r]6,835	7,000
Egypt	121,515	49,032	192,870	•190,000	190,000
Ethiopia (including Eritrea)• [6]	390	670	370	[r]420	500
France (marketable)[7]	346,000	•367,000	•360,000	[r]334,000	325,000
Germany:					
Eastern states (marketable)•	[r]308,000	200,000	—	—	—
Western states (marketable)	[r]737,645	[r]684,183	—	—	—
Total•	[r]1,045,645	[r]884,183	[r]683,505	[r]663,782	650,000
Greece	67,234	169,986	189,235	•100,000	100,000
Guatemala	2,573	2,050	3,281	[r]2,863	3,000
Hungary (processed)	[r]47,175	[r]28,600	[r]14,127	[r]•15,000	16,000
India:					
Salable crude	[r]520,000	631,000	628,000	•625,000	650,000
Processed	110,505	104,000	113,000	•110,000	150,000
Indonesia	157,122	160,098	139,915	[r]230,550	220,000
Iran	•150,000	•150,000	150,473	[r]264,083	280,000
Israel	31,245	42,212	•53,000	•53,000	53,000
Italy:					
Crude	64,196	67,321	49,000	[r]53,000	50,000
Kaolinitic earth	18,924	17,946	16,000	•15,000	15,000
Japan	[r]165,696	[r]165,532	129,942	123,154	[8]110,314
Korea, Republic of	1,219,174	1,446,598	1,755,225	[r]1,856,157	1,900,000
Madagascar	1,315	485	496	[r]756	700
Malaysia	108,347	152,972	186,699	244,573	[8]249,852
Mexico	141,519	156,140	[r]167,238	[r]144,121	[8]124,232
New Zealand	26,324	25,435	21,338	•25,000	25,000
Nigeria	500	1,356	•1,300	•1,300	1,300
Pakistan	39,907	61,630	44,738	[r]37,444	39,000
Paraguay•	[4]74,000	74,000	74,000	74,000	74,000
Peru•	7,000	8,000	[4]7,100	[r]5,500	5,500
Poland	[r]62,000	48,000	[r]48,000	•45,000	45,000
Portugal	58,297	73,849	•74,000	•70,000	60,000
Romania•	400,000	250,000	[r]250,000	[r]200,000	200,000

See footnotes at end of table.

TABLE 27—Continued

KAOLIN: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Serbia and Montenegro:				[r]113,000	113,000
Crude	—	—	—	[e]100,000	100,000
Washed	—	—	—	[e]13,000	13,000
Slovakia[4]	—	—	—	—	25,000
Slovenia:				[r]20,000	14,000
Crude	—	—	—	[e]15,000	10,000
Washed	—	—	—	[e]5,000	4,000
South Africa, Republic of	139,711	132,421	134,485	131,765	120,000
Spain (marketable):[9]					
Crude[e]	[8]40,530	125,000	125,000	125,000	125,000
Washed	395,805	423,357	[e]413,000	[e]350,000	350,000
Sri Lanka	7,761	7,731	7,737	[r]6,759	7,000
Sweden	[r]106	[r]108	[e]100	[e]100	100
Taiwan	98,115	105,084	92,970	[e]100,000	100,000
Tanzania	1,554	2,021	1,739	[e]1,700	1,700
Thailand (beneficiated)	[r]176,281	[r]208,029	[r]255,543	[r]301,035	300,000
Turkey	238,251	[r]251,182	[r]186,517	[r]134,416	150,000
U.S.S.R.[e] [10]	2,000,000	1,800,000	1,600,000	1,300,000	1,000,000
United Kingdom	3,139,672	3,037,486	2,911,000	[r]2,521,000	2,600,000
United States[11]	8,973,668	9,761,775	[r]9,574,900	[r]8,735,204	[8]8,957,565
Venezuela	15,000	12,000	39,000	[r]37,000	36,000
Vietnam[e]	750	750	800	800	800
Yugoslavia[12]	260,141	198,513	[e]170,000	—	—
Zimbabwe	17	—	65	[r]83	90
Total	[r]23,229,511	[r]24,077,858	[r]24,129,623	[r]22,725,873	24,567,753

[e]Estimated. [r]Revised.

[1] Table includes data available through July 26, 1994.

[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] Data for year ending June 30 of that stated.

[4] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved in Dec. 1992. Production in Czechoslovakia from 1989-92 came from the Czech Republic and Slovakia.

[6] Data for year ending July 6 of that stated.

[7] Includes kaolinitic clay.

[8] Reported figure.

[9] Includes crude and washed kaolin and refractory clays not further described.

[10] Dissolved in Dec. 1991. This commodity is believed to be produced mainly in Uzbekistan and Ukraine; however, information is inadequate to formulate reliable estimates of individual country production.

[11] Kaolin sold or used by producers.

[12] Dissolved in Apr. 1992.

COBALT

By Kim B. Shedd

Ms. Shedd is a physical scientist (geologist) with more than 14 years of combined experience working for the U.S. Bureau of Mines (USBM) in research and mineral commodities. She has been the commodity specialist for cobalt since 1988. Domestic survey data and trade data were prepared by Jo-Ann S. Sterling, statistical assistant; and international production data were prepared by Amy M. Burk and Amy Durham, international statistical assistants, in coordination with USBM country specialists.

Cobalt is a strategic and critical metal used in many diverse industrial and military applications. The largest use of cobalt is in superalloys, which are alloys designed to resist stress and corrosion at high temperatures. The main use for superalloys is in jet engine parts. Another important use of cobalt is to make permanent magnets, which are used in a wide range of electrical devices. Cobalt metal powder acts as a binder in cemented carbides and diamond tools, which are used for metal cutting and forming, mining, and oil and gas drilling. Cobalt compounds are used in catalysts for the petroleum and chemical industries; drying agents for paints, varnishes, and inks; ground coats for porcelain enamels; pigments for ceramics, paints, and plastics; battery electrodes; steel-belted radial tires; and magnetic recording media.

The United States is the world's largest consumer of cobalt, but has no domestic production, so it relies on imports to meet its primary cobalt needs. The United States stocks significant quantities of cobalt metal in the National Defense Stockpile (NDS) for military, industrial, and essential civilian use during a national emergency.

World cobalt production decreased for the third year in a row. Most of the decrease occurred in Zaire, which fell from its historical position as the world's largest cobalt producer to sixth place. Decreasing prices during most of 1993 suggested that there were sufficient supplies of cobalt to meet demand. Russian cobalt, releases from Government and industry stocks, and production increases from Canada, Finland, and Norway contributed to supply, while recessionary economic conditions in some cobalt-consuming countries, decreased defense spending, and a drawdown of consumer stocks held back demand.

DOMESTIC DATA COVERAGE

Domestic data on cobalt processing and consumption are developed by the USBM from three separate, voluntary surveys of U.S. operations. In the cobalt processors survey, seven of the eight companies canvassed responded. Most of the data on cobalt chemical uses were obtained from this survey. The second survey covers a broad range of metal-consuming companies, such as superalloy producers, magnetic alloy producers, and tungsten carbide producers. For this survey, more than 100 cobalt consumers were canvassed on a monthly or annual basis. The USBM also canvasses 13 superalloy scrap recyclers to determine the consumption of secondary cobalt in superalloy production. The data in tables 3 through 6 contain estimates to account for nonrespondents.

BACKGROUND

Definitions, Grades, and Specifications

Cobalt is a metallic element. It is silvery gray in color, hard, ductile, somewhat malleable, and magnetic. Other properties include atomic number, 27; atomic weight, 58.93; melting point, 1,493° C; boiling point, 3,100° C; and Curie temperature, 1,121° C. Cobalt-60 (^{60}Co) is produced by irradiating cobalt metal in a nuclear reactor. This radioactive isotope is used in radiation therapy, for the sterilization of medical supplies, and more recently, to treat fresh foods.

Currently, there are no internationally recognized specifications for cobalt metal. The Zairian and Zambian cobalt producers proposed specifications for five grades of cobalt in 1988.[1] The U.S. Government has purchase specifications for NDS cobalt. The current NDS specification, P-13-R6, has been in effect since December 18, 1985. It provides physical and chemical requirements for three grades of refined cobalt metal. Grades A and B must be in the form of electrolytic cathode; grade C can be either cathode or granules. Chemical requirements specify the weight percentage, in order of abundance, of cobalt, nickel, iron, and manganese, as well as maximum levels of 26 impurities.

Products for Trade and Industry

Less than one-half of the cobalt used in the United States was consumed as primary cobalt metal. Most of this metal was in the form of electrolytic cobalt (cathode or rounds), granules (shot), ingot, or metal powder of various grades (particle-size ranges). About one-fourth of U.S. reported consumption in 1993 was from purchased scrap. Cobalt-bearing scrap originated from alloy processing, parts manufacturing, and used cobalt-containing products. The remainder of the cobalt used in the United States, about one-third of total consumption, was in the form of cobalt chemical compounds. These included cobalt oxide of various types, inorganic cobalt compounds (acetate, carbonate, chloride, hydroxide, nitrate, and sulfates), and organic cobalt compounds.

Industry Structure

More than 90% of the world's cobalt is refined in six countries: Canada, Finland, Norway, Russia, Zaire, and Zambia. Until recently, more than three-quarters of world production was from three countries: Zaire, Zambia, and Russia. Zaire was historically the dominant producer, supplying more than one-third of the world's refined cobalt. The ranking of the top six producing countries changed significantly in 1993. A drastic decrease in production caused Zaire to fall from its position as the world's largest producer to sixth place. Zambia became the world's largest producer. Varying estimates for Russian production place it somewhere between second and fifth place.

Zairian and Zambian production was from domestic ores. Canada and Russia produced cobalt from both domestic and imported raw materials. All of the cobalt produced in Norway and most of the cobalt produced in Finland was from imported raw materials. The United States was not a cobalt producer. U.S. mine production of cobalt ceased at the end of 1971, and the sole U.S. cobalt refinery discontinued processing imported nickel-cobalt matte in late 1985. World producers of refined cobalt and producers of intermediate cobalt-containing products are listed in tables 1 and 2. *(See tables 1 and 2.)*

Cobalt processors represent an important source of supply for various industries. Processors differ from producers in the feed materials they use, although some overlap exists. Producers refine cobalt primarily from materials originating from mining or refining operations—ores, concentrates, mattes, or residues—although some refineries supplement their feedstock with cobalt-bearing scrap. In contrast, processors use refined cobalt metal or cobalt-bearing scrap as feed materials. The world's largest cobalt processor is Union Minière S.A. in Belgium (formerly Metallurgie Hoboken-Overpelt S.A.).

Byproducts and Coproducts

Cobalt is rarely produced as the primary product of a mining or refining operation. Zaire and Zambia produce cobalt as a byproduct of copper. Cobalt production in most other countries is a byproduct of nickel. Exceptions are Morocco, where cobalt is produced as a primary product, and the Republic of South Africa, where cobalt is produced as a byproduct of platinum. Future production from Belgium will include cobalt recovery from residues produced during electrolytic zinc refining. A Canadian company plans to produce cobalt from old silver tailings.

Economic Factors

Most of cobalt's production costs are attributed to the primary metal produced at a given operation. The incremental costs applied to cobalt production include costs to separate cobalt from the primary metal, usually during the refining stage; transportation costs; and marketing costs.

Operating Factors

The U.S. Environmental Protection Agency (EPA) regulates releases of cobalt into the environment under various programs. Workplace exposures are regulated by the Occupational Safety and Health Administration (OSHA). In addition to these regulatory agencies, the following groups issue guidelines or develop scientific positions for consideration by Government agencies when making regulations: American Conference of Governmental Industrial Hygienists (ACGIH), International Agency for Research on Cancer (IARC), and Agency for Toxic Substances and Disease Registry (ATSDR). A review of U.S. environmental legislation and regulation pertinent to cobalt was presented in 1993.[2]

Effective March 23, OSHA reverted back to permissible exposure limits (PEL's) for air contaminants in place before January 19, 1989. The suspension of OSHA's stricter PEL's was the result of a 1992 Federal court decision that OSHA could not issue broad standards for hundreds of chemical substances without scientifically justifying changes to each individual standard. As a result of this change, the PEL for cobalt metal, dust, and fume reverted back to an 8-hour time-weighted average of 0.1 milligram per cubic meter of air (mg/m^3). PEL's set in January 1989 for previously unregulated cobalt carbonyl and cobalt hydrocarbonyl were revoked.

On May 18, ACGIH restated its intention to decrease its threshold limit value (TLV) for cobalt from an 8-hour time-weighted average of 0.05 mg/m^3 to 0.02 mg/m^3. ACGIH TLV's are used by regulatory agencies such as OSHA in setting permissible exposure levels. The proposed change in the TLV was still under consideration at yearend.

ANNUAL REVIEW

Legislation and Government Programs

On March 24, 1993, the Defense Logistics Agency (DLA) began bimonthly sales of cobalt from the NDS. The sales were intended to bring the NDS cobalt inventory down to the goal set in the Department of Defense (DOD) 1992 Report to the Congress on National Defense Stockpile Requirements. Approximately 113 metric tons (250,000 pounds) of cobalt granules was available for sale on the second Wednesday of each month and 45 tons (100,000 pounds) of cobalt rondelles was available on the fourth Wednesday of each month. In August, the DLA increased the quantity of cobalt rondelles available each month to 68 tons (150,000 pounds). In September, the DLA decreased the quantity of cobalt granules available each month to 91 tons (200,000 pounds).

The quality of the cobalt for sale by the DLA reflects the technological requirements in existence at the time of its purchase more than 30 years ago. The cobalt content of the granules ranged from 99.20% to 99.83% and the cobalt content of the rondelles ranged from 98.16% to 99.60% cobalt. During the year, the DLA accepted bids at prices close to those quoted by Metal Bulletin for 99.3% cobalt ingot from Russia. Participants in the bidding included trading firms, chemical processors, alloy producers, a scrap processor, a metal powder processor, and a copper refiner.

The DLA sold 276 tons of cobalt during fiscal year 1993 (October 1, 1992, through September 30, 1993). Sixty percent of the sales was cobalt rondelles (164 tons) and 40% was cobalt granules (112 tons). The sales represented just 13% of the quantity allowable for sale under the Annual Materials Plan (AMP) for the fiscal year—2,087 tons (4.6 million pounds). According to DLA's AMP for fiscal year 1994, the maximum amount of cobalt that could be sold in the year beginning October 1, 1993, also would be 2,087 tons (4.6 million pounds).

The DLA sold 418 tons of cobalt during calendar year 1993. Fifty-eight percent of the sales was cobalt granules (244 tons) and 42% was cobalt rondelles (174 tons). At yearend, the total uncommitted cobalt inventory reported by the DLA was 23,650 tons, contained cobalt. The DOD revised the NDS requirement for cobalt to zero in its 1993 Report to the Congress on National Defense Stockpile Requirements. However, the DOD did not recommend adopting new NDS goals until a DOD strategic review was completed and updated ratios relating demand for manufactured goods to demand for strategic and critical materials were received from the Department of Commerce. At that time DOD was to reestimate NDS requirements and submit a revised set of requirements to Congress.

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 1993, the United States consumed about 40% of estimated world refinery production. There was no domestic production, so demand was met primarily from imports, with the exception of about 20% to 25% from purchased scrap.

To ensure an adequate supply for military, industrial, and essential civilian needs, cobalt metal is included in the NDS. Stockpile quantities are intended to sustain the United States for a period of not less than 3 years during a national emergency situation. However, most of the cobalt in the stockpile was purchased prior to 1980 and does not meet current quality requirements for vacuum-melted superalloys.

World cobalt production is concentrated in a limited number of geographic areas. More than one-half of the world's refined cobalt is produced in three countries: Russia, Zaire, and Zambia. Political and economic conditions in the producing countries can impact cobalt production, transportation, and/or exports.

Production

There was no domestic mine or refinery production of cobalt in 1993. Formation Capital Corp., of Vancouver, British Columbia, acquired and explored the Blackpine property southwest of Salmon in Lemhi County, ID. The Blackpine property is a copper-cobalt-gold-silver sulfide deposit in the same mineral belt that contains Noranda Mining Inc.'s Blackbird Mine. Formation Capital's exploration program included geophysics, soil geochemistry, trenching, and drilling. The company is considering three options for possible development: open pit mining followed by heap leaching and solvent extraction; open pit mining followed by milling; and underground mining on the higher grade beds.[3]

U.S. cobalt supply included secondary cobalt from the recycling of superalloy and other forms of scrap. Cobalt was recovered from spent petroleum catalysts at the AMAX Metals Recovery plant in Braithwaite, LA, and by Gulf Chemical and Metallurgical Corp. in Freeport, TX.

Hecla Mining Co. produced cobalt chemicals at its Apex Unit's hydrometallurgical processing plant in St. George, UT. The company reported sales of more than 43 tons of cobalt chemicals in 1993.[4] Hecla continued process trials of cobalt-bearing residues, with plans to develop a business based on the recycling of residues and other cobalt-bearing feedstocks.

Two cobalt processors produced extra-fine cobalt metal powder in the United States. Carolmet, owned by Union Minière of Belgium, produced cobalt metal powder from imported primary metal at its Laurinburg, NC, plant. Osram Sylvania Inc. (formerly GTE Products Corp.) produced cobalt metal powder from recycled materials in Towanda, PA. Production and shipments of extra-fine cobalt metal powder are withheld to avoid disclosing company proprietary data.

Domestic cobalt processors produced 1,979 tons of cobalt contained in cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds in 1993, essentially the same amount as the 1,969 tons produced the previous year. Because this figure includes production of intermediate forms, it does not represent net production. Shipments are defined as sales, transfers, or consumption to make end-use products such as paint driers or catalysts. In 1993, shipments by domestic cobalt processors included 1,793 tons of cobalt contained in cobalt oxide and hydroxide, inorganic cobalt compounds, and organic cobalt compounds, a slight decrease from 1992 shipments of 1,838 tons.

Consumption and Uses

Apparent consumption, as calculated

from net imports, consumption from purchased scrap, and changes in Government and industry stocks increased 12% in 1993 to approximately 7,300 tons. The following factors contributed to the increase: cobalt was shipped from the NDS, industry stocks continued to decrease, and much less cobalt was exported. U.S. reported consumption was unchanged from reported consumption in 1992. As a whole, metallurgical industries consumed approximately the same amount of cobalt in 1993 as they did in 1992. On an industry-by-industry basis, cobalt consumption by superalloy melters and magnetic alloy producers decreased in 1993, while cobalt consumption by producers of cemented carbides, welding materials, mill products from metal powders, steel, and other alloys increased. Total cobalt consumption for chemical uses was essentially unchanged in 1993 as compared with 1992. *(See tables 3, 4, and 5 and figure 1.)*

Stocks

The total amount of cobalt contained in stocks held by U.S. processors and consumers was basically the same as that at yearend 1992. However, 1993 yearend stocks of cobalt metal and scrap were slightly higher than those of 1992 and 1993 yearend stocks of cobalt chemicals were 11% lower than stocks of cobalt chemicals at yearend 1992. *(See table 6.)*

Markets and Prices

During most of 1993, the U.S. spot price for cobalt cathode reported by Platt's Metals Week continued to decline from the high levels of December 1991-January 1992. The highest prices during the year occurred in February and March when the price of cathode increased to $16 to $16.50 per pound. The brief increase in cathode price was in response to reports of renewed violence in Zaire and a tightening of supplies of lower quality Russian cobalt. By mid-March the cathode price resumed its decline and dropped below $11 per pound by early December. The decrease was attributed to weak demand, particularly from Europe and Japan, consumption from stocks, and availability of cobalt on the free market. Russian cobalt imports to Western markets and regular offers of NDS cobalt from the DLA contributed to total cobalt supply, although cobalt from these sources was low quality.

In mid-December, free market prices for both cathode and Russian cobalt rapidly increased. By yearend, the price of cathode was $15 per pound and Russian cobalt exceeded $14 per pound. These price increases reflected a growing concern over cobalt supply prompted by the following factors: delays by the African producers in announcing their 1994 pricing policy; consumers' reduced stock levels resulting from buying on an as-needed basis; press reports that Zaire's Shaba Province, where the copper-cobalt industry is located, declared autonomy from the rest of the country; expectations for reduced production in 1994 from Zambia and from Canadian producer Inco Ltd.; and traders' reports of reduced supplies of Russian cobalt. However, the magnitude and speed of the price increases suggest trader manipulation. Platt's Metals Week reported an average annual U.S. spot cobalt cathode price of $13.79 per pound for the year. *(See table 3 and figure 2.)*

Metal Bulletin reported free market prices for two grades of cobalt—minimum 99.3% cobalt from Russia and higher quality minimum 99.8% cobalt. Prices for the two grades of cobalt more or less paralleled one another, although price increases and decreases for Russian cobalt tended to be steeper than those for the 99.8% cobalt. In January, price quotes for Russian cobalt were $3 to $4 per pound lower than quotes for higher quality cobalt. The price differential narrowed to $2 per pound by March and to $1 per pound in August. In December, price quotes for Russian cobalt overlapped quotes for higher quality cobalt.

The 1993 cobalt producer price was set by La Générale des Carrières et des Mines (Gécamines) of Zaire and Zambia Consolidated Copper Mines Ltd. (ZCCM) at $18 per pound in November 1992. Because of the increasing differential between the producer price and lower free market prices, the African producers reportedly began using free market price quotes as the basis of their transactions by mid-1993.[5] The 1993 price expired on November 20, 1993. At yearend, a new producer price had not been set for 1994. *(See table 7.)*

Foreign Trade

U.S. imports of unwrought cobalt and cobalt in chemicals increased slightly in 1993. More than 90% of these imports was supplied by six countries. Zambia was the leading supplier of cobalt to the United States, followed by Norway, Canada, Finland, Zaire, and Russia. Cobalt imports from Finland, Norway, and Russia increased significantly in 1993 as compared with imports in 1992. *(See tables 8 and 9 and figure 3.)*

In 1993, the United States imported 175 tons, gross weight, of unwrought cobalt alloys valued at $4.7 million. Five countries supplied 94% of these materials: the United Kingdom (53%), Sweden (18%), the Republic of South Africa (14%), France (5%), and Belgium (3%). The United States imported 405 tons, gross weight, of cobalt matte, waste, and scrap, valued at $4.3 million. Four countries supplied 82% of these materials: the United Kingdom (41%), Germany (21%), Japan (15%), and Russia (5%). The United States also imported 172 tons, gross weight, of wrought cobalt and cobalt articles valued at $7.9 million. The leading suppliers of these materials were the United Kingdom (41%) and Japan (30%), followed by Germany (9%), France (6%), and Canada and the Netherlands (5% each).

U.S. net import reliance as a percentage of apparent consumption was estimated to be 79% in 1993. The net import reliance would be 100% if no cobalt was recovered from secondary sources (scrap).

The import duty on cobalt acetates, carbonates, and chlorides was 4.2% ad valorem for most favored nations (MFN) and 30% ad valorem for non-MFN. The duty on cobalt oxides and hydroxides was $0.026 per kilogram for MFN and $0.44 per kilogram for non-MFN. The duty on cobalt sulfates was 1.4% for MFN and 6.5% for non-MFN. Imports of unwrought cobalt metal; cobalt ores and concentrates; and cobalt matte, waste, and scrap were duty free. The duty on unwrought cobalt alloys and wrought cobalt and cobalt articles was 5.5% for MFN and 45% for non-MFN. Special rates of duty are applied to certain cobalt-containing materials under the following programs: Andean Trade Preference Act, Caribbean Basin Economic Recovery Act, Generalized System of Preferences, United States-Canada Free-Trade Agreement, and the United States-Israel Free Trade Area.[6]

U.S. exports of unwrought cobalt and cobalt contained in chemicals decreased 44% as compared with exports in 1992. More than three-quarters of this cobalt was shipped to seven countries: Brazil, Canada, Indonesia, Japan, Mexico, Taiwan, and the United Kingdom. The remainder was shipped to 39 other countries. *(See table 10.)*

Exports also included 249 tons, gross weight, of wrought metal and cobalt articles valued at $11.4 million. More than three-fourths of these materials was sent to eight countries: Canada and the Republic of Korea (each 16%); Norway (10%); France, Sweden, and the United Kingdom (each 8%); and Belgium and Japan (each 6%). The remainder was shipped to 21 other countries. In addition, the United States exported 9 tons, gross weight, of material under the category entitled, "Cobalt ores and concentrates." The material, valued at $77,755, was sent to Canada.

World Review

World cobalt production decreased for the third consecutive year in 1993. Refinery production reported by the seven Cobalt Development Institute (CDI) member producers—Falconbridge Ltd.; Gécamines; Inco Ltd.; OM Group, Inc.; Sherritt Inc. (formerly Sherritt Gordon Ltd.); Sumitomo Metal Mining Co. Ltd.; and ZCCM—decreased 23% from 17,891 tons in 1992 to 13,843 tons in 1993.[7] The decrease was primarily due to the continuing decrease in production by Gécamines, dropping Zaire out of its historical position as the world's largest cobalt producer. If production by Gécamines is excluded, production by the remaining six CDI member producers shows an increase of 3% as compared to production in 1992. Three producers, Falconbridge, OM Group, and Sherritt, reported record-high production levels in 1993. Production by Sumitomo also increased, while production by Inco and ZCCM decreased.

The CDI estimated the following additional cobalt supplies available to Western consumers in 1993: 3,000 tons in nonconsumer stocks from yearend 1992; 1,000 tons produced in Brazil, China, France, and the Republic of South Africa; 420 tons released from the NDS; and 2,000 tons exported from Russia. This resulted in a total availability of approximately 20,260 tons. The CDI concluded that, assuming Western demand was similar to that of 1992 at 19,200 tons, 1993 supply and demand were roughly in balance.

Capacity.—The data in table 11 are rated capacity for refineries as of December 31, 1993. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information available, historical reported or estimated cobalt production data have been used to estimate refinery capacity in some cases. Changes in refinery capacity can result from changes in facilities, changes in the grade of raw materials processed, and/or changes in knowledge about the facilities. *(See table 11.)*

Australia.—QNI Ltd. produced cobalt sulfide from nickel laterites at the Yabulu nickel-cobalt refinery in Townsville, Queensland. About 85% of the feed for the refinery was imported from Indonesia and New Caledonia. The remainder was from the company's Brolga mine in Queensland, which came on-stream in 1993. During the year the company worked on the construction of a pilot plant for upgrading its cobalt sulfide to value-added products. QNI's cobalt sulfide is currently refined to cobalt metal powder, oxide, and salts by OM Group's Kokkola Chemicals Oy refinery in Kokkola, Finland. Kokkola Chemicals' contract to purchase QNI's cobalt sulfide expires at yearend 1996.

Western Mining Corp. (WMC) produced intermediate cobalt products as a byproduct of mining, smelting, and refining nickel sulfide ores in Western Australia. Some of the nickel-copper-cobalt matte produced at WMC's Kalgoorlie smelter was exported to other refiners, including Sumitomo Metal Mining Co. of Japan. The remainder was refined by WMC at its Kwinana nickel refinery. The Kwinana refinery produced cobalt in a nickel-cobalt mixed sulfide. The mixed sulfide has traditionally been refined by Sherritt Inc. in Canada.

WMC continued its evaluation of the Bulong nickel-cobalt laterite deposit east of Kalgoorlie in Western Australia. The company has been investigating the recovery of nickel and cobalt by acid pressure-leaching at high temperatures. Sulfuric acid for the process could be produced from sulfur dioxide generated at WMC's Kalgoorlie smelter. Current annual production estimates from Bulong are 18,000 tons of nickel and 1,200 tons of cobalt.[8]

MIM Holdings Ltd. continued pilot plant studies on the recovery of cobalt from its Mount Isa copper concentrates by bioleaching. Potential production was estimated at 600 tons of cobalt per year.[9]

Cobalt Resources N.L. was incorporated in May to explore and develop manganese-cobalt deposits in the

Mount Tabor district 125 km northeast of Augathella in central Queensland. The deposits are in the form of cobalt mineralization associated with manganiferous wads (a soft mixture of manganese and other oxides formed in weathering zones). The company planned an exploration program to locate all potential cobalt-bearing occurrences, define minable deposits, and prove reserves. The exploration target was 3 million tons of ore averaging 0.3% cobalt. Based on previous laboratory-scale testing by Commonwealth Scientific and Industrial Research Organization (CSIRO), the following process flowsheet was proposed. Run-of-mine ore would be crushed, then acid leached under agitation with added sulfur dioxide gas. The leached pulp would undergo a solid/liquid separation, cobalt would be selectively recovered by solvent extraction, then cobalt metal would be produced by electrowinning.[10]

Belgium.—Union Minière (UM) converted cobalt metal, residues, and other cobalt-bearing materials into cobalt metal powders, oxides, hydroxide, and chloride at its facilities in Olen, Belgium. During the year, UM developed a process to recover cobalt from residues generated during zinc refining. The company upgraded its Olen facilities to treat a wider range of cobalt-bearing feeds and to increase the throughput of secondary materials from 50 tons per month to 100 tons per month. By treating more secondary materials, UM planned to reduce its annual purchases of cobalt metal by several hundred tons.[11]

Botswana.—BCL Ltd. mined nickel-copper ores from company mines in the Selebi-Phikwe district. Copper-nickel-cobalt matte produced by BCL was sent to refineries in Norway and Zimbabwe to be refined. BCL is 85% owned by Botswana RST Ltd. (BRST). At midyear, Amax Inc. sold its 29.8% interest in BRST to the Botswanan Government.

Brazil.—Cia. Niquel Tocantins produced cobalt cathode at its nickel refinery in Sao Miguel Paulista, Sao Paulo State.

Canada.—Cobalt was produced as a byproduct of nickel by three Canadian companies, Falconbridge, Inco, and Sherritt. In 1993, Falconbridge produced 800 tons of cobalt from nickel-copper ores at its Sudbury, Ontario, operations.[12] Cobalt-containing nickel-copper matte from the Sudbury smelter was refined at Falconbridge's Nikkelverk refinery in Norway.

Inco produced cobalt oxide at its Thompson, Manitoba, refinery and cobalt cathode at its Port Colborne refinery. Feed materials for the two refineries originated from nickel mines in Thompson, Manitoba, and Sudbury, Ontario, respectively. In response to excess supply in the nickel market, Inco reduced its nickel production by 8% in 1993. Production of byproduct cobalt decreased 4%. Inco refined 1,410 tons of cobalt in 1993 as compared with 1,465 tons in 1992.[13]

Sherritt refined nickel-cobalt materials from Australia, Canada, Cuba, and the Republic of South Africa at its Fort Saskatchewan refinery in Alberta. During 1993, Sherritt completed the expansion of its nickel-cobalt refinery. The refinery uses a new cobalt-nickel separation process that can treat a wider range of feed materials. At yearend, the cobalt plant was operating at an annual rate of about 1,600 tons (3.5 million pounds). During a plant performance run in the first quarter of 1994, the cobalt plant was run at the design capacity of about 2,000 tons (4.5 million pounds). In 1993, Sherritt produced a record 1,218 tons of cobalt, an increase of 78% over the 686 tons of cobalt produced in 1992.[14]

Cobatec Ltd., a wholly owned subsidiary of Ego Resources Ltd. of Toronto, developed a hydrometallurgical process to produce cobalt from silver-cobalt tailings and ores from the historic silver mining town of Cobalt, in eastern Ontario. The process involved pressure leaching in the presence of oxygen, solvent extraction, then electrolysis to produce cobalt cathode and byproduct nickel cathode. Ego Resources was considering adjusting the process to produce cobalt compounds. The company planned to begin construction in 1994 of a plant with the capacity to produce approximately 300 tons of cobalt per year. Ego Resources reported that it had acquired sufficient feed for approximately 4 years of full production and planned to acquire additional feed to extend production.[15]

In June 1993, the British Columbia government designated the Tatshenshini-Alsek region in northwestern British Columbia as a protected wilderness area, thus preventing any future development of mineral claims in the region. Geddes Resources Ltd. of Vancouver, British Columbia, terminated the permitting process for its Windy Craggy copper-cobalt-gold deposit and began seeking compensation from the government. The deposit had been called "Canada's largest undeveloped source of cobalt."[16] The company estimated reserves at 297 million tons of ore grading 1.38% copper, 0.069% cobalt, 3.83 grams silver per ton, and 0.2 gram gold per ton.[17]

China.—Cobalt was produced at various locations in China from both domestic and imported raw materials. At Jinchuan, Gansu Province, cobalt metal was produced as a byproduct of nickel from the refining of domestic nickel sulfide ores. The Ganzhou cobalt refinery in Jiangxi Province produced cobalt metal and salts from cobalt arsenide concentrates imported from Morocco. Minor production sites included the Zibo Cobalt Works in Shandong Province, where cobalt metal was produced from iron ore from Shandong Province and copper ore from Shanxi Province.

Côte d'Ivoire.—Falconbridge Ltd. and Trillion Resources Ltd. of Canada signed an agreement with Société de Développement Minière de la Côte d'Ivoire (SODEMI) for the exploration of nickel-cobalt laterite deposits near Biankouma, western Côte d'Ivoire. CRU International Ltd. estimated an annual cobalt output of 1,300 tons in a sulfide precipitate, with 1998 as the earliest startup date for the project.[18]

Cuba.—Unión de Empresas del Níquel (UNI) produced nickel-cobalt sulfides at its Moa Bay plant and nickel-cobalt oxide and oxide sinter at its Nicaro and Punta Gorda plants. All three plants used Cuban laterites as their feedstock. The nickel-cobalt sulfides contained a greater percentage of cobalt than the oxide and sinter, roughly 5% as compared with about 1%. Historically, all of the sulfides were refined at the Yuzhural Nickel refinery at Orsk in the southern Ural Mountains in Russia. Since 1991, some of the sulfides have been refined at Sherritt's Fort Saskatchewan nickel-cobalt facility in Canada. Reports indicate that in 1993, two-thirds of the nickel-cobalt sulfides from Moa Bay were sent to Sherritt and approximately 3,000 tons of sulfides were sent to Yuzhural Nickel.[19]

UNI continued with plans to produce cobalt from its nickel-cobalt intermediate materials. The company hoped to begin production within 5 years, assuming foreign investment was secured to develop the nickel-cobalt separation technology. The cobalt separation plant would be built at UNI's fourth nickel refinery, currently under construction at Las Camariocas. Nickel-cobalt intermediate materials from all four of UNI's nickel refineries would be treated at Las Camariocas. Output from the cobalt plant was forecast at 3,000 tons nickel and 1,000 tons cobalt.[20]

Finland.—In June, Outokumpu Metals & Resources Oy decided to expand and upgrade its Harjavalta nickel refinery. Feed for the Harjavalta refinery was traditionally from Finnish nickel mines. As ore reserves in Finland declined, Outokumpu has imported an increasing amount of its nickel feed from Western Australia. The shift from high-copper Finnish concentrates to high-magnesia Australian concentrates created the need for a change in the refining process. As part of the expansion and upgrade, Outokumpu designed a circuit to refine its cobalt hydroxide sludge to cobalt metal powder. Annual cobalt output was expected to double from about 250 tons to about 500 tons of contained cobalt. Feed for Harjavalta would be primarily concentrates from Outokumpu's Forrestania Mine, which is currently producing, and WMC's Mount Keith Mine, which was expected to begin production in 1995.

In October, Outokumpu sold its entire 96% share of OM Group, Inc. in a public offering. OM Group was formed in October 1991 when Outokumpu and U.S.-based Mooney Chemicals, Inc. merged their chemical businesses. OM Group produces cobalt products at three locations: Kokkola, Finland; Ezanville, France; and Franklin, PA. In 1993, OM Group's Kokkola Chemicals Oy refinery produced a record 2,200 tons of cobalt in cobalt metal powders, oxides, and salts.[21] The refinery uses cobalt sulfide from QNI Ltd. in Queensland, Australia, cobalt slag from Gécamines in Zaire, and cobalt hydroxide sludge from Outokumpu's Harjavalta refinery as its raw materials feed. OM Group planned to build a facility at Kokkola in 1994 to produce carboxylates for the European market.[22] Cobalt carboxylates are used by chemical processing, coatings, and tire industries.

Indonesia.—State-owned PT Aneka Tambang (ANTAM) was under contract to supply 1 million wet tons of lateritic nickel ore to QNI Ltd.'s Yabulu nickel-cobalt refinery in Queensland, Australia. The ore was to come from ANTAM's Oeboelie Mine on Gebe Island in eastern Indonesia.

Japan.—Sumitomo produced electrolytic cobalt, cobalt oxide, and cobalt salts as a byproduct of nickel production at its Niihama Nickel Refinery in Ehime Prefecture. According to Japan's Ministry of International Trade and Industry (MITI), 1993 Japanese cobalt consumption increased 8% to 2,417 tons. Cobalt consumption by industry was reported as follows: cobalt in catalysts increased 8% to 385 tons, cobalt in hard-metal tools decreased 6% to 276 tons, cobalt in magnetic materials increased 15% to 547 tons, cobalt in specialty steels increased 6% to 691 tons, cobalt in tube, plate, rod, and wire increased 15% to 234 tons, and cobalt in other uses increased 16% to 285 tons. Japanese demand for cobalt was met primarily from imports. Japan imported 4,009 tons of cobalt in 1993, a slight decrease from the 4,275 tons imported in 1992. Industry stocks also contributed to supply. In 1993, industry stocks decreased from 1,437 tons of cobalt at the beginning of the year to 1,110 tons at yearend.[23]

Mexico.—International Curator Resources Ltd. of Vancouver, British Columbia, began diamond drilling the Boleo copper-cobalt property near Santa Rosalia, Baja California. The drilling program was designed to confirm and expand the known reserves, quantify the cobalt content, and provide information on rock mechanics. Ore samples were sent for metallurgical testing to confirm the use of solvent extraction-electrowinning to process the ore.

New Caledonia.—Three New Caledonian mining companies were under contract to supply lateritic nickel ore to QNI's Yabulu nickel-cobalt refinery in Queensland, Australia. J.C. Berton Mines was to supply 500,000 wet tons of ore from its Bienvenue Mine, Nickel Mining Corp. was to supply 800,000 wet tons from its Kouaoua Mine, and Société des Mines de la Tontouta was to supply 300,000 wet tons from its Moneo and Nakety Mines.

Inco continued exploring the Goro nickel-cobalt property in southern New Caledonia. A bulk sample of lateritic ore was sent to Inco's research laboratory in Mississauga, Ontario, for extraction trials.

Norway.—The Falconbridge Nikkelverk refinery produced a record 2,414 tons of cobalt cathode in 1993,[24] a 5% increase from the previous record of 2,293 tons set in 1992. Feedstock for the refinery was in the form of matte from company operations in Sudbury, Canada; BCL Ltd. in Botswana; and Norilsk Nickel in Russia. During the past few years, Falconbridge has gradually increased the Nikkelverk refinery's annual cobalt capacity from 2,000 tons to 2,600 tons.

Russia.—Most of the cobalt produced in Russia is a byproduct of Russian nickel mining and/or refining. Nickel and cobalt production in Russia involves a complex flow of ores, concentrates, and mattes between various production sites. Russian nickel-cobalt production is organized into two "Complexes." Norilsk Nickel Complex's production is from nickel sulfide ores mined, smelted, and refined at Norilsk in eastern Siberia and at various locations on the Kola Peninsula. In recent years, Norilsk Nickel has also toll-refined nickel and cobalt-bearing scrap and residues at its Monchegorsk refinery at Kola. Yuzhural Nickel Complex's smelters and refineries are in the Ural Mountains. Feedstock to Yuzhural Nickel's plants has included nickel laterites mined from the Ural region, cobalt-arsenide concentrates mined and beneficiated in the Tuva Autonomous Republic, nickel-cobalt sulfides from Cuba, and white alloy from Zaire.

Cobalt mine and refinery production in tables 12 and 13 for the former U.S.S.R. and Russia were increased based on estimated production from various sources. Production estimates for 1993 ranged from 1,850 tons to 4,200 tons. Russian cobalt continued to enter Western markets in 1993, although reportedly at lower levels than those of the previous year. Russian cobalt exports in 1993 were estimated at 1,000 to 3,000 tons.

South Africa, Republic of.—Cobalt was produced as a byproduct of South Africa's platinum industry. Two companies produced refined cobalt: Rustenburg Base Metal Refiners Pty. Ltd. produced cobalt sulfate and Impala Platinum Ltd. produced cobalt metal powder. A third company, Western Platinum Ltd., produced nickel sulfate containing minor amounts of cobalt. Most of South Africa's cobalt was exported.

According to preliminary figures from South Africa's Minerals Bureau, South African cobalt production decreased 27% in 1993 to 172 tons. Local cobalt sales decreased to 46 tons in 1993 from 50 tons in 1992. Exports of cobalt from South Africa decreased to 196 tons in 1993 from 211 tons in 1992.

Taiwan.—Mechema Chemicals International began production of cobalt acetate catalysts in Taiwan. The company purchased the Mechema name, technology, and plant facilities from Mechema Chemicals Ltd. of Port Talbot, Wales. The Welsh plant was dismantled, then rebuilt in Taoyuan. Cobalt acetate catalysts are used in the production of terephthalic acid, which is used to produce polyester textile fibers and polyethylene terephthalate films and bottles.

Tanzania.—Sutton Resources Ltd. and BHP Minerals International Exploration Inc. continued drilling nickel sulfide deposits in the Kabanga region of northwestern Tanzania and began drilling in the adjacent Kagera region. Sutton reported a resource at Kabanga of 25.5 million tons ore at 1.19% nickel, 0.20% copper, and 0.10% cobalt.

Uganda.—In September, the Kasese Cobalt Co. Ltd. completed a detailed feasibility study on the extraction of cobalt from cobaltiferous pyrites stockpiled at the Kilembe copper mines. The Kasese Cobalt Co. is a joint venture between Uganda's state-owned Kilembe Mines Ltd. (45%), Bureau de Récherches Geologiques et Minières (BRGM) of France (27.5%), and Barclays Metals Ltd. of the United Kingdom (27.5%). The study recommended the construction of a bioleaching-solvent extraction-electrowinning plant to produce 1,000 tons of cobalt cathode per year. The recommendations were based on an extensive analysis of the stockpile, followed by tests on an 8-ton sample at BRGM's laboratories in Orleans, France. A pilot plant was built in Uganda to assist with the engineering design of the commercial plant and training of the plant operators. By yearend, financing for the project was underway with a guarantee of $10 million for direct project investment by the World Bank's Multilateral Investment Guarantee Agency and $40 million insurance to commercial banks lending funds for the project.

Zaire.—The political stalemate in Zaire persisted through 1993, causing sporadic periods of political and social unrest, the postponement of much-needed foreign investment, rampant inflation, and continued shortages of consumables and spare parts at state-owned Gécamines. Under these adverse conditions, Gécamines' cobalt production continued to decrease. In 1993, cobalt supply to Gécamines' concentrators (cobalt content of ore milled) decreased to about 5,000 tons from 13,300 tons in 1992. As a result, the cobalt content of concentrates produced decreased to about 2,500 tons from 5,700 tons in 1992. Gécamines 1993 cobalt production dropped to about 2,100 tons from 6,600 tons produced in 1992. These figures include cobalt in matte, slag, and alloys that require further refining before they can be used by consumers. In terms of finished cobalt (cathode from the Luilu refinery and granules and low-quality cathode from Shituru), Gécamines produced only 831 tons in 1993 as compared with 5,049 tons in 1992. As a result of this large decrease in production, Zaire fell from its historical position as the world's largest cobalt producer to sixth place.

In 1993, increased amounts of cobalt-bearing materials were exported from Zaire to be refined. Early in the year, Gécamines sent 45,000 wet tons of cobalt slag from its Lubumbashi smelter to OM Group's Kokkola refinery in Finland. OM Group took delivery and title to the slag, but was not required to pay for it until it was refined. Gécamines also reportedly sent white alloy and matte to Russia for refining.

In mid-December, press reports stated

that Zaire's Shaba Province, where the country's copper-cobalt industry is located, reverted to its former name Katanga and declared autonomy from the rest of the country. The Province reportedly planned to impose taxes on imports and exports to generate revenue. The Zairian Government did not give an official response to the declaration.

Zambia.—In 1993, Zambia replaced Zaire as the world's largest cobalt producer. ZCCM produced 4,211 tons of cobalt metal between January and December 1993, a 9% decrease from the 4,610 tons produced in calendar year 1992.[25] In addition to refining cobalt concentrates from its mining and milling operations, ZCCM has been treating high-cobalt content smelter slags since July 1992. To improve cobalt quality, ZCCM made the following plant modifications: ion exchange columns were installed at the Nkana refinery to reduce nickel levels, and solvent extraction circuits were installed at both the Nkana and Chambishi refineries to reduce zinc levels. In addition, ZCCM planned to increase the installed capacity at its Nkana refinery from 2,500 tons of cobalt per year to 3,000 tons per year during the financial year beginning April 1, 1994.

ZCCM outlined a major mining project intended to maintain current production levels for the next 25 years or more.[26] The Konkola Deep Mining Project would replace production from the Nchanga open pit. Nchanga currently accounts for about 30% of ZCCM's copper production, but it is expected to be mined out by the year 2001. The Konkola project would involve the sinking of a new shaft system and building a new concentrator. At a mining rate of 6 million tons of ore per year, average annual production would be 180,000 tons of finished copper metal and 600 tons of finished cobalt. The total capital cost of the project was estimated at $545 million in 1991 dollars. Once started, the project was expected to take 6 years to complete.

The Zambian Government commissioned a firm of international consultants to study various options and make recommendations on privatizing ZCCM.

Zimbabwe.—Minor amounts of impure cobalt hydroxide were produced in Zimbabwe as a byproduct of nickel mining and refining. The cobalt hydroxide was exported to be refined. *(See tables 12 and 13.)*

Current Research

The USBM researched methods for recycling magnet scrap. The research included a study of mixed grinding swarf generated during magnet fabrication. The grinding swarf was composed of neodymium-iron-boron and samarium-cobalt alloys, cooling and lubricating oils, and grinding media such as silicon carbide. Variations on three metal-recovery methods were investigated: a single-stage sulfuric acid leach, a two-stage sulfuric acid leach, and a simultaneous flotation-leach process. In the simultaneous flotation-leach process, the neodymium-iron-boron leached and remained in solution while the samarium-cobalt concentrated in the froth and the grinding media concentrated in the tails.[27]

The CDI of Wickford, Essex, United Kingdom, published abstracts on cobalt research, articles on selected cobalt uses, and annual and semiannual data on cobalt production by institute members in quarterly issues of Cobalt News. In September, the CDI held a conference on cobalt supply, chemical and metallurgical uses, occupational and environmental exposure, and legislation.[28]

OUTLOOK

Total world cobalt production continued to decline in 1993. This was primarily because of the ongoing decrease in production by Zaire, which has led to several changes in the cobalt market. Political and economic conditions in Zaire were not resolved, and production was not anticipated to return to former levels in the near term.

Cobalt refiners, processors, and consumers have reevaluated their feed material requirements and, where possible, have been making adjustments to their processes to accommodate a wider range of cobalt materials. Several existing cobalt refiners have increased their capacities, and plans are underway for new refiners to begin production in Canada and Uganda. Belgian production of cobalt from residues generated by the zinc industry also would be considered new production. In terms of quantity, these increases in production will not equal the loss of production from Zaire. In addition, the products made—electrolytic cobalt, metal powders, or chemicals—will determine how the increased production will influence the cobalt market.

Cobalt demand is expected to increase as the economies of the major consuming countries improve. Of particular importance to the cobalt market is the outlook for the aerospace industry because of the quantities and quality of cobalt required to make jet engine parts. Although there may be adequate quantities of cobalt available when demand improves, the question remains whether there will be a shortage of high-quality cobalt. One analyst estimated that in addition to high-quality cobalt from other producers, 1,000 to 2,000 tons of electrolytic cobalt would be required annually from Zaire to satisfy market demand during the next 2 to 3 years.[29] Of the new refiners expected to begin production, only Uganda currently plans to produce electrolytic cobalt. At an anticipated rate of 1,000 tons per year, Ugandan cobalt could help ease, but may not eliminate, a potential shortfall in high-quality cobalt metal. Upgrading lower quality cobalt to higher quality cobalt may become an economically viable solution.

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The Northern Miner (Toronto), weekly.

TABLE 1
WORLD PRODUCERS OF REFINED COBALT IN 1993

Country	Company	Cobalt products
Brazil	Companhia Niquel Tocantins	Cathode.
Canada	Inco Ltd.	Cathode, oxide.
Do.	Sherritt Inc.	Metal powder, briquettes.
China	China National Nonferrous Metals Industry Corp.	Cathode,[1] oxide, salts.
Finland	OM Group, Inc.	Metal powder, oxide, salts.
France	Eramet-SLN	Chloride.
Japan	Sumitomo Metal Mining Co. Ltd.	Cathode, oxide, salts.
Norway	Falconbridge Ltd.	Cathode.
Russia	Norilsk Nickel Complex	Ingot, cathode, oxide, salts.
Do.	Yuzhural Nickel Complex	
South Africa, Republic of	Impala Platinum Ltd.	Metal powder.
Do.	Rustenberg Base Metal Refiners Pty. Ltd.	Sulfate.
Zaire	La Générale des Carrières et des Mines.	Cathode, granules.
Zambia	Zambia Consolidated Copper Mines Ltd.	Cathode, crushed bar.

[1] Other metal forms possible.

TABLE 2
WORLD PRODUCERS OF INTERMEDIATE COBALT PRODUCTS[1] IN 1993

Country	Company	Cobalt-containing products
Australia	QNI Ltd.	Cobalt sulfide.
Do.	Western Mining Corp.	Nickel-cobalt sulfide, nickel matte.
Do.	Pacific Smelting and Mining Co. Ltd.	Impure cobalt oxide.
Botswana	BCL Ltd.	Nickel-copper matte.
Cuba	Unión de Empresas del Níquel	Nickel-cobalt sulfide.
Morocco	Compagnie de Tifnout Tiranimine	Cobalt concentrate.
New Caledonia	Société Metallurgique le Nickel	Nickel matte.
South Africa, Republic of	Western Platinum Ltd.	Nickel sulfate, nickel matte.
Zimbabwe	Bindura Nickel Corp. Ltd.	Cobalt-nickel hydroxide.
Do.	Rio Tinto (Zimbabwe) Ltd.	Do.

[1] Excludes companies producing refined cobalt.

TABLE 3
SALIENT COBALT STATISTICS

(Metric tons cobalt content unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Consumption:					
Reported	7,172	7,512	7,240	[r]6,471	6,473
Apparent	7,164	7,635	7,786	6,526	7,305
Imports for consumption	5,793	6,529	6,924	5,757	5,945
Exports	889	1,340	1,536	1,424	795
Stocks, December 31[1]	1,456	1,853	1,622	[r]896	875
Price: Metal, per pound[2]	$7.64	$10.09	$16.92	$22.93	$13.79
World: Production					
Mine	[r]42,873	[r]42,420	[r]32,906	[r]27,131	[e]22,224
Refinery	[r]26,407	[r]27,297	[r]24,761	[r]21,901	[e]16,893

[e]Estimated. [r]Revised.

[1]Stocks held by consumers and chemical processors.

[2]Market price based on weighted average of Metals Week's prices.

TABLE 4
U.S. REPORTED CONSUMPTION OF COBALT,[1] BY END USE

(Metric tons, cobalt content)

End use	1989	1990	1991	1992	1993
Steel:					
Full-alloy	W	W	W	W	W
Stainless and heat-resisting	74	41	51	26	41
Tool	219	123	W	47	59
Superalloys	2,860	3,345	3,066	2,697	2,614
Alloys (excluding alloy steels and superalloys):					
Cutting and wear-resistant materials[2]	538	541	525	522	569
Magnetic alloys	870	710	713	670	629
Nonferrous alloys	27	31	32	W	(3)
Welding materials (structural and hard-facing)[4]	136	180	135	[r]128	171
Other alloys	52	74	62	45	[5]95
Mill products made from metal powder	W	W	W	W	W
Chemical and ceramic uses:					
Catalysts	W	W	W	949	935
Drier in paint or related usage	718	[6]751	[6]781	[6]745	[6]732
Ground coat frit	366	357	W	257	W
Pigments	W	W	W	197	193
Miscellaneous and unspecified[7]	1,313	1,361	1,876	187	433
Total[8]	7,172	7,512	7,240	[r]6,471	6,473

[r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1]Includes estimates.

[2]Includes diamond bit matrices, cemented and sintered carbides, and cast carbide dies or parts.

[3]Included with "Other alloys."

[4]Includes wear-resistant alloys.

[5]Includes "Nonferrous alloys."

[6]Data not comparable with 1989 because of a change in reporting method.

[7]Includes feed or nutritive additive, glass decolorizer, and data indicated by symbol "W."

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

TABLE 5

U.S. REPORTED CONSUMPTION OF COBALT,[1] BY FORM

(Metric tons, cobalt content)

	1989	1990	1991	1992	1993
Chemical compounds (organic and inorganic)[2]	2,081	2,192	2,137	2,105	2,043
Metal	3,907	4,095	3,525	[r]2,753	2,864
Purchased scrap	1,184	1,225	1,578	1,613	1,566
Total	7,172	7,512	7,240	[r]6,471	6,473

[r] Revised.

[1] Includes estimates.

[2] Includes oxides.

TABLE 6

U.S. REPORTED STOCKS OF COBALT MATERIALS,[1] DECEMBER 31

(Metric tons, cobalt content)

	1989	1990	1991	1992	1993
Chemical compounds (organic and inorganic)[2]	394	379	362	344	307
Metal	860	1,342	1,072	[r]399	410
Scrap	202	132	189	153	158
Total	1,456	1,853	[3]1,622	[r]896	875

[r] Revised.

[1] Stocks reported by cobalt processors and consumers; includes estimates.

[2] Includes oxide.

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

TABLE 7

YEAREND PRICES OF COBALT MATERIALS[1]

(Dollars per pound)

Material	1989	1990	1991	1992	1993
Cobalt metal:					
Cathode or granules (shot)[2] [3]	8.40	8.40	11.00	[4]18.00	18.00
Fine powder (less than 1.6 micrometers)[5]	17.75	22.11	31.67	32.11	NA
Powder (300-mesh, 400-mesh, 100-mesh)	14.71	18.63	29.46	29.10	NA
S-grade powder (minus 48-mesh)	[6]8.65	[6]8.65	[7]11.90	XX	XX
Cobalt oxide:					
Ceramic-grade (70% to 71% cobalt)	9.42	11.14	18.94	18.00	NA
Ceramic-grade (72% to 73% cobalt)	9.67	11.44	19.44	18.50	NA
Metallurgical-grade (76% cobalt)	10.06	11.67	19.69	NA	NA

NA Not available. XX Not applicable.

[1] Prices are list prices from African Metals Corp., unless otherwise noted.

[2] See table 3 for cathode market price.

[3] 250-kilogram drums.

[4] Cathode price. Yearend price for granules was $17.00 per pound.

[5] 50-kilogram drums.

[6] Sherritt Gordon Ltd. list price.

[7] Metals Week.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY FORM

(Metric tons unless otherwise specified)

		1991	1992	1993
Metal:[1]				
Gross weight		6,375	5,274	5,388
Cobalt content[2]		6,375	5,274	5,388
Value	thousands	$157,711	$246,393	$166,284
Oxides and hydroxides:				
Gross weight		583	431	444
Cobalt content[2]		420	310	320
Value	thousands	$12,941	$18,651	$12,612
Other forms:				
Acetates:				
Gross weight		33	92	13
Cobalt content[2]		8	22	3
Value	thousands	$309	$646	$141
Carbonates:				
Gross weight		53	34	57
Cobalt content[2]		24	16	26
Value	thousands	$776	$934	$980
Chlorides:				
Gross weight		12	42	17
Cobalt content[2]		3	11	4
Value	thousands	$101	$651	$157
Sulfates:				
Gross weight		350	461	754
Cobalt content[2]		95	125	204
Value	thousands	$2,295	$5,548	$6,037
Total:[3]				
Gross weight		7,406	6,334	6,674
Cobalt content[2]		6,924	5,757	5,945
Value	thousands	$174,134	$272,822	$186,211

[1] Unwrought cobalt, excluding alloys and waste and scrap.

[2] Estimated from gross weights.

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

Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF COBALT, BY COUNTRY

Country of origin	Metal[1]			Oxides and hydroxides			Other forms[2]			Total[3]		
	Gross weight (metric tons)	Cobalt content[4] (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content[4] (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content[4] (metric tons)	Value (thousands)	Gross weight (metric tons)	Cobalt content[4] (metric tons)	Value (thousands)
1992:												
Belgium	345	345	$19,108	150	108	$6,857	50	13	$735	545	465	$26,701
Brazil	8	8	385	—	—	—	2	1	30	10	9	415
Canada	875	875	40,461	2	1	72	16	7	479	892	883	41,013
China	50	50	1,727	11	8	434	—	—	—	61	57	2,161
Finland	223	223	14,141	145	104	5,970	385	104	5,091	753	431	25,202
France	24	24	1,666	7	5	615	—	—	—	31	29	2,281
Germany	86	86	6,200	6	4	238	—	—	—	91	90	6,438
Japan	7	7	382	6	4	145	(5)	(5)	4	13	11	532
Norway	933	933	44,660	—	—	—	—	—	—	933	933	44,660
Russia[6]	431	431	14,698	11	8	444	—	—	—	443	439	15,142
South Africa, Republic of	93	93	4,523	—	—	—	170	46	1,296	263	139	5,819
United Kingdom	44	44	1,871	94	68	3,861	6	2	142	144	114	5,873
Zaire	592	592	27,932	—	—	—	—	—	—	592	592	27,932
Zambia	1,560	1,560	68,421	—	—	—	—	—	—	1,560	1,560	68,421
Other	3	3	216	(5)	(5)	14	—	—	—	4	4	230
Total[3]	5,274	5,274	246,393	431	310	18,651	629	172	7,778	6,334	5,757	272,822
1993:												
Belgium	109	109	6,289	158	114	5,042	21	7	306	288	230	11,637
Brazil	—	—	—	—	—	—	2	(5)	23	2	(5)	23
Canada	790	790	23,198	20	14	449	13	6	222	823	810	23,868
China	—	—	—	2	1	76	—	—	—	2	1	76
Finland	433	433	16,260	158	114	4,078	784	217	6,595	1,375	764	26,932
France	37	37	3,111	6	4	383	—	—	—	43	41	3,494
Germany	120	120	7,677	—	—	—	(5)	(5)	2	120	120	7,679
Japan	2	2	198	18	13	221	(5)	(5)	5	21	15	423
Norway	1,089	1,089	32,474	—	—	—	—	—	—	1,089	1,089	32,474
Russia	539	539	14,505	4	3	82	20	6	141	562	548	14,727
South Africa, Republic of	41	41	1,265	—	—	—	—	—	—	41	41	1,265
United Kingdom	24	24	738	77	56	2,282	3	1	22	104	80	3,042
Zaire	627	627	21,399	—	—	—	—	—	—	627	627	21,399
Zambia	1,556	1,556	38,458	—	—	—	—	—	—	1,556	1,556	38,458
Other	22	22	712	—	—	—	—	—	—	22	22	712
Total[3]	5,388	5,388	166,284	444	320	12,612	842	237	7,315	6,674	5,945	186,211

[1] Unwrought cobalt, excluding alloys and waste and scrap.
[2] Cobalt sulfates, cobalt chlorides, cobalt carbonates, and cobalt acetates.
[3] Data may not add to totals shown because of independent rounding.
[4] Estimated from gross weights.
[5] Less than 1/2 unit.
[6] Formerly part of the U.S.S.R. Includes materials imported during 1992 under the country code for the U.S.S.R.

Source: Bureau of the Census; minor adjustments by the U.S. Bureau of Mines.

TABLE 10
U.S. EXPORTS OF COBALT IN 1993, BY COUNTRY[1]

Country of destination	Metal[2]		Oxides and hydroxides		Acetates		Chlorides		Total content[4] (metric tons)	Total value[3] (thousands)
	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Value[3] (thousands)		
Argentina	11	$336	26	$386	—	—	—	—	29	$722
Australia	7	172	7	163	(5)	$13	—	—	12	347
Brazil	48	781	15	326	52	504	3	$24	73	1,635
Canada	145	2,711	27	692	3	29	272	1,276	233	4,708
Chile	(5)	11	6	154	—	—	—	—	4	165
Colombia	—	—	9	205	—	—	—	—	6	205
El Salvador	—	—	—	—	11	95	—	—	3	95
France	28	482	1	44	—	—	1	21	29	546
Germany	25	1,102	1	47	—	—	—	—	26	1,149
Hong Kong	6	185	23	417	—	—	—	—	23	602
India	2	30	—	—	14	148	—	—	5	178
Indonesia	38	1,471	—	—	—	—	—	—	38	1,471
Japan	46	879	32	814	—	—	—	—	69	1,693
Korea, Republic of	4	158	1	37	—	—	1	5	5	200
Mexico	4	169	106	1,557	76	579	1	15	98	2,320
Netherlands	7	395	5	102	1	7	—	—	11	504
Peru	1	14	6	163	—	—	—	—	5	177
Taiwan	(5)	17	30	594	100	1,074	13	188	49	1,874
Turkey	(5)	7	—	—	5	33	—	—	1	40
United Kingdom	45	1,190	—	—	7	35	—	—	46	1,225
Other	17	819	14	381	4	49	—	—	28	1,249
Total[6]	435	10,928	308	6,081	272	2,566	291	1,530	795	21,104

[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] Free alongside ship (f.a.s.) value.

[4] Estimated from gross weights.

[5] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 11

WORLD ANNUAL COBALT PRODUCTION CAPACITY, DECEMBER 31, 1993

(Metric tons, cobalt content)

Country	Refinery capacity
Brazil	300
Canada[1]	3,400
China[e]	500
Finland[e] [2]	3,000
France[3]	600
Japan[2] [4]	2,800
Norway	2,600
Russia[e]	8,000
South Africa, Republic of[2]	750
United States[5]	900
Zaire	18,000
Zambia	5,000
Total	45,850

[e] Estimated.

[1] Includes oxide.

[2] Includes salts.

[3] Cobalt chloride.

[4] Includes an estimated standby capacity of 1,900 metric tons.

[5] Standby capacity.

TABLE 12

COBALT: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons, cobalt content)

Country[2]	1989	1990	1991	1992	1993[e]
Albania[e] [3]	600	600	600	[r]20	10
Australia[e] [4]	1,100	[r]1,200	[r]1,400	[r]1,600	1,700
Botswana[5]	215	205	208	[r]208	200
Brazil[e]	300	400	400	400	400
Canada[6]	[r]6,167	[r]5,470	[r]5,274	[r]5,102	[7]5,738
Cuba[e] [8]	[7]1,825	1,600	1,600	1,500	1,500
Morocco[9]	121	194	325	[r]461	[7]397
New Caledonia[e] [10]	800	800	800	800	800
Russia[e] [11]	—	—	—	[r]4,000	3,300
South Africa, Republic of[e]	300	350	300	350	350
U.S.S.R.[e] [11] [12]	[r]5,700	[r]5,500	[r]5,000	—	—
Zaire[9] [13]	18,400	19,000	9,900	5,700	2,459
Zambia[9] [14]	7,255	6,999	6,994	[r]6,910	5,300
Zimbabwe[e] [15]	90	102	105	[r]80	70
Total	[r]42,873	[r]42,420	[r]32,906	[r]27,131	22,224

[e] Estimated. [r] Revised.

[1] Table includes data available through July 11, 1994. Figures represent recoverable cobalt content of ores, concentrates, or intermediate products from copper, nickel, platinum, or zinc operations. Morocco was the only country where cobalt was mined as a primary product.

[2] In addition to the countries listed, Bulgaria, China, Germany, Indonesia, and Poland are known to produce ores that contain cobalt, but information is inadequate for reliable estimates of output levels. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.

[3] Calculated from reported and estimated weight of nickeliferous ore.

[4] Figures represent cobalt contained in intermediate metallurgical products (cobalt oxide, cobalt sulfide and nickel-cobalt sulfide) produced from Australian and imported ores. Cobalt content of lateritic nickel ore, nickel concentrate, and zinc concentrate originating in Australia was estimated as follows, in metric tons: 1989—2,268 (revised); 1990—1,870 (revised); 1991—1,670 (revised); 1992—1,270 (revised); and 1993—1,270.

[5] Reported cobalt content of pelletized nickel-copper matte.

[6] Figures represent the assay content of cobalt in concentrates produced. The cobalt content of all products derived from ores of Canadian origin, including cobalt oxide shipped to the United Kingdom for further processing and nickel-copper-cobalt matte shipped to Norway for refining, was reported as follows, in metric tons: 1989—2,344; 1990—2,184; 1991—2,171; 1992—2,223 (revised); 1993—2,370.

[7] Reported figure.

[8] Determined from reported nickel-cobalt content of granular and powder oxide, oxide sinter, and sulfide production.

[9] Cobalt content of concentrates.

[10] Series represents estimated recoverable content of ores and intermediate metallurgical products exported from New Caledonia to France. The estimated cobalt content of total ores mined is as follows, in metric tons: 1989—6,000; 1990—6,000; 1991—6,000; 1992—6,000; and 1993—6,000.

[11] All production in the U.S.S.R. from 1989-91 came from Russia.

[12] Dissolved in Dec. 1991.

[13] In addition to concentrates, cobalt hydrates and scrap are used as feed to the refineries. Cobalt content of these materials was as follows, in metric tons: Hydrates: 1989—0; 1990—3,194; 1991—5,483; 1992—4,106; and 1993—not available. Scrap: 1989—27; 1990—49; 1991—517; 1992—1,113; and 1993—not available.

[14] Fiscal years beginning Apr. 1 of that stated. Cobalt content of ore milled was as follows, in metric tons: 1989—10,590; 1990—10,870; 1991—10,976; 1992—11,366; and 1993—8,700 (estimated).

[15] Estimated cobalt content of ore.

TABLE 13

COBALT: WORLD REFINERY PRODUCTION, BY COUNTRY AND PRODUCT[1]

(Metric tons, cobalt content)

Country[2]	1989	1990	1991	1992	1993[e]
Albania: Oxide[e]	10	20	[r]15	[r]3	1
Brazil: Metal[e]	70	240	240	240	240
Canada: Metal (including metal powder and oxide)	2,110	2,063	2,248	2,210	2,695
China: Metal[e]	[r]255	325	[r]300	[r]220	300
Finland:					
Metal (including metal powder)[e]	292	330	270	230	300
Salts[e]	1,003	970	1,233	1,870	1,900
Total	1,295	1,300	1,503	2,100	[3]2,200
France: Chloride	165	150	[r]123	[e]150	150
Japan: Metal	99	199	185	105	190
Norway: Metal	1,946	1,830	1,983	2,293	[3]2,414
Russia: Unspecified[e] [4]	—	—	—	[r]4,500	4,000
South Africa, Republic of:					
Metal (powder)[e]	60	70	60	65	50
Sulfate[e]	139	179	149	169	122
Total	199	249	209	234	[3]172
U.S.S.R.: Unspecified[e] [4] [5]	[r]6,500	[r]6,300	[r]5,100	—	—
Zaire: Metal[6]	9,311	9,947	8,114	5,049	[3]831
Zambia: Metal[7]	4,447	4,674	4,741	[r]4,797	3,700
Total	[r]26,407	[r]27,297	[r]24,761	[r]21,901	16,893
Of which:					
Metal	[r]18,590	[r]19,678	[r]18,141	[r]15,209	10,720
Salts[8]	1,317	1,319	[r]1,520	[r]2,192	2,173
Unspecified	[r]6,500	[r]6,300	[r]5,100	[r]4,500	4,000

[e]Estimated. [r]Revised.

[1] Table includes data available through July 11, 1994. Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include production of downstream products from refined cobalt.

[2] In addition to the countries listed, Belgium, Czechoslovakia, and Germany may recover cobalt from imported materials, but production is not reported, and information is inadequate to make reliable estimates of production.

[3] Reported figure.

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

[5] Dissolved in Dec. 1991.

[6] Excludes production of cobalt in white alloy, matte, and slag that would require further refining.

[7] Fiscal years beginning Apr. 1 of that stated.

[8] Includes oxide.

FIGURE 1
U.S. COBALT CONSUMPTION IN 1993, BY FORM AND USE

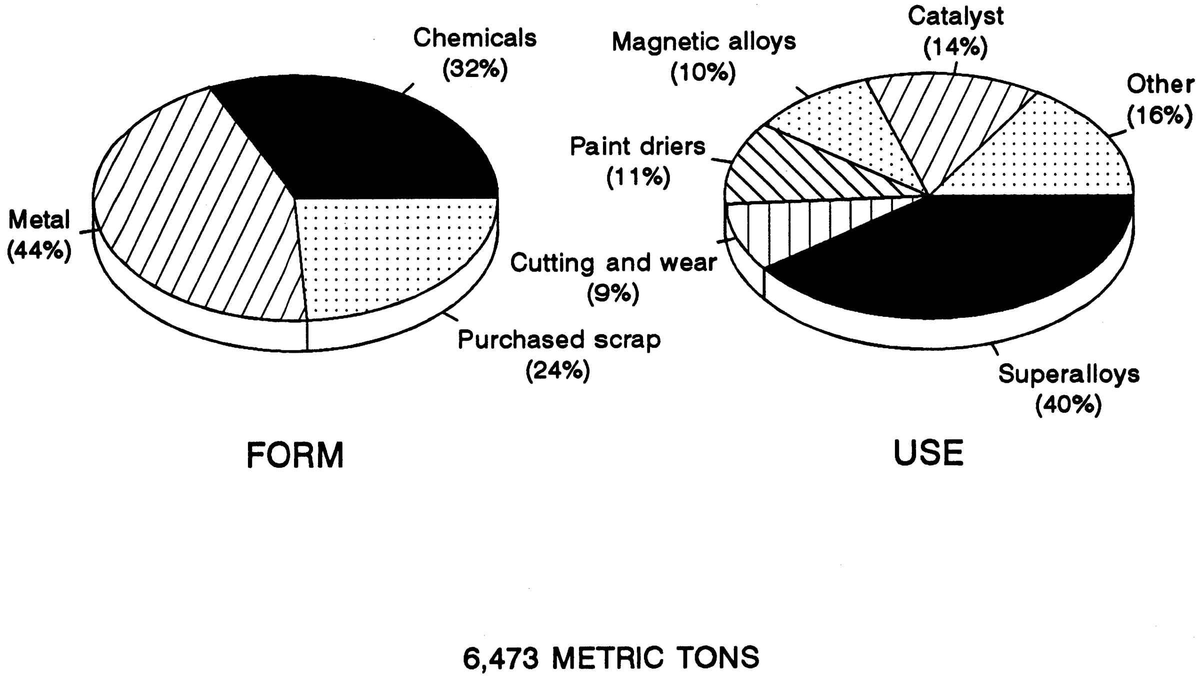
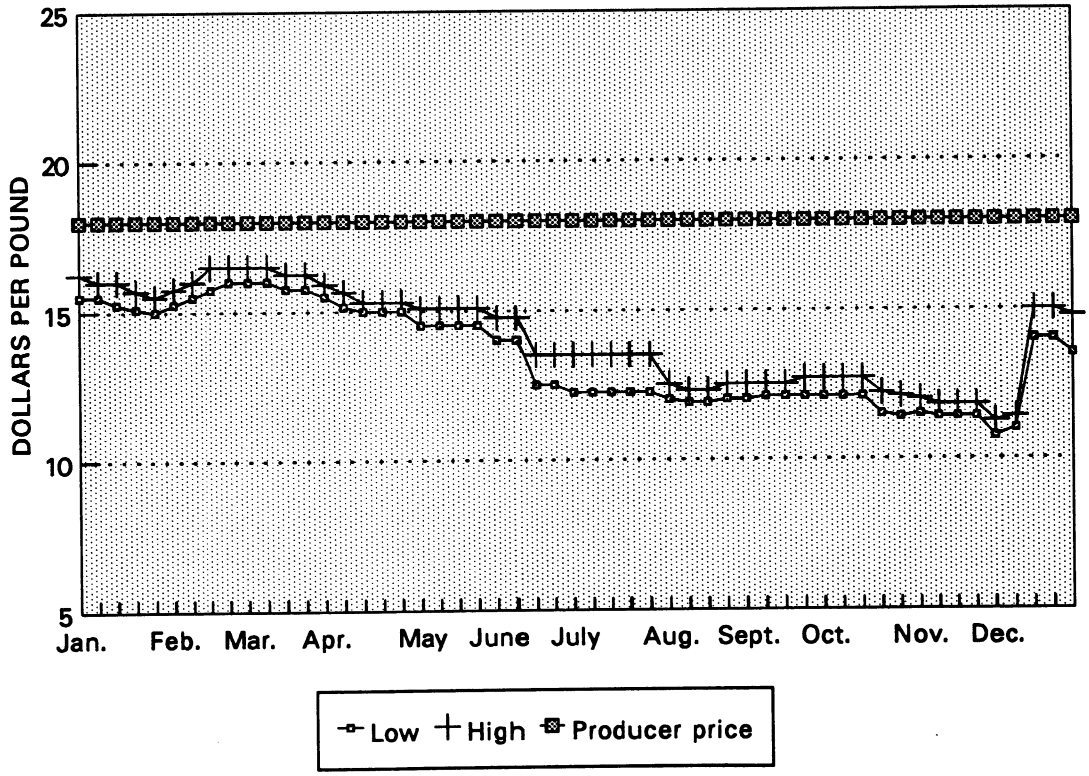
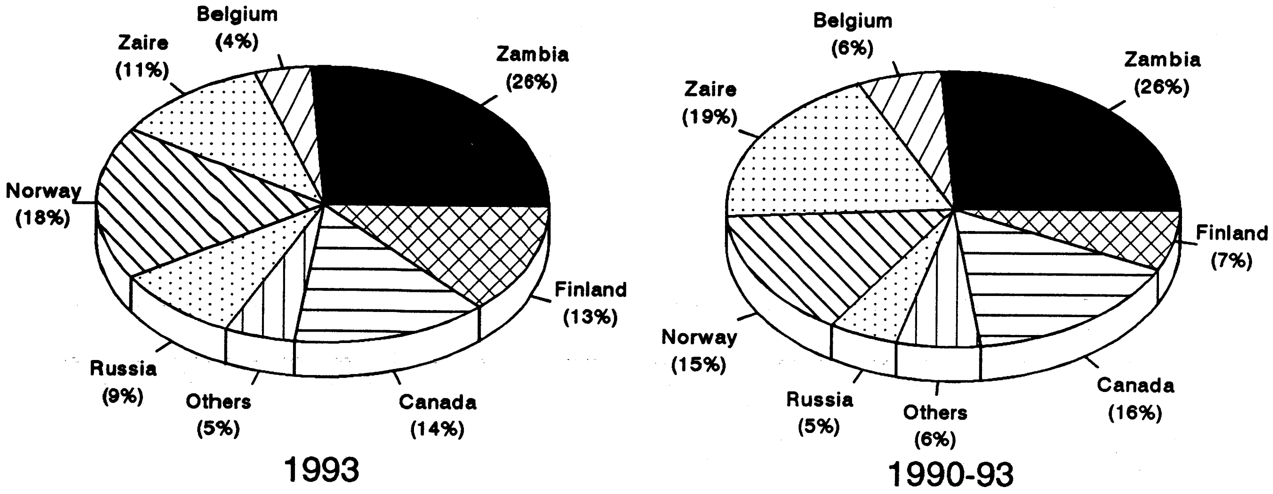


FIGURE 2
TIME-PRICE RELATIONSHIPS FOR COBALT IN 1993



Source: Platt's Metals Week.

FIGURE 3
U.S. COBALT IMPORTS, BY SOURCE



Source: Bureau of the Census.

COLUMBIUM (NIOBIUM) AND TANTALUM

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 14 years of U.S. Bureau of Mines experience, has served as the commodity specialist for columbium and tantalum since 1983. Domestic survey and trade data were prepared by Mr. Dwayne Penn, statistical assistant; and columbium and tantalum world production data, by country, were prepared by Ms. Amy Durham, international data coordinator.

Columbium (Cb) is vital as an alloying element in steels and in superalloys for aircraft turbine engines and is in greatest demand in industrialized countries. Columbium is critical to the United States because of its defense-related uses in the aerospace, energy, and transportation industries. Acceptable substitutes are available for some columbium applications, but in most cases they are less desirable.

Tantalum (Ta) is used mostly in the electronics industry, mainly in capacitors, and in aerospace and transportation applications. Tantalum is also critical to the United States because of its defense-related applications in aircraft, missiles, and radio communications. Substitution for tantalum is made at either a performance or economic penalty in most applications.

Domestic columbium and tantalum resources are of low grade and are not commercially recoverable. The last significant mining of columbium and tantalum was during the Korean conflict when increased military demand resulted in columbium and tantalum ore shortages.

The United States continued to be dependent on imports of columbium and tantalum materials. Brazil remained the major source for columbium imports, and Australia remained the major source for tantalum imports. Columbium and tantalum price quotations remained stable.

The Generalized System of Preferences (GSP), which expired on July 4, 1993, was extended to September 30, 1994. Additionally, legislation prohibiting GSP benefits to the countries that made up the former U.S.S.R. was removed. In September, the President designated Russia as a beneficiary developing country for purposes of the GSP. In October, Congress voted to close down the Department of Energy's (DOE) Superconducting Super Collider (SSC) project in Texas.

There was a slight increase in overall reported consumption of columbium in the form of ferrocolumbium and nickel columbium. Overall demand for tantalum was at the highest level since 1988.

Cabot Corp. acquired a 100% interest in the Bernic Lake, Manitoba, tantalum mining operation of the Tantalum Mining Corp. of Canada Ltd. (Tanco).

DOMESTIC DATA COVERAGE

Domestic production data for ferrocolumbium are developed by the U.S. Bureau of Mines from the annual voluntary domestic survey for ferroalloys. Of the four operations to which a survey request was sent, two responded. Thus, ferrocolumbium production data for 1993 were incomplete at the time this report was prepared.

BACKGROUND—COLUMBIUM

Columbium and niobium are synonymous names for the chemical element with atomic number 41; columbium was the first name given, and niobium was the name officially designated by the International Union of Pure and Applied Chemistry in 1950. The metal conducts heat and electricity relatively well, has a high melting point (2,480° C), is readily fabricated, and is highly resistant to many chemical environments. Columbium exhibits superconductivity at about 9° K, a temperature still too low for most commercial applications. (Superconductivity is the virtual loss of electrical resistance that occurs at a specific material-dependent temperature and results in energy conservation and more rapid operation of electrical circuits.)

Definitions, Grades, and Specifications

Columbium pentoxide (oxide) is a stable, white- to buff-colored compound that is produced in metallurgical, ceramic, and optical grades. Purity of oxide generally exceeds 99%.

Ferrocolumbium is categorized into three grades by American Society for Testing and Materials (ASTM) Specification A550: low-alloy steel grade, alloy and stainless steel grade, and high-purity grade. For all grades, the composition is approximately 65% columbium, with the balance iron; principal impurities are aluminum, silicon, and tantalum. Nickel columbium typically contains 63% columbium, with the balance nickel. Aluminum, iron, silicon, and tantalum are the principal impurities.

Columbium carbide is available as a powder containing about 87% columbium and the balance carbon.

Columbium metal is available in many forms and shapes. Purity of unalloyed metal is usually more than 99%. Iron, tantalum, and zirconium are principal common metallic impurities, and carbon, hydrogen, nitrogen, and oxygen are typical interstitial impurities. Alloys with hafnium, tantalum, titanium, tungsten, and zirconium are of the most commercial importance. Chemical and physical standards for columbium and columbium alloy mill shapes are given in ASTM Specifications B391-B394, B652, and B654-B655.

Products for Trade and Industry

Columbium, in the form of ferrocolumbium, is used worldwide, principally as an additive to improve the strength and corrosion resistance of steel. Columbium-containing, high-strength corrosion-resistant steel is used in applications such as high-strength linepipe, structural members, lightweight components in cars and trucks, and exhaust manifolds. Because of its refractory nature, appreciable amounts of columbium in the form of high-purity ferrocolumbium and nickel columbium are used in nickel-, cobalt-, and iron-base superalloys for applications such as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment. Columbium-base alloys also are used in aerospace applications such as rocket nozzles. Columbium carbide is used in cemented carbides to modify the properties of the cobalt-bonded tungsten carbide-based material. It is usually used with carbides of metals such as tantalum and titanium. Columbium oxide is the intermediate product used in the manufacture of high-purity ferrocolumbium, nickel columbium, columbium metal, and columbium carbide.

Geology-Resources

Columbium is almost always found in nature as an oxide in association with other minerals but not in elemental form or as a sulfide. Columbium has an overall crustal abundance estimated as 20 parts per million and a strong geochemical coherence with tantalum. Pyrochlore and bariopyrochlore (also known as pandaite), its barium analog, have become the main sources of columbium. The minerals contain little tantalum, having a columbium oxide-to-tantalum oxide ratio of 200:1 or greater. Pyrochlore and bariopyrochlore are commonly found in the interior parts of alkalic rock complexes, frequently in association with minerals of such other elements as thorium, titanium, uranium, and those of the rare earths. Columbite, the columbium-rich member of the columbite-tantalite isomorphous series, is normally found in intrusive pegmatites and in biotite and alkalic granites. However, because most such deposits relatively high in columbium content are small and erratically distributed, most columbite has been obtained as a byproduct of mining for other commodities, mainly tin.

Reserve and reserve base data for columbium are shown in table 1 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination. *(See table 1.)*

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 methods, or a combination of both. Currently, all mining for pyrochlore in Brazil is open pit, whereas in Canada underground mining is being done via a large-diameter blasthole method. Ore, with host rock, is usually dislodged from a working face with explosives. Beneficiation of the ore, after it has been finely ground, is achieved primarily by various flotation procedures combined with magnetic separation to remove iron minerals. A chloridizing and leaching process also can be employed to lower barium, lead, phosphorus, and sulfur contents. Methods used to mine columbite have ranged from simple hand operations in small pegmatite mines to hydraulic monitors and dredges at placer deposits.

Beneficiation.—Pyrochlore concentrates are used solely in the manufacture of ferrocolumbium for steelmaking. Aluminothermy is a process being used for making steelmaking-grade ferrocolumbium from pyrochlore concentrates. Processes also have been developed for production of columbium oxide through treatment of ferrocolumbium produced from pyrochlore concentrates. This technology is being used to produce commercial quantities of columbium oxide suitable for the manufacture of high-purity ferrocolumbium, nickel columbium, and columbium metal.

In the extraction of columbium from other mineral concentrates and tin slags, modern technology makes use mainly of digestion with hydrofluoric acid followed by liquid-liquid extraction with methyl isobutyl ketone (MIBK). This procedure efficiently recovers both columbium and tantalum in the form of separate streams that then can be further processed individually into oxides and metal. Columbium oxide is precipitated from the columbium stream by ammonia and then purified and calcined.

Columbium oxide is aluminothermically reduced batchwise to produce high-purity ferrocolumbium, nickel columbium, and columbium metal. Aluminothermically produced columbium metal is commonly purified to remove aluminum and other contaminants by remelting it in an electron-beam furnace. Several remelts may be required before the desired level of purity is reached and a ductile ingot has been produced. The basic method for production of columbium carbide is reduction of columbium oxide by carbon at high temperature under vacuum or a protective atmosphere.

Recycling.—Columbium used in steelmaking and in superalloy manufacture is essentially a dissipative use, and little is reclaimed. However, when strict scrap segregation practices are followed, small quantities of columbium-bearing superalloy scrap are recycled. Aside from sales to alloy melters, columbium metal scrap has not been recycled to any extent other than in-house as home scrap by processors.

Byproducts and Coproducts

In Africa, Australia, Brazil, Malaysia, and Thailand, columbium, as well as tantalum, is produced as a byproduct and/or coproduct of tin mining. Columbium and tantalum also can be recovered economically from some tin slags, which constitute an important raw material source for high-purity columbium and tantalum. Other elements frequently associated with columbium deposits include rare earths, thorium, titanium, and uranium; some of these have been recovered along with columbium in the past and may be coextracted in the future.

Substitutes

For established applications of columbium-bearing steels and superalloys, substitution of some alternative steel or alloy requiring less columbium ordinarily lowers performance and/or cost-effectiveness. In some high-strength low-alloy (HSLA) steels, use of columbium as a microalloying element competes with use of such elements as molybdenum, titanium, and vanadium. In other HSLA steels, it may be desirable to use one or more of these elements along with columbium in complementary fashion. Tantalum is a costly potential substitute for columbium in superalloys. Titanium can be used instead of columbium in stainless steel to improve corrosion resistance.

Economic Factors

Prices.—Time-price relationships for columbium contained in concentrates in terms of actual prices and in constant 1987 dollars are shown in table 2 and figure 1. Actual prices reported are based on historical price quotations or best available information from producers. *(See table 2 and figure 1.)*

By the end of World War II, new columbium-bearing superalloys were being used in jet airplane engines. Subsequently, the involvement of the United States in the Korean conflict and the rapid expansion of jet engine production during this period resulted in columbium concentrate shortages and increased prices. Additionally, the demand for ore to produce ferrocolumbium had outstripped the available supply of columbium-bearing materials. However, a significant activity during this period was the U.S. Government-guaranteed worldwide 100% bonus purchase program under title III of the Defense Production Act. The program was initiated to encourage increased production of columbium-tantalum ore and concentrates of both domestic and foreign origin.

In May 1952, the Defense Materials Procurement Agency (DMPA) announced its schedule for the purchase of columbium concentrates for the National Stockpile at an average price of $3.40 per pound of combined columbium-tantalum oxides. The program was such a success in the expansion of supply that in only 3 years the stockpile had acquired 6.8 million tons of columbium and tantalum oxides contained in columbium concentrates.

Having achieved its basic objectives, the U.S. Government stopped buying foreign material under the program in May 1955. Small-lot purchases of domestically produced material continued until 1958. The DMPA purchase price largely had governed the market quotations for columbium concentrates, and termination of the program was followed by lower prices and reduced production worldwide.

With the trend of increasing columbium demand, concentrate prices began to escalate in the mid-1970's with the peak year occurring in 1977. The price increase was attributed to inflation, higher labor costs, and resulting higher raw material costs.

In 1980, an important change in the nature of columbium supply occurred with the commercialization both in Brazil and the United States of plants for producing columbium oxide from pyrochlore-based materials. This event resulted in the lowering of prices for columbium oxide and high-purity columbium products. Columbium prices were lowered during much of the 1980's, owing to the large quantities of pyrochlore produced in Brazil and Canada and the products produced from this feed material. Through 1993, columbium prices were essentially the same as those in the late 1980's.

Depletion Provisions.—U.S. columbium-producing companies are granted a depletion allowance of 22% for domestic production of columbium minerals and 14% for foreign production.

BACKGROUND—TANTALUM

Tantalum is a refractory metal that is ductile, easily fabricated, has a high melting point (2,996° C), is highly resistant to corrosion by acids, and is a good conductor of heat and electricity. It combines readily with other refractory metals such as hafnium and tungsten to form alloys having high-temperature strength and stability. Tantalum forms highly stable anodic films and exhibits a rectifying, or electronic valve, action in an electrolyte. Tantalum is twice as dense as steel with a specific gravity of 16.6.

Definitions, Grades, and Specifications

Metallic forms of tantalum are produced chiefly in unalloyed form or alloyed with up to about 10% tungsten. Unalloyed metal and alloys with tungsten are available as ingot, plate, sheet, strip, bar, rod, wire, and tubing in accordance with ASTM Specifications B364, B365, and B521. Allowable impurity levels do not exceed 0.3% in most cases; the main impurities are columbium and oxygen, plus tungsten in the case of unalloyed tantalum. Purity of tantalum metal powder is usually about 99.9%. Depending on powder usage, impurities that must be controlled consist mainly of calcium, carbon, columbium, iron, nickel, nitrogen, oxygen, silicon, and sodium. Commercial tantalum carbide usually contains about 93% tantalum and about 6.3% carbon.

Products for Trade and Industry

The major end use for tantalum, as tantalum metal powder, is in the production of electronic components, mainly tantalum capacitors. Applications for tantalum capacitors include computers, communication systems, and instruments and controls for aircraft, missiles, ships, and weapon systems. The tantalum capacitor exhibits reliable performance and combines compactness and high efficiency with good shelf-life. Because of its high melting point, good strength at elevated temperatures, and good corrosion resistance, tantalum is combined with cobalt, iron, and nickel to produce superalloys that are employed in aerospace structures and jet engine components. Tantalum carbide, used mostly in mixtures with carbides of such metals as columbium, titanium, and tungsten, is used in cemented-carbide cutting tools, wear-resistant parts, farm tools, and turning and boring tools. Because of its excellent corrosion-resistant properties, tantalum mill and fabricated products are used in the chemical industry in applications such as heat exchangers, evaporators, condensers, pumps, and liners for reactors and tanks.

Geology-Resources

The principal source of tantalum is an isomorphous series of minerals containing columbium, iron, manganese, and tantalum oxides. Tantalum and columbium have strong geochemical affinity and are found together in most rocks and minerals in which they occur. Tantalite-columbite occurs mainly as accessory minerals disseminated in granitic rocks or in pegmatites associated with granites. The microlite-pyrochlore mineral series is also a source of tantalum. These minerals consist essentially of complex oxides of calcium, columbium, sodium, and tantalum in combination with hydroxyl ions and fluorides. Microlite occurs mainly in the albitized zones of granite pegmatites, often associated with tantalite or columbite. Struverite is a low-grade source of tantalum recoverable from tin-mining wastes in Southeast Asia. Struverite is a variation of the titanium mineral rutile. Tantalum also is obtained through byproduct recovery from tantalum-bearing tin slags, principally from smelters in Brazil and Southeast Asia.

Reserve and reserve base data for tantalum are shown in table 3 and are based on a judgmental appraisal of current information. Reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. Reserves are defined as that part of the reserve base that could be economically extracted or produced at the time of determination. *(See table 3.)*

Technology

Exploration.—Exploration for tantalum is generally pursued on the basis of its known frequent association with tin and certain other elements in pegmatite environments, some features of which can be distinguished by aerial photography. Application of X-ray fluorescence analysis techniques has been helpful in measuring tantalum at the low concentrations at which it occurs. The high specific gravity of tantalum minerals makes it possible to reveal their presence in placer deposits by test pitting and panning.

Mining.—Most tantalum-related mining developments in the past generally were small, relatively high-cost intermittent operations that depended on the recovery of byproduct or coproduct minerals for economic viability. However, current mine development has shifted more to primary tantalum sources, notably operations in Australia.

Both alluvial and residual tantalum and tantalum-containing tin deposits are normally mined by hand, by hydraulic monitors, by dredges, or by mechanized open pit mining. The mining of pegmatite deposits, which may be either open pit or underground, is carried out by blasting, transporting, and crushing the rock to free the tantalum and associated coproduct minerals. The materials are then concentrated by wet gravity methods (sluices, jigs, spirals, and tables) and finally separated from associated minerals by gravity and electrostatic and electromagnetic processes.

Tantalum is recovered from slags produced at tin smelters throughout the world. Tantalum content varies in tin slag depending on ore and smelting practice.

Beneficiation.—Tantalum mineral concentrates and tin slags are the predominant feed materials for preparation of tantalum metal and compounds. Both raw materials usually contain recoverable amounts of columbium as well. Depending on circumstances, tin slags may be used directly for extraction of tantalum or they may be first upgraded. Upgrading is typically performed by means of an electric furnace process that yields a synthetic concentrate.

In the extraction of tantalum from these source materials, technology makes use mainly of digestion with hydrofluoric acid followed by liquid-liquid extraction with MIBK. This procedure efficiently recovers both tantalum and columbium in the form of separate streams that then can be further processed individually into salts, oxides, and metal. The two streams are produced by a series of countercurrent extractions that also remove impurities. The tantalum product stream is a fluotantalic acid solution from which either potassium fluotantalate (K-salt), by addition of potassium chloride or fluoride, or tantalum pentoxide, by addition of ammonia, can be precipitated. Reducing K-salt by sodium is the standard commercial method for making tantalum metal. The product of sodium reduction is a powder that is consolidated by a pressing, vacuum sintering, and melting sequence.

Tantalum carbide can be manufactured by several methods, the most common being solid-state reaction between tantalum oxide and carbon. Tantalum carbide also can be made by reacting metallic tantalum directly with carbon.

Recycling.—Recycling of tantalum largely takes place within the processing and product-producing industry and is mostly runaround or home scrap that is consumed internally. In addition, quantities of tantalum are recycled indirectly in the form of used tantalum-bearing cutting tools and high-temperature alloy melting scrap.

Byproducts and Coproducts

Economic exploitation of tantalum minerals often is dependent on the price of associated recoverable byproduct or coproduct minerals, principally tin and columbium. Tantalite-columbite minerals occur in deposits associated with beryllium, lithium, rare-earth, tin, titanium, tungsten, uranium, and zirconium minerals. Minerals associated with tantalum in pegmatite deposits include beryl, feldspar, lepidolite, mica, pollucite, and spodumene. Tantalum and columbium also can be recovered economically from some tin slags, which constitute an important raw material source for tantalum and high-purity columbium. Tantalum is usually extracted in conjunction with columbium with much the same type of equipment.

Substitutes

Substitution for tantalum is usually made at a performance or economic penalty for most uses. Also, substitution requires both investment and experimentation and does not necessarily occur quickly. Aluminum and ceramics compete strongly with tantalum for use in electronic capacitors. In cemented carbides, columbium carbide and columbium-hafnium carbide can take the place of tantalum carbide in some cutting tools. Replacements for tantalum in corrosion-resistant equipment are columbium, glass, platinum, titanium, and zirconium. Columbium, hafnium, molybdenum, tungsten, and some platinum-group metals can be substituted for tantalum in high-temperature applications.

Economic Factors

Prices.—Time-price relationships for tantalum contained in concentrates in terms of actual prices and in constant 1987 dollars are shown in table 4 and figure 2. Actual prices reported are based on historical price quotations or best available information from producers. The prices show large swings between the high and low in response to market conditions. *(See table 4 and figure 2.)*

The Korean conflict in 1950 increased demand for tantalum in military requirements. Thus, consumption rose sharply with resulting ore shortages. During this period, the U.S. Government-guaranteed worldwide 100% bonus purchase program was initiated to increase production of columbium-tantalum ore and concentrates of both domestic and foreign origin. In May 1952, a schedule was announced for the purchase of 15 million pounds of the combined columbium-tantalum oxides at prices about double prevailing world prices. The program had the effect of increasing tantalum ore prices to a high of $8 per pound of oxide.

Having achieved its basic procurement objectives, the purchase of foreign material was stopped in May 1955. Small-lot purchases of domestically produced material continued until December 1958. When Government purchase of domestic ore stopped, the immediate effect was a confused market in which production and prices of ore began to drift downward. By 1959, prices for tantalum ore had dropped to about $4 per pound of oxide.

By 1960, tantalum demand for use in capacitors, high-temperature alloys, corrosion-resistant chemical applications, machine cutting tools, and aerospace applications had increased substantially. During the 1960's, the variations in supply and demand resulted in a repetition of 2 or 3 years of oversupply with lower prices followed by 2 or 3 years of high demand with higher prices. Price peaks in 1961 and 1966 were occasioned by a sudden increase in demand for tantalum, which outstripped the supply, driving prices up. This cyclical trend continued into the 1970's.

The 1970's can be characterized as a decade of increasing tantalum demand, ore shortages, escalating prices, and substitution. A 7-year trend of declining price, 1967-73, was followed by a trend of rapid price increase that was sustained through midyear 1980. The record price levels during this period were attributed in part to a state of panic buying influenced by anticipated greater tantalum demand amidst concerns at the time of a shrinking world tantalum supply. The high prices brought about substitution for tantalum and more widespread search for and development of new tantalum sources. However, prices began declining by yearend 1980 and by midyear 1986 were the lowest since first quarter 1977, hastened by a weak tantalum demand and an increase in tantalum material stockpiles. Subsequently, prices rebounded through yearend 1988 and were at the highest level since the third quarter of 1981, responding to increased demand for feed materials along with the drawdown of stockpiles. The price of tantalum continued its cyclic pattern with the 1993 average price quote at about $26 per pound of oxide, the lowest level since 1987.

Depletion Provisions.—U.S. tantalum-producing companies are granted a depletion allowance of 22% for domestic production of tantalum minerals and 14% for foreign production.

ANNUAL REVIEW—COLUMBIUM AND TANTALUM

Legislation and Government Programs

At yearend, the National Defense Stockpile (NDS) overall goal for the columbium group was 5.047 million kilograms, and the overall goal for the tantalum group was 3.959 million kilograms. Government inventoried stocks of columbium and tantalum materials in the NDS had decreased by 5% and 6%, respectively, compared with those at yearend 1992. *(See table 7.)* The decline in stocks results from the columbium and tantalum upgrade program initiated in 1992. In its fiscal year 1992 Annual Materials plan for the NDS, the Department of Defense provided for the upgrading of some existing columbium and tantalum materials. In September 1992, the Defense Logistics Agency contracted with Cabot Performance Materials (CPM), Boyertown, PA, and Hermann C. Starck Inc. (formerly NRC Inc.), Newton, MA, to conduct the upgrade program. CPM will convert quantities of Government-owned (stockpiled) columbium-tantalum concentrates (materials) into vacuum-grade columbium and tantalum metal ingot pieces and upgrade Government-owned columbium metal powder to vacuum-grade columbium metal ingot pieces. Starck will upgrade Government-owned tantalum metal powder to vacuum-grade tantalum metal ingot pieces.

In August, the U.S. Trade Representative announced that the GSP, which had expired on July 4, 1993, was extended to September 30, 1994. The GSP extension was part of the Budget Reconciliation Act signed by the President. The legislation extending the GSP was retroactive to July 4. Additionally, the legislation removed the statutory prohibition against providing GSP benefits to the countries that made up the former U.S.S.R. Under GSP, the United States grants duty-free access to goods from more than 140 developing countries and territories. U.S. import duties for columbium and tantalum products range from duty free to 5.5% ad valorem for most-favored-nation (MFN) status and from duty free to 45% ad valorem for non-MFN status.

In Proclamation 6599 of September 30, 1993, the U.S. President designated Russia as a beneficiary developing country for purposes of the GSP. GSP status for Russia is part of the administration's overall efforts to help that country pursue badly needed market reforms. Kazakhstan, Romania, and Ukraine also were being considered for GSP status.

In October, Congress voted to close down DOE's Superconducting Super Collider (SSC), particle accelerator, project in Texas. All Federal funds for the SSC were halted except for $640 million in fiscal year 1994 for the orderly termination of the project. The SSC was approved for construction in 1987 at a cost of about $4 billion with a targeted completion date in 1996. At the time of its termination, cost estimates for the SSC had escalated to about $11 billion, with about $2 billion reportedly having already been spent. Superconducting magnets reportedly using about 1 million pounds of a 50% columbium-50% titanium alloy would have been used in the project.

Strategic Considerations

The high degree of import reliance for columbium and tantalum is the principal strategic problem faced by the United States. Summaries of important columbium and tantalum statistics are shown in tables 5 and 6, respectively. In the case of both columbium and tantalum, there has been no significant mining since the 1950's. Domestic columbium and tantalum resources are of low grade, some mineralogically complex, and most are not currently commercially recoverable. To ensure a supply of columbium and tantalum during an emergency, goals for both materials have been established for the NDS. However, inventories for both materials are substantially under set goals. Consequently, a degree of vulnerability still remains. *(See tables 5 and 6.)*

The NDS inventory for both columbium and tantalum are mostly in the form of source materials (feedstocks). However, the United States has become more reliant on the processing capability of foreign sources and the availability of intermediate products from those sources. At the start of the 1980's, there were four major processors of columbium- and tantalum-bearing source materials. One of the operations was shut down in 1985, and another shut down its processing operation at yearend 1989. Of the remaining two companies, one is dedicated solely to the processing of columbium materials and the other company processes both columbium and tantalum materials. Thus, there is some concern whether the United States would have on hand in an emergency adequate processing capacity for conversion of the stockpile materials to an upgraded form and quality required by the critical end uses. However, in 1992, the Defense Logistics Agency contracted with a U.S. company to convert (upgrade) some of the Government-owned columbium-tantalum concentrates (minerals) into vacuum-grade columbium and tantalum metal ingot pieces.

Production

In 1993, there were two processors of columbium- and tantalum-bearing source materials that were integrated from raw material processing to columbium and tantalum end products: Cabot Corp. for columbium and tantalum processing and Shieldalloy Metallurgical Corp., dedicated solely to columbium processing. Hermann C. Starck Inc., a major supplier, and Thai Tantalum Inc. produced tantalum products. Reading Alloys Inc. and Teledyne Wah Chang Albany were major producers of high-purity columbium products. Kennametal Inc. was the major producer of columbium and tantalum carbides.

Cabot Corp., Boston, MA, reported that its CPM business, Boyertown, PA, had acquired the remaining two-thirds interest in the Bernic Lake, Manitoba, tantalum mining operation of Tanco for an undisclosed sum. CPM, a major world processor of tantalum raw materials, already held a one-third interest in Tanco. Tanco is the sole Canadian producer of tantalum feed material. CPM's acquisition reportedly strengthened its raw materials supply position and insulated itself and its customers from dramatic material price swings.[1] Additionally, CPM reportedly purchased a second 1,200-kilowatt electron beam furnace for its boyertown plant for the production of columbium and tantalum metal.[2]

Kennametal Inc., Latrobe, PA, acquired an 81% interest in the German company Hertel AG, a major manufacturer of cemented carbide tools and tooling systems. The cost of the purchase consisted of $43 million in cash and $44 million of assumed debt. The transaction significantly increases Kennametal's access to European and Asia-Pacific markets.[3]

Metallurg Inc., New York, NY, a supplier of specialty alloys and metals, announced in September that it had filed a voluntary petition for protection from its creditors under chapter 11 of the U.S. Bankruptcy Code. Included in the filing was Shieldalloy Metallurgical Corp. and its manufacturing plant in Newfield, NJ.[4] Shieldalloy is a major U.S. producer of ferrocolumbium for steelmaking.

Consumption and Uses

Overall reported consumption of columbium as ferrocolumbium and nickel columbium increased slightly compared with that of 1992. *(See table 8.)* Consumption of columbium by the steelmaking industry increased by 2%, in line with a 5% increase in raw steel production. There was about a 4% decrease in the percentage of columbium usage per ton of steel produced. Columbium consumption in HSLA steel rose by about 10%, while columbium consumption in carbon, and stainless and heat-resisting steels were down. Demand for columbium in superalloys was down by about 9%. However, that portion used in the form of nickel columbium increased to about 160,000 kilograms.

Overall consumption of tantalum was up to 410,000 kilograms, the highest level since 1988, aided by increased consumption of capacitor-grade tantalum powder in the electronics sector. Factory sales of tantalum capacitors rose by about 20%, as reported by the Electronic Industries Association.

Markets and Prices

A published price for pyrochlore concentrates produced in Brazil and Canada was not available. A price for Brazilian pyrochlore has not been available since 1981, and the published price for Canadian pyrochlore was suspended in early 1989. Unchanged since June 1989, the Platt's Metals Week published price for regular-grade ferrocolumbium, produced from pyrochlore concentrates, was $6.58 per pound of contained columbium, f.o.b. shipping port.

The Metal Bulletin published price for columbite ore quoted since March 1990 at a range of $2.60 to $3.05 per pound, on the basis of a minimum 65% contained Cb_2O_5 and Ta_2O_5, fell to a range of $2.40 to $2.80 per pound in May, where it remained through December. For the year, the Metals Week published price for columbium oxide was quoted at $8.17 per pound of oxide; the published price for high-purity ferrocolumbium containing 62% to 68% columbium was quoted at $18.50 per pound of contained columbium, f.o.b. shipping point; the published price for nickel columbium was quoted at $20.50 per pound of contained columbium; and the published price for columbium metal was quoted at a range of $30 to $50.

The Metals Week published spot price for tantalite ore, on the basis of contained Cb_2O_5 and Ta_2O_5, c.i.f. U.S. ports, fell from a range of $28 to $30 to a range of $25.50 to $26.50 in late March, where it remained through December. The Metal Bulletin published price for tantalite fell from a range of $30 to $33 per pound of contained Ta_2O_5 to a range of $28 to $32 in early February, where it remained through December. The Metal Bulletin published price for tantalite produced by Greenbushes Ltd. of Australia on the basis of 40% contained Ta_2O_5 was unchanged throughout the year at $40 per pound. A published price for tantalite from the Canadian producer, Tanco, was not available. Industry sources indicated that tantalum mill products continued to be sold at an average of about $170 per pound, depending on specification, and that tantalum capacitor-grade powder continued to be sold at about $145 per pound.

A published price for columbium and tantalum carbide was not available.

Foreign Trade

Data for exports and imports are summarized in table 9. Net trade for columbium and tantalum continued at a deficit and was at the highest level since 1989. Overall trade value for exports was down by 8%, with total volume up slightly. For imports, trade value was down by 2%, with total volume down by 10%. *(See table 9.)*

Imports for consumption of columbium mineral concentrates continued to decline. *(See table 10.)* Canada was the leading supplier, providing more than 90% of both total quantity and total value. Imports at an average grade of approximately 60% Cb_2O_5 and 1% Ta_2O_5 were estimated to contain 970,000 kilograms of columbium and 25,000 kilograms of tantalum.

Imports for consumption of tantalum mineral concentrates were down by 8%, with a slight decrease in the average unit value for overall imports. *(See table 11.)* Imports from Australia, Brazil, and Rwanda (producing countries) accounted for more than 60% of both total quantity and total value. Imports at an average grade of approximately 35% Ta_2O_5 and 27% Cb_2O_5 were estimated to contain 365,000 kilograms of tantalum and 240,000 kilograms of columbium.

Imports for consumption of synthetic tantalum-columbium concentrates totaled 36,000 kilograms valued at $912,000 compared with no imports in 1992. These figures are not included in the salient statistics data.

The schedule of applied tariffs during 1993 to U.S. imports of selected columbium and tantalum materials is given in table 12. Brazil continued to be the major source for U.S. columbium imports, accounting for 60% of the total, and Australia remained the major source for U.S. tantalum imports, accounting for about 30% of the total. *(See table 12 and figures 3 and 4.)*

World Review

Industry Structure.—Principal world columbium and tantalum raw material and product producers are shown in tables 13 and 14, respectively. Brazil and Canada remained the major producers of columbium raw materials feedstock, while tantalum raw materials continued to be produced mainly in Australia, Brazil, and Canada and in Thailand in the form of high-grade tantalum-bearing tin slags. Synthetic concentrates, produced from low-grade tin slags from Germany, were an additional source of columbium and tantalum raw material supply. Annual world production of columbium and tantalum mineral concentrates, by country, is given in table 15. World tantalum supply in 1981-93 is shown in figure 5. *(See tables 13, 14, and 15 and figure 5.)*

Australia.—For its fiscal year ending June 30, 1993, Gwalia Consolidated Ltd. reported that tantalum oxide production in tantalum concentrates (tantalite) at its Greenbushes Mine, southwest Western Australia, was about 134 tons compared with about 197 tons the previous year. Most of the tantalite production was sold to overseas markets. Company sales of tantalum products were down by about 25% to 136 tons, reflecting a depressed tantalum industry in Europe and a weak spot market for the product. Gwalia is the world's largest producer of tantalum concentrates, with long-term contractual relationships with processors in Germany and North America.[5]

As reported by Pancontinental Mining Ltd. for its fiscal year ending June 30, 1993, tantalum production at the Wodgina Mine was about 94 tons of tantalum oxide contained in concentrate compared with about 107 tons the previous year. The decrease in production was attributed to the processing of lower grade tantalum ores.[6] Pancontinental has a 50% interest in, and is the operator of, the Wodgina tantalum mine, which is located in the Pilbara region of Western Australia.

Brazil.—The TEX Report reported that Brazil's production of columbium oxide in concentrates was 13,900 tons, 10,430 tons produced by Cia. Brasileira de Metalurgia e Mineração (CBMM) and 3,470 tons produced by Mineração Catalào de Goiás S.A. (Catalão). Brazil's consumption of columbium was 1,050 tons, down 13% from that of the previous year.

In December, Brazil's Commerce Secretariat reportedly proposed a 5% import duty on aluminum, cast iron, cobalt, ferroalloys, lead, and zinc. The duty was proposed at the request of domestic producers claiming a need for protection due to low world prices, increased imports from countries of the former U.S.S.R., and exchange rate difficulties. Brazil's domestic consumers, the aluminum association, and the nonferrous metals institute opposed the introduction of the proposed 5% import duty.[7]

Canada.—As reported by Teck Corp., production of Cb_2O_5 at the Niobec Mine at St. Honoré, Quebec, increased to about 3.42 million kilograms, the highest level since 1989. Niobec is a 50-50 joint venture between Teck, operator, and Cambior Inc., product marketing. Ore milled was about 812,000 tons, as the mill operated on the average of 2,225 tons of ore per day. Average recovery was 59.9% with Cb_2O_5 grade of concentrate at 70%. Teck reported that ore reserves, at the current rate of production, are sufficient for another 12 years. For the year, operating changes at the mine included automation of the grinding and flotation circuits. A completed feasibility study indicated that a capital investment of $7.5 million would be required to establish a concentrate convertor facility at the mine site. In late 1993, a decision was made to build a ferrocolumbium plant with startup of construction beginning in early 1994. Completion of construction is anticipated by yearend 1994. Once the plant is operational, Niobec will commence marketing ferrocolumbium in lieu of columbium concentrates.[8]

Since midyear 1992, tantalum mining at the Bernic Lake, Manitoba, tantalum operation of Tanco has remained suspended. However, about 40,000 kilograms of contained tantalum oxide was produced from tailings retreatment.

Japan.—According to The Tex Report, Japan's production of ferrocolumbium rose to 1,213 tons from the 1,002 tons reported in 1992. Columbium ore imported for ferrocolumbium production increased substantially to 2,045 tons, with Canada accounting for about 80% of the total. Ferrocolumbium imports increased to 4,361 tons from the 4,187 tons reported in 1992. Brazil accounted for most of the ferrocolumbium imports. Japan's demand for ferrocolumbium for steelmaking totaled 4,574 tons, an alltime high, compared with 4,412 tons in 1992.

Roskill's Letter from Japan reported that Japan's demand for tantalum, in the form of powder, compounds, and products, was 225 tons compared with 217 tons in 1992. Japan's imports of tantalum powder, compounds, and products fell to 53 tons from the 63 tons in 1992.

Thailand.—In March, it was reported that the Thai Tantalum Co. Ltd. was anticipating that its tantalum facility in Rayong Province would reach full annual production capacity by midyear 1993, about 450 tons of potassium fluotantalate (K-Salts) and about 45 tons of capacitor-grade tantalum powder. Tantalum production will be for export, likely to Japan and the United States.[9]

OUTLOOK

Columbium

The major components of U.S. supply-demand relationships for columbium in 1983-93 are given in table 16. Columbium is used principally as an additive in steelmaking, which annually accounts for more than 80% of U.S. reported consumption. No significant change to this trend is expected in the near term because there are few other significant growth markets and/or uses for columbium. Thus, future columbium demand growth will continue to be directly related to the worldwide performance of the steel industry. U.S. apparent consumption of columbium has been in the range of 3,300 to 3,500 tons of contained columbium for the period 1989-93. Any major future variations from this trend will depend on future activities of the domestic steel industry. The outlook for steel is discussed in the annual report for iron and steel. The outlook for columbium also will be dependent to a lesser degree on the performance of the aerospace industry. In recent years, reported domestic consumption of columbium in the production of superalloys continues to be no more than 20% of total demand. In 1993, columbium consumption in the production of superalloys decreased by more than 35% compared with that of the previous year. Future growth for this end use will be affected mainly by the demand for columbium-containing superalloys by the aircraft industry. Continued reduction in military spending is expected to lead to reduced aerospace shipments throughout the decade. *(See table 16.)*

Tantalum

The major components of U.S. supply-demand relationships for tantalum in 1983-93 are given in table 17. For the past decade, more than 60% of the tantalum consumed in the United States was used to produce electronic components, mainly tantalum capacitors, with major markets in recent years being computer and communication systems. In 1993, U.S. factory sales of tantalum capacitors were at an alltime high, an increase of 60% over that in 1990. However, overall tantalum demand growth in this sector has been slowed owing to the industry's continued emphasis on higher capacitance powders and the miniaturization of electronic components resulting in less tantalum used per unit. Tantalum demand in the cemented carbide sector continues to decline owing to the growing use of mixed carbides, coated cutting tools, improved tool life, and the downsizing of components. *(See table 17.)*

OTHER SOURCES OF INFORMATION

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Roskill's Letter from Japan.
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The Wall Street Journal (daily paper).

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[1] Cabot Corp. 1993 Annual Report. 40 pp.

[2] American Metal Market. V. 101, No. 216, Nov. 8, 1993, p. 6.

[3] Kennametal Inc. 1993 Annual Report. 36 pp.

[4] Platt's Metals Week. V. 64, No. 36, Sept. 7, 1993, p. 1.

[5] Gwalia Consolidated Ltd. 1993 Annual Report. 55 pp.

[6] Pancontinental Mining Ltd. 1993 Annual Report. 84 pp.

[7] Metal Bulletin. No. 7839, Dec. 13, 1993, p. 9.

[8] Teck Corp. 1993 Annual Report. 56 pp.

[9] Metal Bulletin. No. 7768, Mar. 29, 1993, p. 12.

TABLE 1
WORLD COLUMBIUM RESERVES AND RESERVE BASE, 1993

(Thousand kilograms columbium content)

Country	Reserves	Reserve base[1]
Brazil	3,311,000	3,629,000
Canada	136,000	408,000
Nigeria	64,000	91,000
United States	—	(2)
Zaire	32,000	91,000
Other countries[3]	6,000	9,000
World total	3,549,000	4,228,000

[1] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[2] Negligible.

[3] Excludes any reserves and reserve base from countries of the Commonwealth of Independent States.

TABLE 2
TIME-PRICE RELATIONSHIPS FOR COLUMBIUM

Year	Average annual price, dollars per pound of contained columbium in concentrates	
	Actual price	Based on constant 1987 dollars
1960	1.73	6.65
1961	1.43	5.44
1962	1.36	5.06
1963	1.36	5.00
1964	1.36	4.91
1965	1.34	4.72
1966	1.43	4.86
1967	1.42	4.69
1968	1.42	4.47
1969	1.42	4.25
1970	1.65	4.69
1971	1.65	4.45
1972	1.87	4.82
1973	1.97	4.77
1974	2.23	4.97
1975	2.23	4.53
1976	2.73	5.22
1977	5.53	9.89
1978	3.69	6.12
1979	3.79	5.79
1980	4.55	6.35
1981	4.87	6.17
1982	4.83	5.76
1983	4.73	5.42
1984	4.71	5.18
1985	4.63	4.90
1986	3.78	3.90
1987	3.71	3.71
1988	3.71	3.57
1989[e]	3.93	3.62
1990[e]	3.93	3.47
1991[e]	3.93	3.34
1992[e]	3.93	[r]3.27
1993[e]	3.90	3.14

[e] Estimated. [r] Revised.

TABLE 3

WORLD TANTALUM RESERVES AND RESERVE BASE, 1993

(Thousand kilograms tantalum content)

Country	Reserves	Reserve base[1]
Australia	4,500	9,100
Brazil	900	1,400
Canada	1,800	2,300
Malaysia	900	1,800
Nigeria	3,200	4,500
Thailand	7,300	9,100
United States	—	(2)
Zaire	1,800	4,500
Other countries[3]	1,400	1,800
World total	21,800	34,500

[1] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[2] Negligible.

[3] Excludes any reserves and reserve base from countries of the Commonwealth of Independent States.

TABLE 4

TIME-PRICE RELATIONSHIPS FOR TANTALUM

Year	Average annual price, dollars per pound of contained tantalum in concentrates[1]	
	Actual price	Based on constant 1987 dollars
1960	7.28	28.00
1961	11.11	42.24
1962	7.29	27.10
1963	7.93	29.15
1964	7.31	26.39
1965	10.26	36.13
1966	14.72	50.07
1967	12.24	40.40
1968	9.13	28.71
1969	9.15	27.40
1970	9.15	25.99
1971	8.26	22.26
1972	8.09	20.85
1973	8.00	19.37
1974	14.13	31.47
1975	18.32	37.24
1976	20.31	38.83
1977	25.64	45.87
1978	34.19	56.70
1979	80.00	122.14
1980	126.37	176.25
1981	99.51	126.12
1982	49.95	59.61
1983	30.60	35.09
1984	37.44	41.14
1985	33.68	35.68
1986	23.74	24.50
1987	27.08	27.08
1988	47.37	45.59
1989	44.93	41.41
1990	38.06	[r]33.59
1991	36.70	[r]31.18
1992	34.42	[r]28.66
1993	32.25	25.97

[r] Revised.

[1] 60% basis, combined tantalum and columbium pentoxides.

TABLE 5
SALIENT COLUMBIUM STATISTICS

(Thousand kilograms of columbium content unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Mine production of columbium-tantalum concentrates	(1)	(1)	(1)	(1)	—
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials	NA	NA	NA	NA	NA
Production of ferrocolumbium	NA	NA	NA	NA	NA
Consumption of primary products:					
Ferrocolumbium and nickel columbium[e]	2,439	2,586	2,412	[r]2,467	2,477
Exports: Columbium metal, compounds, alloys (gross weight)	NA	NA	NA	NA	NA
Imports for consumption:					
Mineral concentrates[e]	1,216	1,125	1,160	1,230	1,210
Columbium metal and columbium-bearing alloys[e]	12	2	1	1	111
Ferrocolumbium[e]	2,411	1,897	2,133	2,449	2,188
Tin slag	NA	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	[r]14,062	[r]15,335	[r]15,847	[r]15,407	12,721

[e] Estimated. [r] Revised. NA Not available.

[1] A small unreported quantity was produced.

TABLE 6
SALIENT TANTALUM STATISTICS

(Thousand kilograms of tantalum content unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Mine production of columbium-tantalum concentrates	(1)	(1)	(1)	(1)	—
Releases from Government excesses	—	—	—	—	—
Consumption of raw materials	NA	NA	NA	NA	NA
Exports:					
Tantalum ores and concentrates (gross weight)[2]	4	1	11	17	11
Tantalum metal, compounds, alloys (gross weight)	162	161	219	136	235
Tantalum and tantalum alloy powder (gross weight)	96	82	66	61	57
Imports for consumption:					
Mineral concentrates[e]	499	299	340	420	390
Tantalum metal and tantalum-bearing alloys[3]	37	21	19	14	67
Tin slag	NA	NA	NA	NA	NA
World: Production of columbium-tantalum concentrates[e]	[r]395	[r]395	[r]477	[r]400	317

[e] Estimated. [r] Revised. NA Not available.

[1] A small unreported quantity was produced.

[2] Includes reexports.

[3] Exclusive of waste and scrap.

TABLE 7

COLUMBIUM AND TANTALUM MATERIALS IN GOVERNMENT INVENTORIES AS OF DECEMBER 31, 1993

(Thousand kilograms of columbium or tantalum content)

Material	Stockpile goals	Disposal authority	National Defense Stockpile inventory			
			Uncommitted[1]			Committed
			Stockpile-grade	Nonstockpile-grade	Total	
Columbium:						
Concentrates	—	—	520	344	864	—
Carbide powder	—	—	10	—	10	—
Ferrocolumbium	—	—	271	151	422	—
Metal	—	—	7	—	7	—
Total	[2]5,047	—	808	495	1,303	—
Tantalum:						
Minerals	—	—	761	460	1,221	—
Carbide powder	—	—	13	—	13	—
Metal[3]	—	—	73	(4)	73	—
Total	[2]3,959	—	847	460	1,307	—

[1] The stockpile also contained uncommitted inventories of 26,000 kilograms in columbium concentrates, 40,000 kilograms in ferrocolumbium, 37,000 kilograms in both tantalum minerals and metals, and 65,000 kilograms in tantalum oxide with status (inventory) not yet determined.

[2] Overall goals for the columbium and tantalum groups.

[3] Capacitor grade.

[4] 45 kilograms.

Source: Defense Logistics Agency, Defense National Stockpile Center.

TABLE 8

CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF FERROCOLUMBIUM AND NICKEL COLUMBIUM IN THE UNITED STATES

(Kilograms of contained columbium[1])

End use	1992	1993
Steel:		
Carbon	837,541	819,428
Stainless and heat-resisting	346,936	317,457
Full alloy	(2)	(2)
High-strength low-alloy	931,096	1,019,127
Electric	—	—
Tool	(3)	(3)
Unspecified	8,044	5,957
Total	2,123,617	2,161,969
Superalloys	[r]322,032	294,475
Alloys (excluding alloy steels and superalloys)	(4)	(4)
Miscellaneous and unspecified	[r]21,737	20,870
Total consumption	[r]2,467,386	2,477,314
STOCKS		
Dec. 31:		
Consumer	NA	NA
Producer[5]	NA	NA
Total stocks	NA	NA

---

[r] Revised. NA Not available.

[1] Includes columbium and tantalum in ferrotantalum-columbium, if any.

[2] Included with "Steel: High-strength low alloy."

[3] Included with "Steel: Unspecified."

[4] Included with "Miscellaneous and unspecified."

[5] Ferrocolumbium only.

TABLE 9
U.S. FOREIGN TRADE IN COLUMBIUM AND TANTALUM METAL AND ALLOYS, BY CLASS

(Thousand kilograms, gross weight, and thousand dollars)

Class	1992		1993		Principal destinations and sources, 1993
	Quantity	Value	Quantity	Value	
EXPORTS[1]					
Columbium:					
Ores and concentrates	—	—	6	46	All to Taiwan.
Ferrocolumbium	902	8,254	815	7,313	Canada 697, $6,299; Mexico 116, $1,006; Venezuela 1, $5; Chile (2), $4.
Tantalum:					
Synthetic concentrates	2	17	—	—	—
Ores and concentrates	17	33	11	111	All to China.
Unwrought and waste and scrap	62	2,918	177	5,007	Germany 39, $2,127; Hong Kong 111, $1,276; United Kingdom 13, $962; Canada 7, $512; China 1, $70; Russia 4, $49.
Unwrought powders	61	18,741	57	17,476	United Kingdom 23, $7,771; France 18, $4,956; Germany 12, $3,666; Japan 3, $1,054; Taiwan (2), $15.
Unwrought alloys and metal	8	2,670	8	2,393	Canada 5, $1,668; Barbados 1, $377; Germany 2, $244; United Kingdom 1, $40; Mexico (2), $24; Singapore (2), $23.
Wrought	66	22,668	50	18,674	Japan 20, $8,365; Germany 9, $3,284; United Kingdom 7, $2,692; France 4, $1,449; Canada 6, $1,050.
Total	XX	55,301	XX	51,020	United Kingdom $11,500; Canada $9,500; Japan $9,400; Germany $9,300; France $6,400.[3]
IMPORTS FOR CONSUMPTION					
Columbium:					
Ores and concentrates	2,428	8,764	2,348	8,614	Canada 2,217, $7,971; Germany 73, $347; Belgium 10, $151; Nigeria 47, $146.
Oxide	792	13,473	301	5,392	Germany 161, $3,751; Brazil 91, $1,367; Russia 46, $253; Thailand 2, $11; United Kingdom (2), $10.
Ferrocolumbium	3,767	31,075	3,367	28,997	Brazil 3,262, $27,106; Germany 103, $1,878; United Kingdom 2, $14.
Unwrought alloys, metal, and powders	1	101	111	2,381	Germany 79, $1,558; Estonia 16, $429; United Kingdom 9, $162; Brazil 5, $161.
Tantalum:					
Synthetic concentrates	—	—	36	912	All from Australia.
Ores and concentrates	1,367	35,600	1,258	31,828	Australia 440, $14,637; Brazil 135, $3,187; Germany 146, $3,185; Rwanda 193, $2,996; Japan 40, $2,973; Burundi 50, $1,063.
Unwrought waste and scrap	91	3,551	101	4,269	Mexico 55, $1,342; Germany 11, $1,145; Hong Kong 7, $768; France 12, $366; China 2, $237; United Kingdom 8, $189.
Unwrought powders	8	1,571	56	9,463	Germany 31, $4,097; Thailand 17, $3,566; Japan 5, $1,165; China 3, $529.
Unwrought alloys and metal	4	635	8	1,038	Germany 7, $870; Japan (2), $168.
Wrought	2	768	3	547	Kazakhstan 3, $290; Austria (2), $64; Switzerland (2), $61; Germany (2) $54; Japan (2) $52.
Total	XX	95,538	XX	93,441	Brazil $31,800; Germany $17,000; Australia $15,500; Canada $8,800.[3]

XX Not applicable.

[1] For columbium, data on exports of metal and alloys in unwrought and wrought form, including waste and scrap, are not available; included in nonspecific tariff classifications.

[2] Less than 1/2 unit.

[3] Rounded.

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

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF COLUMBIUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1992		1993	
	Gross weight	Value	Gross weight	Value
Belgium[1]	—	—	10	151
Brazil	2	25	—	—
Canada	2,214	7,558	2,217	7,971
Germany[1]	54	239	73	347
Nigeria	134	564	47	146
Zaire	24	379	—	—
Total[2]	2,428	8,764	2,348	8,614

[1] Presumably country of transshipment rather than original source.

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

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

TABLE 11

U.S. IMPORTS FOR CONSUMPTION OF TANTALUM MINERAL CONCENTRATES, BY COUNTRY

(Thousand kilograms and thousand dollars)

Country	1992		1993	
	Gross weight	Value	Gross weight	Value
Australia	476	17,937	440	14,637
Austria[1]	—	—	5	181
Belgium[1]	32	618	—	—
Bolivia	6	110	2	43
Brazil	24	555	135	3,187
Burundi[1]	70	1,874	50	1,063
Canada	140	3,650	40	830
China	—	—	32	602
Estonia[1]	—	—	7	305
French Guiana	(2)	14	—	—
Germany[1]	64	1,157	146	3,185
Japan[1]	20	1,592	40	2,973
Mexico[1]	(2)	10	—	—
Namibia	2	84	1	43
Nigeria	4	76	66	171
Rwanda	120	2,125	193	2,996
Singapore[1]	125	1,639	—	—
South Africa, Republic of	38	228	—	—
Spain	3	60	6	99
Thailand	37	458	45	615
Uganda	5	46	—	—
United Kingdom[1]	(2)	8	—	—
Zaire	200	3,359	48	898
Total[3]	1,367	35,600	1,258	31,828

[1] Presumably country of transshipment rather than original source.

[2] Less than 1/2 unit.

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

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

TABLE 12
U.S. IMPORT DUTIES ON COLUMBIUM AND TANTALUM MATERIALS

Item	HTS No.	Rate of duty effective January 1, 1993	
		Most favored nation (MFN)	Non-MFN
Synthetic tantalum-columbium concentrates	2615.90.3000	Free	30.0% ad valorem.
Columbium ores and concentrates	2615.90.6030	do.	Free.
Tantalum ores and concentrates	2615.90.6060	do.	Do.
Columbium oxide	2825.90.1500	3.7% ad valorem[1,2]	25.0% ad valorem.
Tantalum oxide	2825.90.6000[3]	3.7% ad valorem[1,4]	Do.
Potassium fluotantalate	2826.90.0000[3]	3.1% ad valorem[1,4]	Do.
Ferrocolumbium	7202.93.0000	5.0% ad valorem[5]	Do.
Unwrought tantalum waste and scrap	8103.10.3000	Free	Free.
Unwrought tantalum powders	8103.10.6030	3.7% ad valorem[1]	25.0% ad valorem.
Unwrought tantalum alloys and metal	8103.10.6090	do.	Do.
Wrought tantalum	8103.90.0000	5.5% ad valorem[1]	45.0% ad valorem.
Unwrought columbium waste and scrap	8112.91.0500[3]	Free	Free.
Unwrought columbium alloys, metal, and powders	8112.91.4000	4.9% ad valorem[5]	25.0% ad valorem.
Wrought columbium	8112.99.0000[3]	5.5% ad valorem[1]	45.0% ad valorem.

[1] Free from certain beneficiary developing countries under the Generalized System of Preferences (GSP), for products of Canada under the United-States-Canada Free-Trade Agreement, from beneficiary countries under the Caribbean Basin Economic Recovery Act (CBERA), for products of Israel under the United States-Israel Free-Trade area, and for products under the Adean Trade Preference Act (ATPA).

[2] Not duty free for Brazil and India.

[3] Nonspecific tariff classification.

[4] Not duty free for India.

[5] Free from products of Canada, from beneficiary countries under the CBERA, for products of Israel, and for products under ATPA.

Source: U.S. International Trade Commission.

TABLE 13
PRINCIPAL WORLD COLUMBIUM AND TANTALUM RAW MATERIAL PRODUCERS

Country	Company and/or mine	Material type
	MINING OF COLUMBIUM- AND TANTALUM-BEARING ORES	
Australia	Gwalia Consolidated Ltd. (Greenbushes)	Columbium-tantalum.
	Pan West Tantalum Pty. Ltd. (Wodgina)	Tantalum.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM) (Araxa)	Columbium.
	Cia. de Estanho Minas Brasil (MIBRA)[1]	Columbium-tantalum.
	Paranapanema S.A. Mineração Indústria e Construção (Pitinga)	Columbium-tantalum.
	Mineração Catalão de Goiás S.A. (Catalão)	Columbium.
Canada	Cambior/Teck Corp. (Niobec)	Columbium.
	Tantalum Mining Corp. of Canada Ltd. (Tanco)	Tantalum.
China	Government-owned	Columbium-tantalum.
Zaire	Société Minière du Kivu (SOMIKIVU)[1]	Columbium.
	PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING TIN SLAGS	
Australia	Gwalia Consolidated Ltd. (Greenbushes).	
Brazil	Cia. Industrial Fluminense.[1]	
	Mamoré Mineração e Metalurgia.[2]	
Malaysia	Malaysia Smelting Corp. Sdn. Bhd.	
Thailand	Thailand Smelting and Refining Co. Ltd. (Thaisarco).	
	PRODUCTION OF COLUMBIUM- AND TANTALUM-BEARING SYNTHETIC CONCENTRATES	
Germany:		
Western states	Gesellschaft Für Elektrometallurgie mbh (GFE).[1]	
	Hermann C. Starck Berlin KG.	

[1] A wholly owned subsidiary of Metallurg Inc., New York, NY.

[2] A subsidiary of Paranapanema S.A. Mineração Indústria e Construção.

TABLE 14

PRINCIPAL WORLD PRODUCERS OF COLUMBIUM AND TANTALUM PRODUCTS

Country	Company	Products[1]
Australia	Gwalia Consolidated Ltd. (Greenbushes)	Cb and Ta oxide.
Austria	Treibacher Chemische Werke AG	Cb and Ta oxide/carbide, FeCb, NiCb.
Brazil	Cia. Brasileira de Metalurgia e Mineração (CBMM)	Cb oxide/metal, FeCb, NiCb.
	Cia. Industrial Fluminense[2]	Cb and Ta oxide.
	Mineração Catalão de Goiás S.A. (Catalão)	FeCb.
Germany:		
Western states	Gesellschaft Für Elektrometallurgie mbH (GFE)[2]	Cb and Ta oxide/metal, K-Salt, FeCb, NiCb, Ta capacitor powder.
	Herman C. Starck Berlin KG	Cb and Ta oxide/metal/carbide, K-salt, FeCb, NiCb, Ta capacitor powder.
Japan	Awamura Metal Industry Co. Ltd.	FeCb.
	Japan Metals & Chemicals Co. Ltd.	FeCb.
	Mitsui Mining & Smelting Co.	Cb and Ta oxide/metal/carbide.
	Showa Cabot Supermetals[3]	Ta capacitor powder.
	V Tech[4]	Ta capacitor powder.
Kazakhstan	Ulba Metallurgical	Cb oxide, Ta metal, K-salt.
Russia	Solikamsk Magnesium Works	Cb and Ta oxide, Cb and Ta metal.
United Kingdom	London & Scadinavian Metallurgical Co. Ltd.[2]	Cb and Ta carbide.
United States	Cabot Corp.	Cb and Ta oxide/metal, K-Salt, FeCb, NiCb, Ta capacitor powder.
	Hermann C. Starck Inc.[5]	Cb and Ta metal, Ta capacitor powder.
	Kennametal, Inc.	Cb and Ta carbide.
	Reading Alloys, Inc.	FeCb, NiCb.
	Shieldalloy Metallurgical Corp.[2]	FeCb, NiCb.
	Teledyne Wah Chang Albany	Cb oxide/metal, FeCb, NiCb.
	Thai Tantalum Inc.	Ta metal.

[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, NY.

[3] A joint venture between Showa Denko and Cabot Corp.

[4] A subsidiary of Hermann C. Starck Berlin KG.

[5] Formerly NRC Inc., jointly owned by Bayer USA and Hermann C. Starck Berlin KG.

TABLE 15
COLUMBIUM AND TANTALUM: WORLD PRODUCTION OF MINERAL CONCENTRATES, BY COUNTRY[1]

(Thousand kilograms)

Country[2]	Gross weight[3]					Columbium content[4]					Tantalum content[4]				
	1989	1990	1991	1992	1993^{e}	1989	1990	1991	1992	1993^{e}	1989	1990	1991	1992	1993^{e}
Australia: Columbite-tantalite^{e}	555	529	703	^{r}656	495	64	69	94	^{r}69	50	119	165	218	^{r}224	170
Brazil:															
Columbite-tantalite	436	310	^{e}290	^{e}200	175	101	71	66	45	40	126	90	84	60	50
Pyrochlore	26,290	29,380	30,450	^{r}29,640	23,130	11,040	12,340	12,790	^{r}12,450	9,716	—	—	—	—	—
Canada:															
Pyrochlore	5,443	5,272	5,230	^{e}5,100	5,320	2,449	2,372	2,354	2,295	2,393	—	—	—	—	—
Tantalite^{e}	^{r}310	^{r}350	^{r}380	^{r}200	130	^{r}12	^{r}14	^{r}15	^{r}8	5	^{r}76	^{r}86	^{r}93	^{r}48	31
Malaysia: Columbite-tantalite	—	4	—	—	—	—	1	—	—	—	—	(5)	—	—	—
Namibia: Tantalite	6	4	(5)	(5)	(5)	1	1	(5)	(5)	(5)	1	1	(5)	(5)	(5)
Nigeria: Columbite	46	44	36	^{e}40	40	19	18	15	17	17	3	2	2	2	2
Rwanda: Columbite-tantalite	64	^{r}110	^{re}100	^{re}100	100	19	^{r}33	^{r}30	^{r}30	30	14	^{r}24	^{r}22	^{r}22	22
South Africa, Republic of:															
Columbite-tantalite	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)
Spain:^{e} Tantalite	^{r}10	10	8	8	6	NA	NA	NA	NA	NA	3	3	^{r}2	2	2
Thailand: Columbite-tantalite	109	9	3	^{e}3	3	19	2	1	1	1	29	2	1	1	1
Zaire:															
Columbite-tantalite	48	36	57	^{r}29	20	13	9	15	^{r}8	5	13	10	16	^{r}8	6
Pyrochlore	711	900	^{e}1,000	^{r}1,048	1,000	320	400	450	470	450	—	—	—	—	—
Zimbabwe: Columbite tantalite	32	35	^{r}111	^{r}94	94	5	5	^{r}17	^{r}14	14	11	12	^{r}39	^{r}33	33
Total	^{r}34,060	^{r}36,993	^{r}38,368	^{r}37,118	30,513	^{r}14,062	^{r}15,335	^{r}15,847	^{r}15,407	12,721	^{r}395	^{r}395	^{r}477	^{r}400	317

^{e}Estimated. ^{r}Revised. NA Not available.

[1] Excludes columbium- and tantalum-bearing tin ores and slags. Production of tantalum contained in tin slags was, in thousand kilograms: 1989—362; 1990—343; 1991—244; 1992—160; and 1993—132 according to data from the Tantalum-Niobium International Study Center. Table includes data available through July 28, 1994.

[2] In addition to the countries listed, Bolivia, China, Russia, and Zambia also produce, or are believed to produce, columbium and tantalum mineral concentrates, but available information is inadequate to make reliable estimates of output levels.

[3] Data on gross weight generally have been presented as reported in official sources of the respective countries, divided into concentrates of columbite, tantalite, and pyrochlore where information is available to do so, and reported in groups such as columbite and tantalite where it is not.

[4] Unless otherwise specified, data presented for metal content are U.S. Bureau of Mines estimates based on, in most part, reported gross weight and/or pentoxide content.

[5] Less than 1/2 unit.

TABLE 16

COLUMBIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms columbium content)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993[p]
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	—	—	—	—	—	—	([1])	([1])	([1])	([1])	—
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Industry stocks, Jan. 1	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Total U.S. supply	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Exports[e]	35	36	35	33	39	45	104	227	270	350	300
Government accessions	—	—	97	—	—	—	—	—	—	—	—
Industrial demand	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311	3,500	3,500
U.S. DEMAND PATTERN											
Construction	1,043	1,324	1,506	1,411	1,424	1,683	1,701	1,678	NA	NA	NA
Machinery:											
Metalworking machinery	78	104	103	96	90	90	82	82	NA	NA	NA
Special industry machinery	235	279	274	256	277	268	254	254	NA	NA	NA
Total	313	383	377	352	367	358	336	336	NA	NA	NA
Oil and gas industries	339	485	513	417	431	358	445	436	NA	NA	NA
Transportation	678	903	857	767	694	789	649	635	NA	NA	NA
Other	235	384	172	256	395	395	272	272	NA	NA	NA
Total U.S. primary demand	2,608	3,479	3,425	3,203	3,311	3,583	3,403	3,357	3,311	3,500	3,500

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

[1] A small unreported quantity was produced.

[2] Includes concentrates, ferrocolumbium, tin slags, and other.

TABLE 17
TANTALUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand kilograms tantalum content)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993p
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mine production	—	—	—	—	—	—	(1)	(1)	(1)	(1)	—
Secondarye	18	59	41	34	57	59	54	54	50	55	60
Shipments of Government stockpile excesses	—	—	—	—	—	—	—	—	—	—	—
Imports[2]	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Industry stocks, Jan. 1	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Total U.S. supply	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Distribution of U.S. supply:											
Industry stocks, Dec. 31	W	W	W	W	W	NA	NA	NA	NA	NA	NA
Exportse	119	174	145	142	171	256	195	200	180	150	170
Government accessions	—	—	115	—	—	—	—	—	—	—	—
Industrial demand	536	762	363	372	381	422	376	390	370	375	410
U.S. DEMAND PATTERN											
Electronic components	333	477	201	219	229	277	227	236	NA	NA	NA
Transportation	75	99	60	56	57	32	54	59	NA	NA	NA
Machinery:											
Chemical equipment	21	27	22	20	15	14	14	14	NA	NA	NA
Metalworking machinery	86	120	46	51	27	27	27	27	NA	NA	NA
Total	107	147	68	71	42	41	41	41	NA	NA	NA
Other	21	39	34	26	53	72	54	54	NA	NA	NA
Total demand	536	762	363	372	381	422	376	390	370	375	410
Total U.S. primary demand (industrial demand less secondary)	518	703	322	338	324	363	322	336	320	320	350

eEstimated. pPreliminary. NA Not available. W Withheld to avoid disclosing company proprietary data.

[1] A small unreported quantity was produced.

[2] Includes concentrates, tin slag, and other.

FIGURE 1
TIME-PRICE RELATIONSHIPS FOR COLUMBIUM

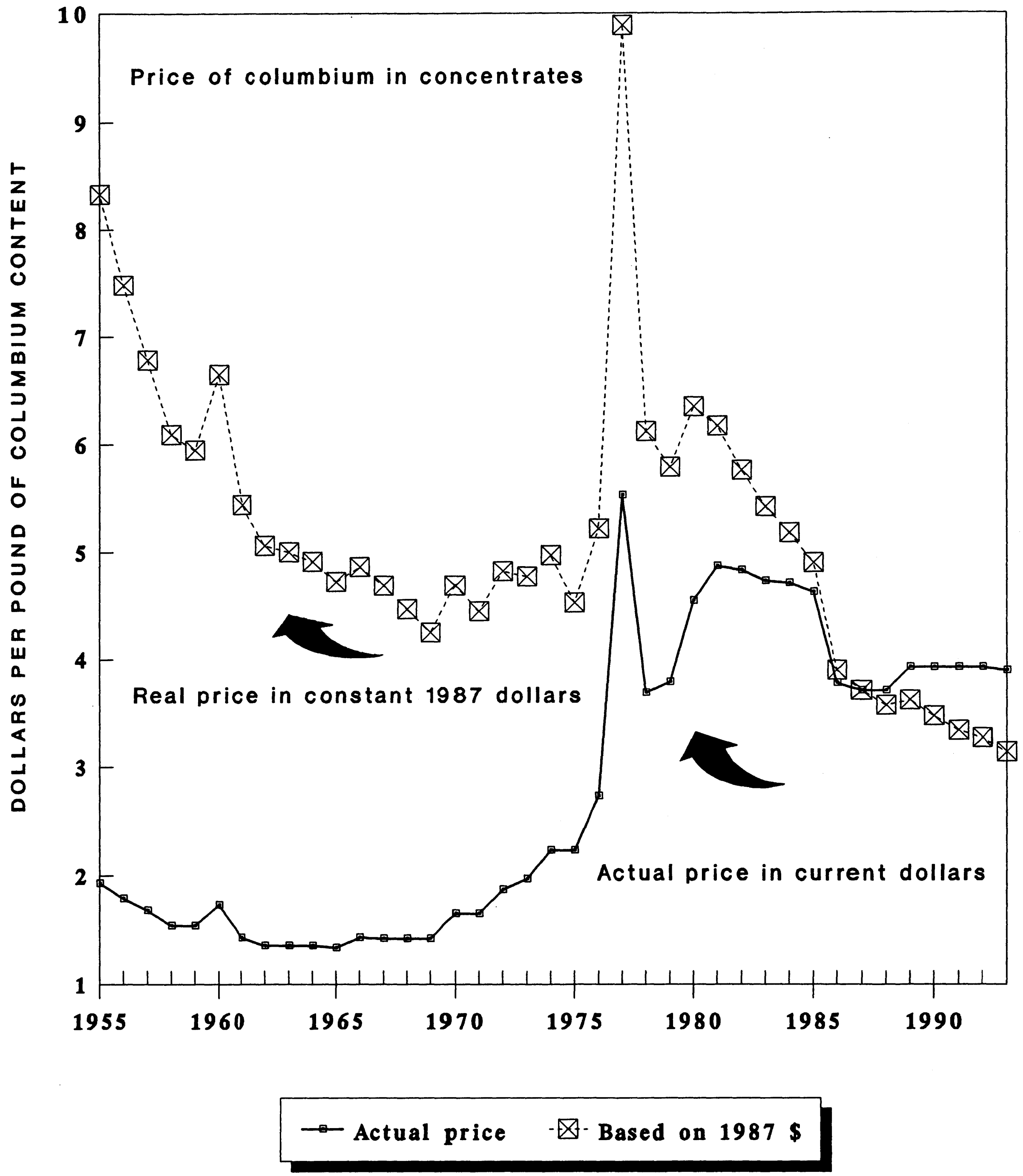


FIGURE 2

TIME-PRICE RELATIONSHIPS FOR TANTALUM

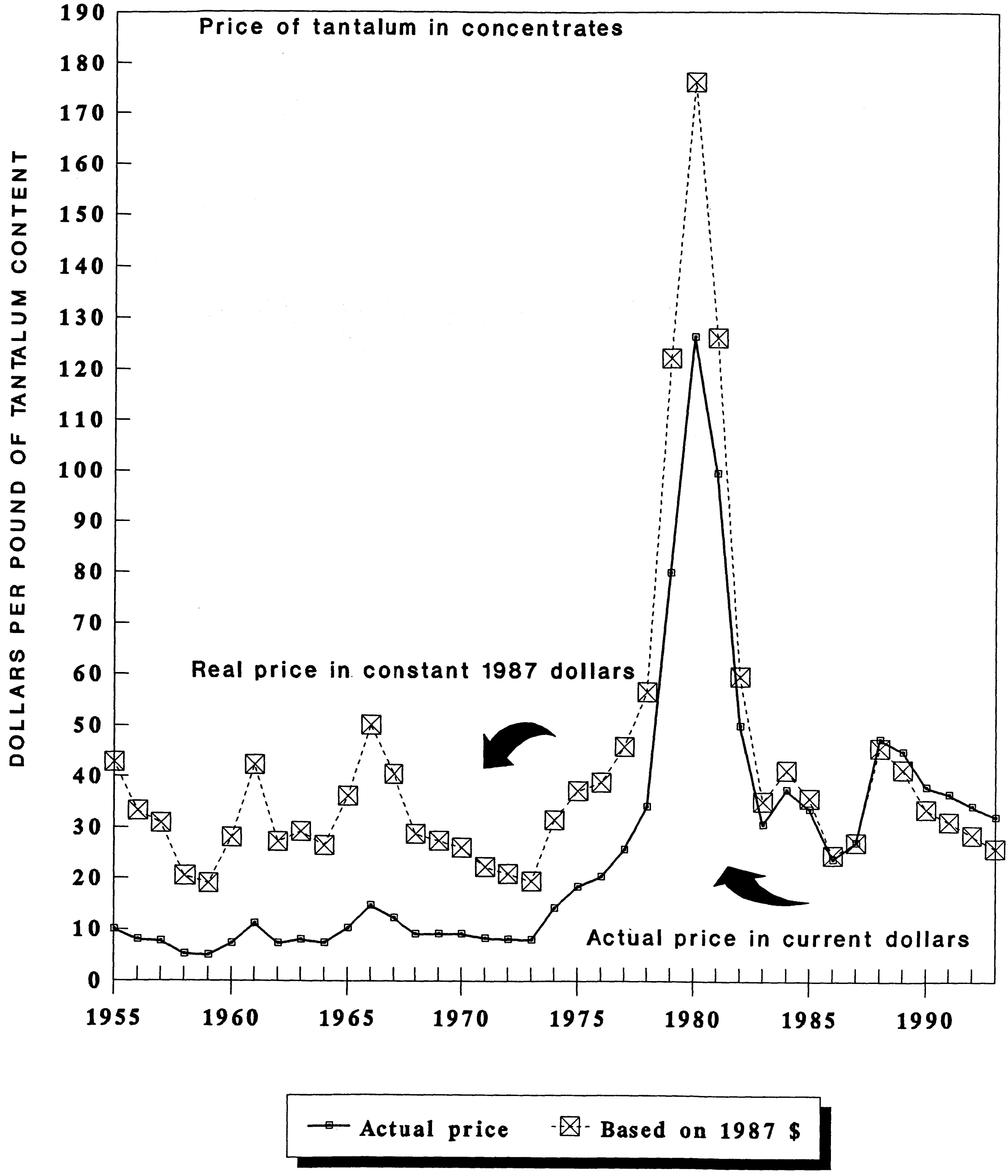
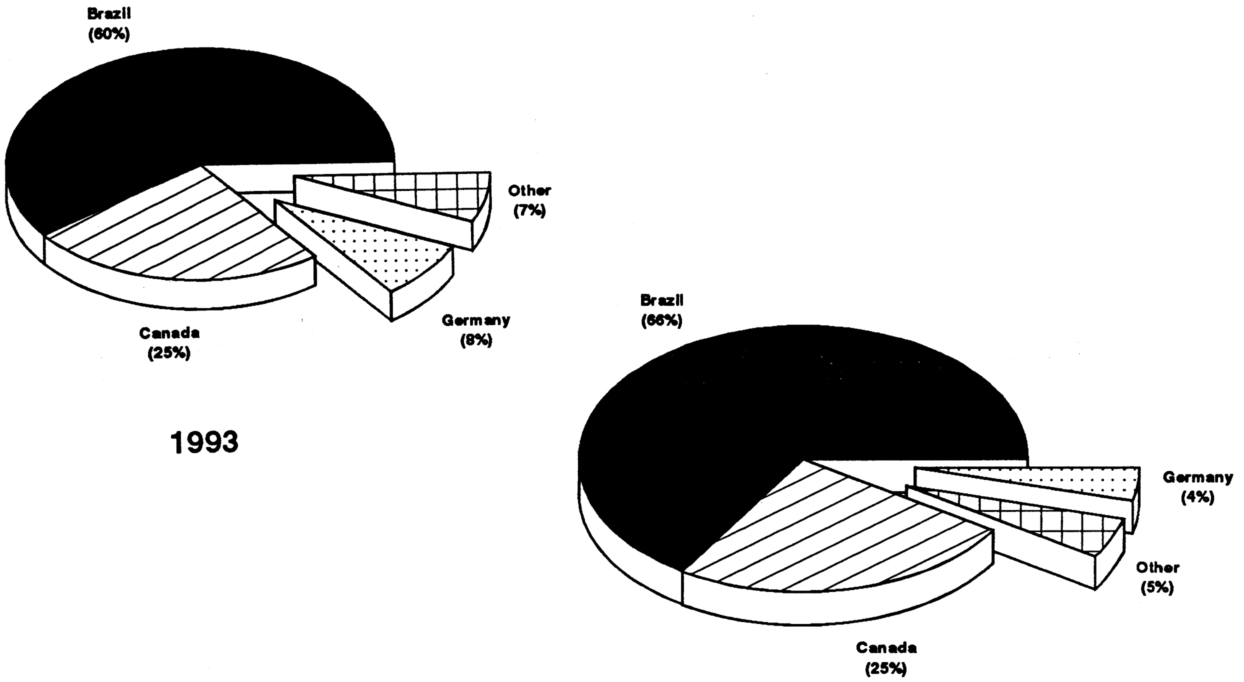


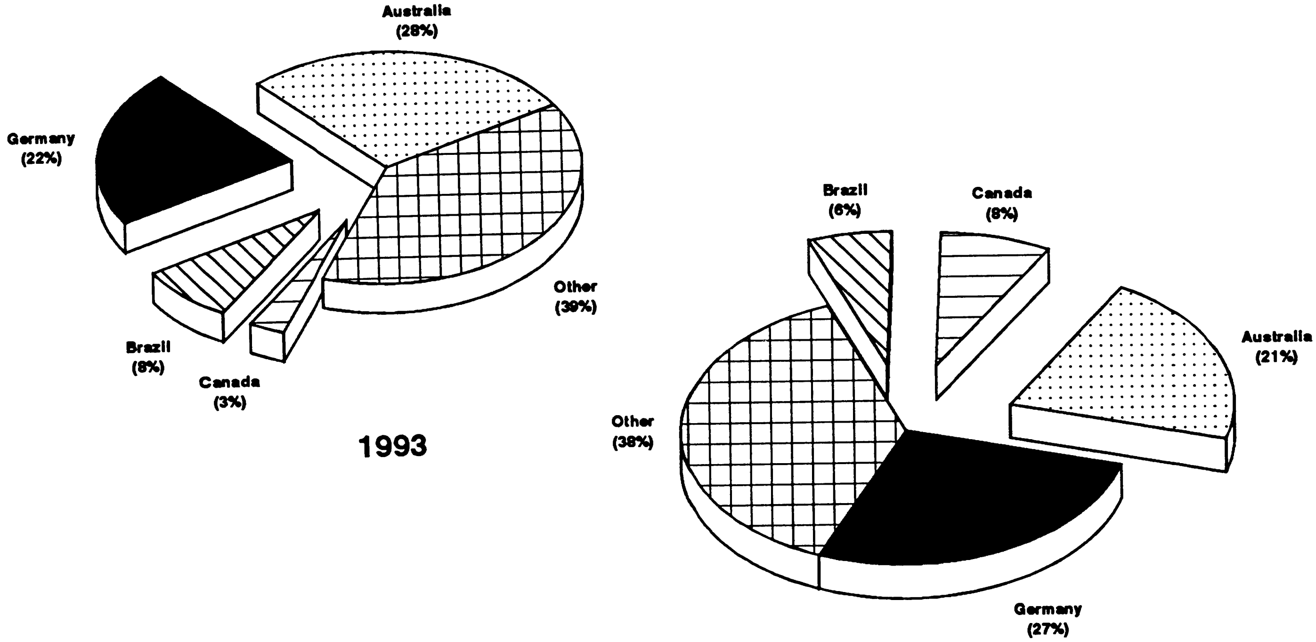
FIGURE 3
MAJOR SOURCES OF U.S. COLUMBIUM IMPORTS



1993

1990-93

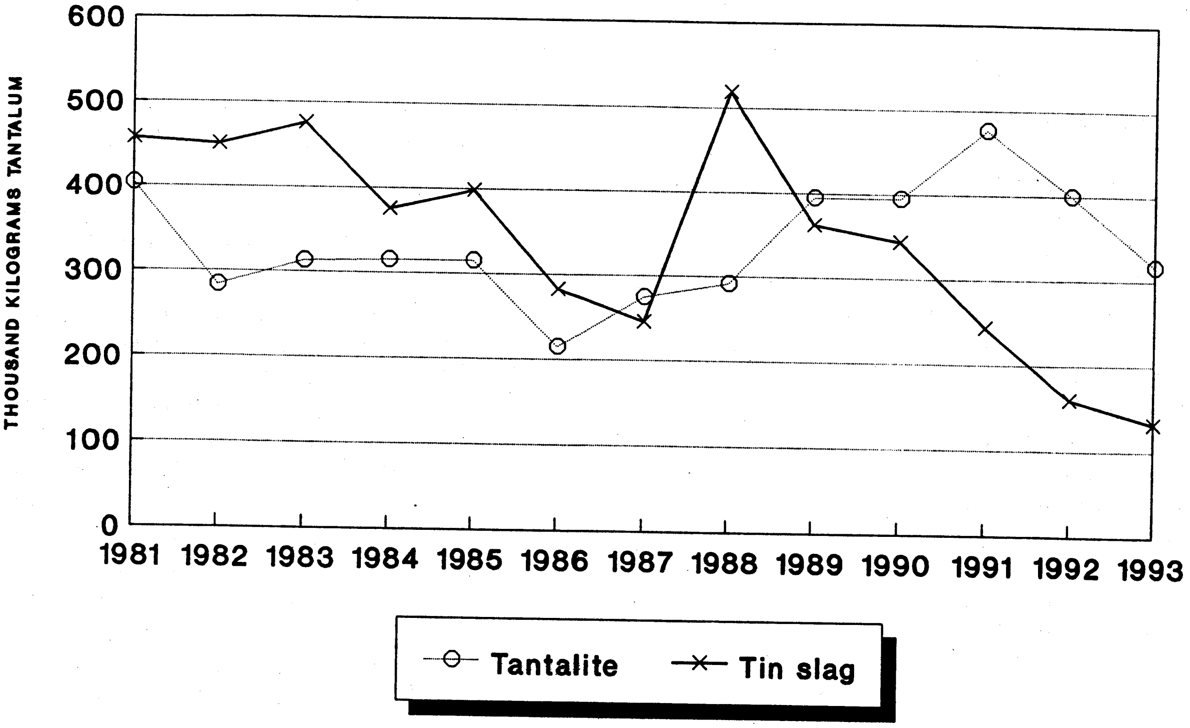
FIGURE 4
MAJOR SOURCES OF U.S. TANTALUM IMPORTS



1993

1990-93

FIGURE 5
WORLD TANTALUM SUPPLY



COPPER

By Daniel L. Edelstein

Mr. Edelstein is a physical scientist with 20 years of combined experience working for the U.S. Bureau of Mines in mineral processing research, process evaluation, and mineral commodities. He has been a copper commodity specialist for 10 years as well as a specialist for the byproduct metals arsenic, selenium, and tellurium.

Domestic mines yielded one-fifth of the world's copper in 1993, maintaining the U.S. position as the world's second largest copper-producing nation. Domestic mine production continued to trend upward in 1991, to 1.8 million metric tons, valued at about $3.6 billion. More than 60 mines operating in 13 States produced reportable quantities of copper; however, the top 15 mines accounted for more than 95% of production. The principal mining States, in descending order Arizona, Utah, New Mexico, Michigan, and Montana, accounted for 98% of production. The 2% increase above the 1992 level was attributable to incremental expansion of mill capacity at several mines and the opening of one medium-sized mine. Most of the increase resulted from a full year's production from projects that were completed during 1992. Total U.S. mine capacity in 1993 was estimated at 2.06 million tons, an increase of about 50,000 tons from the year before. U.S. copper companies continued to invest heavily in South America, influenced by favorable geologic settings and a positive international investment climate there.

At yearend, 8 primary and 5 secondary smelters, 9 electrolytic and 6 fire refineries, and 15 electrowinning plants were operating in the United States. Electrowon production of about 490,000 tons accounted for 27% of domestic mine production, and was down slightly from that of the previous year. Conversion of old scrap to alloys and refined copper contributed about 555,000 tons of copper to the market, a quantity equivalent to about 22% of industrial copper consumption.

Copper was consumed, both as refined copper and as direct melt scrap, at about 35 brass mills, 15 wire rod mills, and 750 foundries, chemical plants, and miscellaneous consumers. Copper adn copper alloys found both structural and electrical use in building construction 42%; electrical products, 24%; industrial machinery and equipment, 13%; transortation equipment, 12%; and consumer and general products, 9%.

Copper was mined in 55 countries in 1993, of which the top 2, Chile and the United States, accounted for more than 40%, and the top 11 for more than 80% of the world total. Land-based world copper resources at yearend 1993 were estimated at 1.6 billion tons. The reserve base was estimated at 590 million tons, and reserves at 310 million tons. The United States has about 15% of reserves and the reserve base.

The oversupply of copper that led to rising global inventories during 1992 persisted into 1993; while world refined production and capacity increased slightly, world demand for refined copper remained stagnant. Demand in Western Europe was particularly poor, falling by almost 10%. Weak demand in Japan was partially offset by growth in other Asian markets. Refined copper demand in the United States and Canada, however, ran counter to the world trend, rising by 8.5% and 19%, respectively. Global inventories rose during the year by over 250,000 tons. Again, the United States was an exception, inventories having declined slightly by yearend. As a result of these trends, prices moved downward throughout the year, except for a period at mid-year when prices were artificially high owing to market manipulation. At yearend, tight domestic supplies of copper were pushing domestic prices above those in the rest of the world.

DOMESTIC DATA COVERAGE

Domestic production data for copper were developed by the U.S. Bureau of Mines from seven separate surveys of U.S. operations. Typical of these surveys is the lode mine production survey. Of the 117 operations to which this survey was sent in 1993, 91 responded and of those, 67 reported copper production. The respondents accounted for an estimated 99.7% of the mine production shown in tables 1, 3, and 5. The remaining production was estimated using other surveys.

ANNUAL REVIEW

Production

There were relatively few changes in the operating status of domestic mines, smelters, and refineries. One significant coproduct mine, ASARCO Incorporated's Troy Mine, closed in April owing to lower copper and silver prices. Arimetco International Inc. closed its Emerald Isle Mine in September owing to high operating costs and limited reserves. After delays associated with environmental permitting, Kennecott Corp. began production from its high-grade Flambeau Mine in Wisconsin. Though recovery of copper precipitate continued, Asarco's Silver Bell Mine remained closed throughout the year. In August, Mitsubishi Materials Corp. announced the suspension of operations at its Cox Creek refinery in Baltimore. The refinery had been operating at significantly less than full capacity, processing mainly imported anode. Mitsubishi had intended to feed the refinery from a new smelter in Texas, whose development was abandoned in 1992 when it was unable to secure necessary environmental permits.

Production of electrowon copper, which had been rising steadily over the past 8 years, declined slightly in 1993; heavy rains in the Southwest during January and February served to dilute leach solutions and reduce electrowon production at several mines. In addition, with expansion of its smelter, Cyprus AMAX Minerals Co. ceased electrowon production from surplus concentrates it was roast-leaching at its Casa Grande, AZ, operations.

Mine and Plant Labor.—Domestic mines employed an average of 13,300 mine, mill and office workers, a decline of about 300 from the previous year. Productivity, at domestic copper mines was 64 kilograms of copper per worker-hour in 1993, an increase from 63 kilograms of copper per worker-hour in 1992, and 57 kilograms in 1991. Productivity, which had increased dramatically during the early 1980's, stabilized and even decreased slightly in the late 1980's as copper prices rose. Productivity declined from a high of 58 kilograms per worker-hour in 1985 to a low of 50 kilograms in 1989, the year of peak copper prices. In the 1990's, a renewed round of capital investments and expansions of electrowinning capacity intended to lower costs in the face of declining prices, resulted in a renewed improvement in worker productivity.

Labor contracts for at least four major copper producers expired in June, but were renegotiated without disruption to production. Workers at Asarco's Ray Mine ratified a 3-year contract in June that established wage increases of $1.30 per hour over the life of the contract, as well as increases in health, illness, and pension benefits. Also included was approval of a "labor-management participation program" similar to one adopted by Magma Copper Co. in 1991. Workers at Phelps Dodge Corp.'s Chino Mine remained on the job until a new contract was ratified in July that included provisions for a $0.95 per hour increase in base salary over the life of the mine, wage bonuses tied to the price of copper, and improvements in other benefits. Workers remained on the job without a contract at Kennecott's Utah operation until a new contract was negotiated at the end of September. The new comprehensive 3-year contract included a wage increase of $1.80 per hour over the life of the contract. In November, Copper Range Co. employees ratified a new 4 1/2-year collective bargaining agreement that provided for no wage increases for 2 years. In addition, as part of their "employee share ownership program" (ESOP), workers agreed to lend the company the value of future ESOP benefits.

Costs and Earnings.—Higher operating costs and lower copper prices contributed to lower profits for the major copper producing companies. The heavy rains early in the year particularly took their toll on earnings during the first half of the year.

Asarco, whose Ray and Mission mines were hard hit by flooding, reported a net loss of $55 million during the first half of the year and a $15.6 million annual profit. Operating costs for Asarco's copper operations reportedly rose from $0.70 per pound to $0.82 per pound during the first half of the year. Startup problems with its retrofit smelter in El Paso, and mill expansions at Ray and Mission also contributed to higher costs. In the second quarter, Asarco was reorganized to bring all of its copper operations under common management at offices in Tucson, AZ.

Despite unexpected capital expenditures at the Morenci Mine as a result of flooding, Phelps Dodge reported record production at all of its copper operations. This and forward sales of copper that guaranteed a minimum of $0.95 per pound of copper for 44% of its production resulted in revenues for Phelps Dodge Mining Co. falling by only about 5%, to $1.32 billion. Net earnings, however, fell by about 39%, to $223.6 million, owing to increased mining cost and capital depreciation from recent projects.

Magma Copper Co., which also had record sales of copper, reported a 59% decline in net income, to $24.3 million. Magma calculated that it lost $15.5 million in net earnings during the first half of the year owing to flooding. Despite this, Magma reported net operating costs of 66 cents per pound of cathode, unchanged from 1992. Operating costs for December, however, were reported to be only 59.6 cents per pound.

On November 15, Cyprus Minerals Co. merged with Amax Inc. to form Cyprus Amax Minerals Co. Amax had extensive coal and gold assets; Cyprus had extensive coal, copper, lithium, and molybdenum assets. Cyprus Climax Metals Co. became the new operating company for the former Cyprus Minerals copper operations. While total copper production, sales, and revenue fell in 1993, net operating income for the copper segment was reported as increasing by $17.2 million, to $55 million, owing to nonrecurring write-downs for mine assets and reorganization expenses attributed to the copper segment in 1992. Cyprus Copper Co. in 1992 had relocated its headquarters from Colorado to Phoenix, AZ. A $5.6 million loss, net of insurance recovery, was attributed to the heavy rains in 1993. Cyprus reported full-cash costs and net-cash costs of 77 cents and 72 cents per pound of copper, respectively, down by 1 cent per pound from that of 1992.

Mines, Smelters, and Refineries.—Arimetco International Inc. operated several small leach properties in Arizona and Nevada. According to the Company's annual report for 1993, production rose slightly from 8,100 tons to 8,400 tons. This occurred despite rain-induced losses at its Johnson Camp Mine and Emerald Isle Mine. Mining at Emerald Isle was curtailed in June and leaching suspended in September. At yearend, the mine was still on care and maintenance. In addition, shaft rehabilitation work was suspended at the Van Dyke underground mine. Early in the year, Arimetco acquired the remaining 50% share of the MacArthur Mine, allowing it to consolidate operations with the adjacent Yerington Mine. By yearend, it had acquired the necessary permits to develop MacArthur and to increase leach pad areas at Yerington from 0.4 million square meters to 2 million square meters. Insufficient pad area at Yerington had limited 1993 production and resulted in higher operating costs than in 1992, though overall the company reported a decline in cash costs from 74 cents per pound in 1992 to 70 cents per pound in 1993. The company completed a 2.8-kilometer haul road to transport MacArthur ore to leach dumps at Yerington.

According to ASARCO Incorporated's 1993 annual report, the company's total copper mine production was essentially unchanged in 1993 at 280,000 tons, despite 1993 being the first full year of operation of expanded capacity at the Ray Mine. Smelter and downstream refinery production declined owing to startup problems with its new CON-TOP smelter at El Paso. By yearend, the smelter was operating at 90% of its 100,000-ton annual capacity. Asarco completed installation and startup of a new electrolyte purification facility at its Amarillo, TX, refinery. Solvent extraction-electrowinng (SX-EW) production at Ray declined slightly owing to rain-induced problems.

Metall Mining Corp., Toronto, Canada, owner of Copper Range Co., reported in its 1993 annual report that operating costs at its White Pine, MI, facilities had been reduced from 82 cents per pound to 79 cents per pound of copper. The cost savings were attributed to the purchase of concentrate to process through its smelter and refinery. Because of the relatively high cost of its mining operation, Copper Range initiated a feasibility study to determine if it could economically leach existing pillars in abandoned mine areas. The pillars reportedly contained 145 million tons of ore and 1.4 million tons of copper. The company projected a 30% recovery rate during a 30-year period. The company also was studying the construction of a new smelter with expanded capacity and was expected to reach a decision on the $200-million project by yearend 1994. If the project were to prove infeasible, Copper Range, which has faced environmental challenges, was committed to closing the existing smelter.

According to Cyprus Amax Minerals Co.'s 1993 annual report, the company's domestic copper mine production declined by about 7,000, tons to 285,000 tons. At its Bagdad Mine in Arizona, a 13% expansion of the mill to 77,000 tons of ore per day and a 25% expansion of SX-EW to 14,000 tons of copper per year were completed in late 1993. At the Sierrita/Twin Buttes consolidated operation, a 10% expansion of the Sierrita concentrator to 100,000 tons of ore per day was completed by yearend. Twin Buttes ore was transported via a 4.2-kilometer conveyor system to Sierrita. With depletion of oxide reserves, an agitation-leach process at Twin Buttes was closed at yearend 1992. In 1992, this process had yielded 18,600 tons of copper at Twin Buttes. The Miami smelter, which experienced shutdowns for repairs and modifications of the new ISAMELT furnace in 1992 and early 1993, was reported to be operating at 90% of capacity during the second half of 1993. With smooth operation of the smelter, Cyprus suspended operation of its Casa Grande, AZ, roast-leach operation during the fourth quarter, and diverted concentrates to the lower-cost smelter. Cyprus was reportedly evaluating open pit mining and heap leaching of Casa Grande oxide reserves. Construction of a new refinery at Miami, AZ, making Cyprus fully integrated, was scheduled for startup in late 1994.

According to the RTZ Corp. PLC 1993 annual report, mine production at Kennecott's Bingham Canyon Mine rose 6%, to a record 307,000 tons; Kennecott was a wholly owned subsidiary of RTZ. Though refined production rose by 5%, only 47% of mine output was processed to refined copper at Bingham Canyon; most of the balance was exported as concentrate. RTZ reported cost savings owing to high capacity utilization and improved operating procedures. Permits were secured and construction commenced in July on a new smelter. The smelter was anticipated to be on-stream by April 1995. The refinery also was undergoing modernization. In May, Kennecott's Flambeau Mine in Ladysmith, WI, was commissioned. Production in 1993 of 24,000 tons exceeded company expectations by 16%. Annual capacity over the 5-year life of the mine was expected to be 27,000 tons of copper.

According to its 1993 annual report, Magma Copper Co. produced 181,000 tons of copper, a nominal increase from the 1992 level. While Pinto Valley Mine production fell, owing to flooding during the first quarter, SX-EW production from open-pit mining at San Manuel reached a record level of 45,000 tons. Underground development at the Superior Mine, completed in 1992, allowed for a 33% increase in production at that mine. The San Manuel smelter operated in excess of its design capacity, increasing production by 12% to a record 309,000 tons. An expansion of the smelter, including the addition of a third acid plant, was expected to add 20,000 tons of capacity by mid-1994. During the third quarter, Magma began tunnel boring operations at San Manuel for development of the deep Kalamazoo ore body, scheduled to come into production in 1997. Exploration efforts at Magma's Robinson, NV, property increased reserve estimates by 25%. Pending permitting, construction at Robinson was slated to begin in 1994 and startup was planned for 1997. The 60,000-ton-per-year project was expected to cost $300 million.

Mine production at Phelps Dodge's operations increased nominally to 600,000 tons, according to the company's 1993 annual report. SX-EW production accounted for a record 47% of production. At Morenci, where a record 367,000 tons of copper was produced, Phelps Dodge continued to study the feasibility of mining the Coronado deposit, which contained an estimated 180 million tons of milling ore, and 300 million tons of lower-grade leach ore. Completion of the adjacent Northwest Extension project in May 1992 had already added 64,000 tons of SX-EW capacity at Morenci. At Chino, a $5-million expansion of the electrowinning tankhouse enabled a record production of 58,000 tons of electrowon cathode, and a record mine production of 145,000 tons. The Hidalgo smelter cast 203,000 tons of anode, surpassing a record set in 1986. In addition to reserves reported for existing operations, Phelps Dodge held various other domestic properties it believed to have strong potential for development should market conditions warrant. These deposits, including Ajo, Cochise, Copper Basin, Coronado, Dos Pobres, Lone Star, Southside, and Western Copper, contain over 17 million tons of copper. This compares with reported reserves of only 9.3 million tons at existing Phelps Dodge operations.

Foreign Investments.—In response to improved investment climates, privatization of Governmnt-owned properties, and cost reduction strategies, domestic copper companies sought to increase production capacity through investment in South American copper projects. In October, Cyprus and its joint-venture partner, Lac Minerals Ltd. of Canada., competing against other groups that included several other domestic producers, were awarded the rights to develop the El Abra copper poperty in Chile, owned by Corporacion Nacional del Cobre de Chile (Codelco). This was the fist Codelco-owned property subject to international competition following changes in Chilean mining law that allowed Codelco to enter into joint-venture arrangements for its undeveloped properties. While the initial contract called for Cyprus to pay $404 million for a controlling interest in the $1 billion project, the project was postponed in February 1994 pending resolution of a technical discrepancy concerning ore grades. In May, Cyprus submitted a new bid, following the withdrawal of Lac Minerals, that was accepted. El Abra was projected to produce 225,000 tons of electrowon copper per year beginning in 1997. In addition to oxide reserves in excess of 20 years, El Abra had sulfide reserves that were slated for future development.

In November 1993, Cyprus Amax won a second bid for a controlling interest (up to 91.5%) of the Cerro Verde Mine in Southern Peru, which, according to Cyprus, contained leachable reserves of almost 200 million tons grading 0.8% copper. An initial cash payment of $37 million was to be followed by an investment of about $110 million to upgrade SX-EW operations to produce about 45,000 tons of copper per year. Long-term plans called for studying the feasibility of developing sulfide reserves.

Phelps Dodge Mining Co. continued construction throughout 1993 on the La Candelaria copper-gold deposit in Chile. Discovered in 1987, full production of 95,000 tons per year of copper was anticipated by 1995. Phelps Dodge estimated sulfide reserves of 365 million tons grading 1.09% copper and a mine life in excess of 30 years. Total development costs for the mine, concentrator, port, and associated facilities were projected at $550 million.

Asarco has long held interests in Peruvian and Mexican mining operations. In 1993, Southern Peru Copper Corp. (SPCC), 52.3%-owned by Asarco, signed a $60-million financial agreement for the construction of a 37,000-ton-per-year SX-EW operation near its Cuajone and Toquepala mines. The plant, which was to cost $106 million, was part of 5-year, $300-million program to expand production, replace equipment and make environmental upgrades at SPCC facilities. SPCC had already secured $200 million for financing the program. The redevelopment program was part of an agreement SPCC reached with the Peruvian Government that allowed SPCC to resume cash distributions to its shareholders. Asarco received a $9.34-million distribution in 1993. Asarco also reached an agreement with Grupo Industrial Minera Mexico, S.A. de C.V. (Grupo Mexico), a publicly traded company, to restructure Asarco's 28.3% holdings in privately held Mexico Desarrollo Industrial Minero, D.A. de C.V. (MEDISMA). MEDISMA was to be combined with Grupo Mexico and Asarco was to own a 23.6% stake in the new public corporation, thus adding liquidity to Asarco's holdings.

Exxon Coal and Minerals Co. continued expansion of its investments in Chile. Production at its Los Bronces mine increased by almost 70%, reflecting the first full year of operation of an expansion completed in 1992. Expansion of the Chargres smelter was expected to be completed in 1994.

Freeport McMoran Inc.'s subsidiary, P.T. Freeport Indonesia Co., continued to explore and develop its operations in Indonesia. In 1993, its exploration activities added 2.7 million recoverable tons of copper to its reserves, principally from the Grasberg deposit. In addition, Freeport has identified at least 50 targets for further exploration. Despite caving in two of four ore passes, which resulted in reduced mill throughput for 8 weeks, production rose to almost 300,000 tons, an increase of almost 20,000 tons from 1992, and more than double production of 1989. Freeport reported that cash costs dropped from 40.7 cents per pound in 1992 to 31.1 cents in 1993. Freeport was continuing with a mill expansion program that would double capacity to 115,000 tons per day. In March, Freeport purchased a 65% interest in Rio Tinto Minera S.A.'s smelter in Spain. Plans called for expanding the smelter's capacity from 150,000 tons per year to 180,000 tons per year.

Trade

Several trade agreements were negotiated during 1993 that potentially impact the domestic copper industry. The North American Free Trade Agreement was expected to open trade between Canada, Mexico, and the United States, with tariff reductions beginning in 1994. Then in December, the 7-year-long negotiations were completed on the Uruguay Round of the General Agreement on Tariffs and Trade (GATT), though participating countries had until April 1994, to submit additional tariff reduction proposals. At yearend, U.S. copper producers continued to lobby for elimination of Japanese tariffs on refined copper before actual signing of the agreement. The goal was a zero-for-zero total elimination of tariffs in an effort to increase exports of refined copper to Japan. Because domestic production is located in the Western States and major consuming areas are in the East, a natural trade flow had developed, with the export of refined copper from the west coast to Asian consuming countries, and the importation of Canadian copper on the east coast. Canadian refineries are primarily located in the eastern Provinces. Despite the existing tariff, U.S. producers had had some success in penetrating Japanese markets: in 1992 and 1993 Japan accounted for about 50,000 tons of U.S. exported copper per year, or 30% and 22%, respectively, and in 1991, Japan was the largest recipient at 122,000 tons, 46%. U.S. producers contended that, on average, Japan was a higher-cost smelter than was the United States and was thus maintaining "noncompetetive" capacity through tariff protection.

In April 1994, Japan announced that it would phase down its copper duty over a 5-year period from a flat 15,000 yen per ton, about 8% ad valorem at prevailing prices, to a 3% ad valorem.

Prices and Stocks

Copper prices declined for the first 5 months of the year in response to a global increase in inventories. Domestic inventories, which had increased by more than 50% in 1992, remained relatively stable at the higher level of about 200,000 tons. However, while the domestic market was strong and stock levels stable, the global demand picture was much weaker. Consequently, stocks held in London Metal Exchange (LME) warehouses continued their upward climb from the previous year, rising more that 40% during the first 6 months of the year. Except for a slight dip during the first half of 1992, LME stocks had risen almost continuously since mid-1990, when they dipped below 50,000 tons. In August, an anomalous condition developed on the LME. Despite the high inventories, LME copper available for immediate delivery became tight, spot prices rose, and a pricing backwardation developed, with forward copper contracts selling at a discount to spot prices. This "artificially" high price may have served to further attract copper into LME warehouses, with the result that stocks soared to more than 600,000 tons. In the United States, though prices rose slightly, they remained in contango (forward contracts selling at a premium to spot contracts) and below LME prices. The LME price premium over the Commodity Exchange, Inc. (COMEX) price rose to more than 6.5 cents per pound, compared with an average 1.5 cents during the first 6 months of the year. On September 8, amid concerns that the pricing structure was the result of several large market participants exercising undue influence on the market, the board of the LME intervened and limited the backwardation of copper contracts. The board action had an almost immediate effect on prices. By the end of September, the LME spot price had fallen to 76 cents, the lowest price in 6 years, from an average of 88.3 cents in August, and the backwardation was eliminated. While COMEX prices followed suit, falling from 85 cents to 74 cents at monthend, the U.S. producer price was slower to follow, closing the month at 86 cents per pound, a drop of only about 6 cents per pound.

With the correction made to the "artificially" high LME prices in September, the LME/COMEX price spread narrowed, and by mid-November reversed, with COMEX copper trading at a slight premium. The spread continued to widen in December, reflecting the increasingly tight domestic supply of copper. Domestic inventories, which had been stable during the first half of the year, were down by 25% at yearend. This tight supply appeared to be the driving force for a yearend rally in prices; COMEX spot prices rose almost 10 cents per pound during December, and the price spread between spot purchases and 3-month forward contracts began to narrow. LME inventories dropped marginally at yearend to about 600,000 tons.

In March, the Defense Logistics Agency (DLA) began liquidating the approximately 20,000 tons of refined copper contained in the National Defense Stockpile. DLA held monthly offerings of 4-million-pound lots of copper from March through October. In November and December, it modified its sales and offered the balance of the refined copper inventories in two lots of about 8 million pounds each. At yearend, the stockpile still contained about 18 million pounds of brass slabs, though its sale was anticipated for 1994.

Consumption

U.S. demand for refined copper rose by 8.5% to record levels during 1993. This surge in demand overshadowed a 4% increase in refined production, resulting in a drawdown in inventories and a 12% rise in net imports. Demand was particularly strong during the second half of the year, increasing by 16% over the comparable 1992 period, when the traditional summer slowdown failed to materialize. The rise in consumption resulted from strong growth in demand in major copper consuming industries. In construction, the largest end use for copper, housing starts rose by 7.1% in 1993 and total construction spending climbed by 7.9%. According to data compiled by the Copper Development Association on mill shipments to the domestic market, building construction demand rose by 6% and accounted for 42% of mill shipments to domestic markets; electric and electronic products remained unchanged and accounted for 24% of shipments; transportation uses rose by 12% and accounted for 12% of shipments; and consumer and general products rose by about 2% and accounted for 9% of shipments. According to estimates by the U.S. Bureau of Mines, electrical applications in all the industry segments accounted for about 78% of reported demand.

World Review

World mine production of copper declined slightly in 1993 despite the addition of almost 200,000 tons of new capacity, largely in Chile, but also in the

United States and Indonesia. Mine shut-downs in Canada and the Philippines, and political turmoil and accompanying supply and infrastructure disruptions in Kazakhstan, Russia, and Zaire, accounted for much of the decline in production. Production in Chile reached a record level of slightly more than 2 million tons, owing to a 13% increase in private sector production. Major expansions were reported at La Escondida, where production rose by about 50,000 tons to 390,000 tons, and at the Los Bronces Mine, where production increased by 48,000 tons to 118,000 tons. Production at state-owned Codelco declined slightly, owing to lower ore grades and production disruptions at the Chuquicamata and El Teniente mines.

In Canada, where much of copper production is from byproduct or coproduct mines, overall low metal prices resulted in temporary mine closures, including the Gibralter and Similco mines in British Columbia. The Myra Falls copper-zinc mine remained closed throughout most of the year owing to a labor dispute. In addition, several mines closed permanently owing to exhaustion of reserves. Similarly, Atlas Consolidated Mining and Development Corp. in the Philippines reduced production because of low prices and weather-related damage. In Zaire, the copper industry remained all but shuttered in the face of continuing political turmoil and the need for a large capital infusion.

While world capacity increases in 1993 were limited, coming from incremental expansions of existing facilities, numerous projects that were in the planning stage could account for more than 2 million tons of new capacity by 1996. Key to the global expansion has been the liberalization of foreign investment and ownership laws in South America. Chile alone was anticipating more than $5 million in copper mine investments over the next 3 years that could boost production to more than 3 million tons. In addition to expansions at existing mines, as many as 12 new mines could come on stream. Much of Chile's new capacity will be from SX-EW projects. In addition to the aforementioned projects under development by U.S. companies, major Chilean SX-EW projects under development included the 75,000-ton-per-year Quebrada Blanca project; the 125,000-ton-per-year Zalvidar project; an 80,000-ton-per-year plant at La Escondida; the 40,000-ton-per-year Cerro Colorado Mine; and the 10,000-ton-per-year Ivan project. At yearend, Zambia was exploring options regarding privatization of its copper operations. Key to this was the need to attract capital for the development of reserves in the Konkola Deep Mining Project at the Nchanga Division. Reserves at the Nchanga open pit were nearing exhaustion.

The bottleneck in world smelter production that had developed in 1991 and 1992 and led to surplus concentrates and higher smelting and refining charges began to ease in the latter part of 1992 and 1993. Higher charges allowed concentrates to be shipped greater distances to underutilized smelters, including those in Zambia and Russia. In addition, numerous smelter expansions and modernizations were underway. The International Copper Study Group (ICSG) estimated yearend smelter capacity at 12.6 million tons, about 400,000 tons of which were at new or renovated smelters in Canada, Chile, China, Germany, and the United States. According to CRU International Ltd., combined spot smelting and refining charges, cif Japan, fell from 26 cents per pound of copper during the fourth quarter of 1992 to 18 cents per pound in December 1993.

Total world production of refined copper increased slightly during 1993. The United States accounted for about half of the increase, the balance being from small incremental production in several countries.

Estimated total world demand for refined copper rose marginally in 1993 on the strength of consumption in the United States and the newly industrialized Asian countries. Demand in Europe remained depressed, with estimated consumption declines of 14% in Belgium, 9% in Germany, and about 2% each in Italy and France. Of the major European consumers, only the United Kingdom reported a slight increase. While demand in Japan decreased nominally from the severely depressed 1992, level, demand in Korea, Taiwan, and Thailand continued to grow, increasing by 13%, 15%, and 30%, respectively.

As a result of both continued weak demand and growth in world refined production, the surplus supply of copper that developed in 1992 increased throughout much of 1993. Copper inventories held in commodity exchange warehouses peaked at 700,000 tons in October, a 140% increase during a 2-year period. According to the International Copper Study Group (ICSG) total reported world stocks rose by 260,000 tons, to 1.4 million tons, or the equivalent of 6 1/2 weeks of consumption.

In June 1993, the ICSG held its first Regular General Session in Lisbon Portugal. The ICSG was formally established as an autonomous intergovernmental organization in January 1992. As part of its mission to promote greater transparency in the market, the ICSG began developing an international set of copper production, consumption, and trade statistics. In January 1994, it began publishing a monthly statistical bulletin that was expected to be made available to the public beginning in 1995. The 22 member countries of the ICSG represented more than 80% of the world trade in copper.

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TABLE 1

SALIENT COPPER STATISTICS

(Metric tons unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Ore produced	thousand metric tons	237,301	249,500	276,891	[r]295,953	290,706
Average yield of copper percent		0.61	0.62	0.57	[r]0.59	0.61
Primary (new) copper produced:						
From domestic ores, as reported by:						
Mines		1,497,818	1,587,742	1,631,078	[r]1,764,756	1,801,382
Value	millions	$4,324	$4,311	$3,931	[r]$4,179	$3,636
Percent of world total		[r]16	[r]17	18	19	19
Smelters[1]		1,120,445	1,158,462	1,122,926	1,180,305	1,265,200
Refineries		1,351,747	1,502,014	1,500,544	1,614,509	1,704,146
From foreign ores, matte, etc., as reported by refineries		125,085	74,620	76,889	96,135	88,553
Total new refined, domestic and foreign[2]		1,476,833	1,576,633	1,577,433	1,710,644	1,792,699
Secondary scrap copper produced:						
Smelter from scrap (new and old)		359,066	304,860	364,331	393,609	414,692
Refined copper from scrap (new and old)		480,018	440,757	417,761	[r]43,184	459,788
Secondary copper recovered from old scrap only		[r]547,561	536,732	[r]518,401	[r]554,608	554,815
Exports:						
Refined		130,189	211,164	263,217	176,913	216,741
Unmanufactured[3]		725,000	780,000	806,000	[r]676,000	685,000
Imports for consumption:						
Refined		300,110	261,672	288,586	289,077	343,375
Unmanufactured[3]		515,000	512,000	512,000	593,000	637,000
Stocks, Dec. 31: Total industry and COMEX:						
Refined		106,656	101,274	132,050	[r]204,687	153,078
Blister and materials in solution		131,650	118,924	135,099	166,154	145,583
Consumption:						
Refined copper (reported)		2,203,116	2,150,426	2,048,323	[r]2,178,823	2,364,024
Apparent consumption, primary and old copper (old scrap only)		[r]2,168,865	[r]2,169,255	[r]2,090,028	[r]2,304,779	2,525,292
Price: Weighted average, cathode, cents per pound, producers		130.95	123.16	109.33	107.42	91.56
World:						
Production:						
Mine	thousand metric tons	[r]9,090	[r]9,078	[r]9,281	[r]9,453	[e]9,352
Smelter	do.	[r]9,741	[r]9,645	[r]9,503	[r]9,957	[e]9,856
Refineries	do.	[r]10,919	10,805	10,637	[r]11,163	[e]11,375
Price: London, Grade A, average cents per pound		128.91	121.02	106.21	103.72	86.75

[e] Estimated. [r] Revised.

[1] Includes primary copper produced from foreign ores, matte, etc., to avoid disclosing company proprietary data.

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

[3] Includes copper content of alloy scrap. Copper content of alloy scrap imported and exported in 1989 and 1990 was estimated from gross weight.

TABLE 2
MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1993

Company and deposit	Percent company ownership	Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)	Deposit and company share, thousand metric tons copper	Deposit and company, percent of grand total
ASARCO Incorporated:[1]						
Copper deposits:						
Mission Complex, AZ	100.0	492,511	0.67	3,300	3,300	7.9
Ray, AZ	100.0	995,363	.63	6,271	6,271	15.0
Silver Bell, AZ	100.0	91,898	.47	432	432	1.0
Continental, MT	49.9	496,321	.35	1,737	867	2.1
Total copper deposits[2]	XX	2,076,093	.57	11,740	10,869	25.9
Copper Range Co.:[3]						
White Pine, MI	100.0	164,200	1.12	1,839	1,839	4.4
Cyprus Minerals Co.:[4]						
Bagdad	100.0	1,078,099	.37	3,989	3,989	9.5
Sierrita/Twin Buttes	100.0	849,125	.29	2,462	2,462	5.9
Miami	100.0	257,822	.45	1,160	1,160	2.8
Casa Grande	100.0	19,958	.67	134	134	.3
Pinos Altos	100.0	181	6.01	11	11	(5)
Mineral Park	100.0	61,144	.23	141	141	.3
Total reserves[2]	XX	2,266,330	.35	7,897	7,897	18.8
Kennecott Corp.:						
Bingham Canyon[6]	100.0	1,088,000	.59	6,419	6,419	15.3
Flambeau[7]	100.0	1,450	10.63	154	154	.4
Total reserves	XX	1,089,450	.60	6,573	6,573	15.7
Magma Copper Co.:[8]						
Magma Superior	100.0	939	5.34	50	50	.1
San Manuel:						
Oxide pit	100.0	11,167	.59	66	66	.2
In situ leach ores	100.0	178,556	.56	993	993	2.4
Underground sulfide	100.0	52,709	.64	337	337	.8
Open Pit, sulfide	100.0	514	.99	5	5	(5)
Kalamazoo underground:						
Sulfide reserves	100.0	29,802	.63	188	188	.4
Lower Kalamazoo	100.0	168,653	.65	1,096	1,096	2.6
Underground development and miscellaneous muck	100.0	7,421	.46	34	34	.1
Pinto Valley:						
Miami tailings leach	100.0	20,665	.37	76	76	.2
Open pit sulfide	100.0	167,000	.39	651	651	1.6
Leach ore (sulfide)	100.0	60,365	.22	133	133	.3
Robinson Nevada:						
Open pit, sulfide	100.0	228,347	.55	1,256	1,256	3.0
Total reserves[2]	XX	926,137	.53	4,887	4,887	11.7
Phelps Dodge Corp.:[9]						
Morenci, AZ (milling)	85.0	468,198	.69	3,231	2,746	6.6
Morenci, (leach)	85.0	1,052,244	.31	3,262	2,773	6.6
Chino, NM (milling)	66.7	240,313	.69	1,658	1,105	2.6
Chino, (leach)	66.7	106,776	.34	363	242	.6

See footnotes at end of table.

TABLE 2—Continued
MAJOR U.S. COPPER-PRODUCING COMPANY RESERVES IN 1993

Company and deposit	Percent company ownership	Ore (thousand metric tons)	Percent copper	Copper content (thousand metric tons)	Deposit and company share, thousand metric tons copper	Deposit and company, percent of grand total
Phelps Dodge Corp.—Continued:						
Burro Chief, NM leach[e]	100.0	148,234	0.31	460	460	1.1
Total reserves	XX	2,015,767	.45	8,973	7,327	17.5
Grand total, major companies[2]	XX	8,537,977	.49	41,909	39,392	94.0

[e] Estimated. XX Not applicable.

[1] Source: ASARCO Incorporated 1993 Annual Report.

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

[3] Source: Metall Mining Corp. 1993 Annual Report.

[4] Source: Cyprus Minerals Co. Form 10-K, Dec 31, 1993.

[5] Less than 0.05%.

[6] Source: Kennecott Corp.

[7] Source: Estimated from RTZ Corp. form 20-F ending Dec. 31, 1992.

[8] Source: Magma Copper Co. 1993 Annual Report.

[9] Source: Phelps Dodge Corp. 1993 Annual Report.

TABLE 3
MINE PRODUCTION OF RECOVERABLE COPPER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1989	1990	1991	1992	1993
Arizona	898,466	978,767	1,024,066	[r]1,152,878	1,158,759
Michigan, Montana, Utah	314,313	322,301	337,137	384,506	387,242
New Mexico	259,640	262,815	252,859	211,337	224,305
Other States[1]	25,399	23,859	17,016	[r]16,035	31,076
Total	1,497,818	1,587,742	1,631,078	[r]1,764,756	1,801,382

[r] Revised.

[1] Includes California, Colorado, Idaho, Illinois, Missouri, Nevada, and Tennessee; in addition, 1990 includes Kentucky; and 1991 and 1992 includes Oregon.

TABLE 4

TWENTY-FIVE LEADING COPPER PRODUCING MINES IN THE UNITED STATES IN 1993, 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	410
2	Bingham Canyon	Salt Lake, UT	Kennecott, Utah Copper Corp.	do.	300
3	San Manuel	Pinal, AZ	Magma Copper Co.	do.	172
4	Ray	do.	ASARCO Incorporated	Copper ore, concentrated and leached	165
5	Chino	Grant, NM	Phelps Dodge Corp.	Copper-molybdenum ore, concentrated and leached	157
6	Sierrita	Pima, AZ	Cyprus Climax Metals Co.	do.	125
7	Bagdad	Yavapai, AZ	do.	do.	115
8	Mission Complex	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	100
9	Pinto Valley	Gila, AZ	Magma Copper Co.	Copper-molybdenum ore, concentrated and leached	92
10	Tyrone	Grant, NM	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper ore, concentrated and leached	78
11	Inspiration	Gila, AZ	Cyprus Climax Metals Co.	Copper ore, leached	65
12	White Pine	Ontonagon, MI	Copper Range Co.	Copper ore, concentrated	60
13	Continental	Silver Bow, MT	Montana Resources Inc.	Copper-molybdenum ore, concentrated	50
14	San Xavier	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	30
15	Flambeau	Rusk, WI	Kennecott Corp.	do.	20
16	Superior (Magma)	Pinal, AZ	Magma Copper Co.	do.	17
17	Miami	Gila, AZ	do.	Copper ore, leached	12
18	Continental	Grant, NM	Cobre Mining Co.	Copper ore, concentrated	10
19	Pinos Altos	do.	Cyprus Pinos Altos Corp.	do.	9
20	Twin Buttes	Pima, AZ	Cyprus Climax Metals Co.	Copper ore, leached	20
21	Yerington	Lyon, NV	Arimetco Incorporated	do.	7
22	Troy	Lincoln, MT	ASARCO Incorporated	Copper-silver ore, concentrated	18
23	Casteel	Iron, MO	The Doe Run Co.	Lead-copper ore, concentrated	NA
24	Johnson Camp	Cochise, AZ	Arimetco Incorporated	Copper ore, leached	5
25	Silver Bell	Pima, AZ	ASARCO Incorporated	Copper ore, concentrated	5

NA Not available.

TABLE 5

MINE PRODUCTION OF COPPER-BEARING ORES AND RECOVERABLE COPPER CONTENT OF ORES PRODUCED IN THE UNITED STATES, BY SOURCE AND TREATMENT PROCESS

(Metric tons)

Source and treatment process	1989		1990		1991		1992[r]		1993	
	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper	Gross weight	Recoverable copper
Mined copper ore:										
Concentrated	230,526,000	1,126,742	240,618,000	1,150,416	261,204,000	1,146,865	262,984,000	1,223,551	[1]261,999,000	1,265,871
Leached[2]	6,775,000	311,885	8,882,000	393,463	15,687,000	441,241	32,969,000	501,603	28,707,000	490,535
Total	237,301,000	1,438,627	249,500,000	1,543,879	276,891,000	1,588,106	295,953,000	1,725,154	290,706,000	1,756,406
Copper precipitates shipped; leached from tailings, dump, and in-place material	47,388	34,485	31,344	22,997	41,370	27,684	32,493	27,196	25,865	19,043
Other copper-bearing ores[3]	15,285,000	24,707	10,111,000	20,866	8,999,000	15,288	7,788,000	12,407	5,874,000	25,932
Grand total[4]	XX	1,497,818	XX	1,587,742	XX	1,631,078	XX	1,764,756	XX	1,801,382

[r] Revised. XX Not applicable.

[1] In 1993, 584,189 ounces of gold, and 14,366,989 ounces of silver, were recovered from concentrated ore. The average value of gold and silver per metric ton of ore concentrated was $1.04.

[2] Includes electrowon from concentrates roast-leached.

[3] Includes gold ore, gold-silver ore, lead ore, lead-copper ore, lead-zinc ore, molybdenum ore, silver ore, tungsten ore, zinc ore, fluorspar, flux ores, cleanup, ore shipped directly to smelters, and tailings.

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

TABLE 6
PRODUCTION OF REFINED COPPER, BY SOURCE AND METHOD OF RECOVERY

(Metric tons)

Period	Primary materials				Scrap			Total refined
	Electrolytically refined[1]		Electrowon	Total[2]	Electrolytically refined[1]	Fire refined	Total[2]	
	Domestic[3]	Foreign						
1989	1,039,862	125,085	311,885	1,476,833	376,595	103,424	480,018	1,956,851
1990	1,108,550	74,620	393,463	1,576,633	328,196	112,561	440,757	2,017,390
1991	1,059,303	76,889	441,241	1,577,433	318,182	99,575	417,761	1,995,194
1992	[r]1,112,906	96,135	[r]501,603	1,710,644	331,057	[r]102,127	[r]433,184	[r]2,143,828
1993	1,213,611	88,553	490,535	1,792,699	337,221	122,567	459,788	2,252,487

[r] Revised.

[1] Based on source of material at smelter level.

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

[3] Includes fire-refined copper.

TABLE 7
PRODUCTION, SHIPMENTS, STOCKS, IMPORTS, AND EXPORTS OF COPPER SULFATE IN THE UNITED STATES

(Metric tons)

Year	Production		Shipments[1,2]	Stocks, Dec. 31	Imports	Exports
	Quantity	Copper content				
1989	[r]33,186	8,349	[r]33,911	3,485	13,458	571
1990	34,286	8,627	36,357	1,414	12,251	[r]560
1991	40,186	10,104	39,220	2,380	10,309	827
1992	46,777	11,782	46,296	2,860	8,290	1,049
1993	46,393	11,689	46,261	2,993	9,431	334

[r] Revised.

[1] Includes consumption by producing companies.

[2] In 1993, U.S. producers reported 59% of domestic shipments were for agriculture; 31% for industrial use; and 10% for water treatment.

TABLE 8
BYPRODUCT SULFURIC ACID (100% BASIS) PRODUCED IN THE UNITED STATES[1]

(Thousand metric tons)

Plant type	1989	1990	1991	1992[r]	1993
Copper[2]	3,076	3,381	[r]3,368	3,344	3,643
Lead[3]	156	165	[r]196	180	202
Zinc[4]	410	413	419	425	398
Total	[r]3,642	3,959	[r]3,983	3,949	4,243

[r] Revised.

[1] Includes acid from foreign materials.

[2] Excludes acid made from pyrite concentrates.

[3] Includes acid produced at molybdenum plants to avoid disclosing company proprietary data.

[4] Excludes acid made from native sulfur.

TABLE 9
CONSUMPTION OF COPPER AND BRASS MATERIALS IN THE UNITED STATES, BY ITEM

(Metric tons)

Item	Brass mills	Wire rod mills	Foundries, chemical plants, miscellaneous users	Secondary smelters-refiners[2]	Total[1]
1992:					
Copper scrap	[r][3]748,955	W	[r]66,002	[r]845,841	[r]1,660,798
Refined copper[4]	458,496	1,674,985	[r][5]45,344	(6)	[r]2,178,823
Hardeners and master alloys	714	—	[r]2,767	—	[r]3,481
Brass ingots	—	—	[r]112,536	—	[r]112,536
Slab zinc	93,049	—	16,346	3,593	112,988
Miscellaneous	—	—	—	47	47
1993:					
Copper scrap	[3]740,774	W	60,732	896,540	1,698,045
Refined copper[4]	504,128	1,819,072	[5]40,824	(6)	2,364,024
Hardeners and master alloys	875	—	3,012	—	3,886
Brass ingots	—	—	112,505	—	112,505
Slab zinc	85,822	—	19,011	3,391	108,224
Miscellaneous	—	—	—	41	41

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Brass mills."

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

[2] Includes ingot makers.

[3] Includes consumption of copper scrap at wire rod mills to avoid disclosing company proprietary data.

[4] Detailed information on consumption of refined copper can be found in table 10.

[5] Includes consumption of refined copper at secondary smelters-refiners to avoid disclosing company proprietary data.

[6] Withheld to avoid disclosing company proprietary data; included in "Foundries, chemicals plants, miscellaneous users."

TABLE 10

REFINED COPPER CONSUMED IN THE UNITES STATES, BY CLASS OF CONSUMER

(Metric tons)

Class of consumer	Cathodes	Ingots and ingot bars	Cakes and slabs	Wirebar, billets and other	Total
1992:					
Wire rod mills	1,660,794	—	—	14,191	1,674,985
Brass mills	311,147	12,420	43,641	91,288	458,496
Chemical plants	W	—	—	870	870
Ingotmakers	W	W	W	3,035	3,035
Foundries	2,960	[r]7,713	28	4,472	[r]15,173
Miscellaneous[1]	W	W	W	[r]26,264	[r]26,264
Total	1,974,901	[r]20,133	43,669	[r]140,120	2,178,823
1993:					
Wire rod mills	1,819,072	—	—	—	1,819,072
Brass mills	313,524	32,602	56,236	101,766	504,128
Chemical plants	—	—	—	870	870
Ingotmakers	W	W	W	2,174	2,174
Foundries	1,582	5,090	W	3,534	10,206
Miscellaneous[1]	W	W	W	27,574	27,574
Total	2,134,178	37,692	56,236	135,918	2,364,024

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Billets and other."

[1] Includes iron and steel plants, primary smelters producing alloys other than copper, consumers of copper powder and copper shot, and other manufacturers.

TABLE 11

STOCKS OF COPPER IN THE UNITED STATES, END OF PERIOD

(Metric tons)

Period	Blister and materials in process of refining[1]	Refined copper					
		Primary and secondary refiners	Wire rod mills	Brass mills	Other[2]	New York Commodity Exchange	Total
1989	131,650	23,580	31,720	12,447	23,909	15,000	106,656
1990	118,924	26,031	24,294	9,775	23,174	18,000	101,274
1991	135,099	38,334	29,578	10,724	22,811	30,603	132,050
1992	166,154	35,450	36,973	12,454	[r]23,773	96,037	[r]204,687
1993:							
January	157,157	30,293	24,977	12,297	23,383	112,475	203,425
February	149,536	30,293	24,836	13,167	23,383	104,156	195,835
March	156,037	32,055	26,310	12,525	21,404	97,618	189,912
April	158,884	35,417	36,738	12,206	19,588	100,527	204,476
May	163,479	38,339	38,208	15,435	17,939	98,239	208,160
June	146,153	33,037	39,746	11,292	16,080	95,694	195,849
July	164,073	31,118	35,222	15,252	14,285	103,241	199,118
August	153,884	33,150	29,941	17,342	12,447	90,814	183,694
September	171,769	30,128	22,822	12,571	10,975	85,379	161,875
October	160,421	31,301	19,205	7,266	9,304	87,666	154,742
November	166,982	33,276	23,942	13,540	5,607	73,065	149,430
December	145,583	33,431	34,743	14,583	3,168	67,153	153,078

[r] Revised.

[1] Includes copper in transit from smelters in the United States to refineries therein.

[2] Includes chemical plants, foundries, miscellaneous plants and the National Defense Stockpile; the 20,000 tons contained in the stockpile were sold-off beginning in Mar. 1993.

TABLE 12
U.S. EXPORTS OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate (copper content)		Matte, ash and precipitates (copper content)		Refined		Unalloyed copper scrap		Blister and anodes		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992	265,769	$339,972	12,963	$14,891	176,913	$396,296	101,195	$115,830	16,926	$40,538	573,766	$907,527
1993:												
Australia	2,481	2,721	(2)	12	3	5	—	—	—	—	2,485	2,738
Belgium	245	1,107	18	161	—	—	3,134	1,403	—	—	3,398	2,671
Brazil	2,432	2,904	17	15	—	—	155	272	—	—	2,604	3,191
Canada	85,844	106,173	10,944	12,907	19,318	43,559	42,763	39,308	9,377	21,926	168,246	223,873
China	10,500	5,869	167	179	10,961	21,565	13,206	12,428	—	—	34,834	40,041
Costa Rica	—	—	—	—	1,170	2,105	—	—	—	—	1,170	2,105
Dominican Republic	—	—	—	—	343	684	—	—	4	6	347	690
El Salvador	—	—	—	—	706	1,329	—	—	—	—	706	1,329
France	—	—	—	—	351	602	—	—	—	—	351	602
Germany	7	7	833	7,107	39	58	294	322	—	—	1,172	7,494
Honduras	9	12	—	—	534	1,143	—	—	—	—	543	1,155
Hong Kong	20	31	35	48	3,076	6,354	9,996	7,686	—	—	13,126	14,118
India	67	51	40	25	206	101	690	695	11	17	1,014	889
Indonesia	—	—	—	—	503	866	77	57	—	—	580	923
Italy	—	—	—	—	3,052	5,719	231	278	47	72	3,330	6,069
Japan	87,886	98,638	706	1,311	47,183	89,234	25,279	44,028	310	370	161,363	233,581
Korea, Republic of	12,677	13,700	38	54	4,381	9,212	10,424	16,307	176	231	27,696	39,504
Mexico	78	298	13	26	10,468	19,626	430	459	1,085	1,809	12,075	22,218
Netherlands	—	—	—	—	26,329	49,585	377	657	—	—	26,706	50,242
Philippines	12,401	16,374	—	—	13	20	—	—	—	—	12,415	16,394
Singapore	12	12	25	235	1,178	2,440	1,184	844	23	235	2,422	3,766
Spain	1,745	2,454	—	—	—	—	—	—	—	—	1,745	2,454
Taiwan	10,132	13,246	—	—	81,506	151,291	1,082	759	300	764	93,020	166,059
Thailand	9	10	—	—	4,716	8,808	160	336	—	—	4,884	9,154
United Kingdom	324	433	73	53	278	449	102	110	7	25	783	1,070
Other	14	19	239	311	426	971	169	197	84	292	934	1,793
Total[1]	226,883	264,056	13,148	22,446	216,741	415,725	109,753	126,147	11,423	25,748	577,948	854,122

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

Source: Bureau of the Census.

TABLE 13

U.S EXPORTS OF COPPER SEMIMANUFACTURES, BY COUNTRY

Country	Pipes and tubing		Plates, sheets, foil, and bars		Bare wire, including wire rod[1]		Wire and cable, stranded		Oxides and hydroxides	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992	19,663	$73,512	38,531	$120,410	30,981	$122,273	10,208	$57,663	9,351	$26,664
1993:										
Argentina	61	347	56	114	56	285	27	846	—	—
Australia	160	711	70	285	24	246	11	176	352	932
Austria	—	—	57	178	—	—	9	83	11	43
Bahamas, The	6	12	1	11	1	10	213	809	—	—
Belgium	121	301	235	771	1	31	1	24	6	19
Brazil	—	—	10	116	19	116	487	2,457	15	50
Canada	5,636	20,718	17,024	47,224	12,347	32,257	4,351	15,767	389	1,091
Chile	228	721	40	149	69	261	77	351	—	—
China	75	361	1,500	3,539	282	890	16	131	262	716
Colombia	202	542	50	290	31	130	26	164	29	93
Costa Rica	154	533	383	2,939	30	88	428	708	30	99
Dominican Republic	63	191	5	36	1,927	4,761	707	2,795	9	27
Ecuador	57	218	4	12	80	228	20	67	29	83
Egypt	96	304	46	435	12	74	—	—	25	93
El Salvador	7	23	6	24	29	165	132	541	8	25
France	96	407	6	34	4	65	96	741	369	531
Germany	6	42	156	555	32	353	233	2,638	110	585
Greece	84	270	1	5	21	216	—	—	121	431
Guatemala	31	113	12	66	6	12	338	888	12	40
Honduras	13	37	42	369	4	17	86	263	—	—
Hong Kong	46	174	1,845	13,980	622	2,829	45	765	—	—
India	19	49	61	68	9	143	15	82	—	—
Ireland	4	8	5	16	32	185	140	658	—	—
Israel	8	90	40	178	92	845	98	411	43	129
Italy	30	95	1	16	20	226	15	248	83	230
Jamaica	25	71	264	628	47	164	143	442	8	26
Japan	32	124	460	3,001	67	1,699	185	1,656	2,077	5,231
Korea, Republic of	97	202	264	2,419	141	347	91	760	1,265	4,029
Kuwait	334	1,099	92	231	3	22	119	78	—	—
Malaysia	16	78	22	102	77	183	3	281	56	156
Mexico	4,187	15,969	1,257	5,060	23,095	93,801	1,788	10,603	75	166
Netherlands	483	1,580	454	720	6	100	51	246	325	865
New Zealand	184	750	24	152	(2)	8	1	13	153	413
Norway	82	240	(2)	5	6	78	5	96	90	244
Panama	91	309	49	101	5	31	55	205	3	9
Philippines	125	429	8	51	77	308	67	638	45	133
Russia	184	552	2	52	—	—	2	18	1	19
Saudi Arabia	1,045	3,492	—	—	299	2,411	212	1,540	(2)	3
Singapore	39	232	135	759	39	1,388	47	388	384	954
South Africa, Republic of	27	111	1	8	8	87	9	81	32	86
Spain	659	2,058	2	49	—	—	7	80	75	229
Sweden	2	5	3	14	22	264	7	188	643	2,427
Switzerland	—	—	17	200	11	599	49	521	(2)	3

See footnotes at end of table.

TABLE 13—Continued

U.S EXPORTS OF COPPER SEMIMANUFACTURES, BY COUNTRY

Country	Pipes and tubing		Plates, sheets, foil, and bars		Bare wire, including wire rod[1]		Wire and cable, stranded		Oxides and hydroxides	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1993—Continued:										
Taiwan	1,317	$4,964	1,159	$8,627	252	$1,444	49	$470	438	$1,016
Thailand	433	1,502	134	380	(2)	7	9	57	75	215
Trinidad and Tobago	1	8	211	525	488	1,194	30	74	2	7
United Arab Emirates	859	3,102	—	—	—	—	5	71	—	—
United Kingdom	305	1,443	76	498	1,916	9,081	280	2,888	568	1,565
Venezuela	399	1,609	229	595	63	194	727	4,079	1	3
Other	688	2,633	102	549	197	1,024	328	1,841	530	1,741
Total[3]	18,815	68,829	26,622	96,134	42,567	158,867	11,840	58,927	8,749	24,757

[1] Total exports of wire rod for 1992 were 1,312 tons, valued at $4,106,161 and 1993 were 3,273 tons, valued at $8,451,379.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS FOR CONSUMPTION OF UNMANUFACTURED COPPER (COPPER CONTENT), BY COUNTRY

Country	Ore and concentrate		Matte, ash, and precipitates		Blister and anode		Refined		Unalloyed scrap		Total[1]	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
1992	102,122	$124,829	7,876	$9,751	58,158	$128,877	289,077	$660,358	52,398	$96,193	509,631	$1,020,008
1993:												
Belgium	—	—	—	—	—	—	497	969	—	—	497	969
Brazil	—	—	—	—	—	—	240	426	—	—	240	426
Bulgaria	—	—	—	—	4,223	8,434	—	—	—	—	4,223	8,434
Canada	1,963	2,431	992	785	(3)	2	244,029	477,504	14,564	25,462	261,547	506,184
Chile	16,908	17,244	1,200	1,432	36,774	78,359	62,822	119,169	4,995	9,419	122,699	225,623
Costa Rica	—	—	—	—	—	—	—	—	640	531	640	531
Dominican Republic	—	—	—	—	—	—	—	—	624	879	624	879
Germany	—	—	—	—	1	54	3,156	6,340	4,511	8,075	7,667	14,469
Guatemala	—	—	—	—	—	—	—	—	394	353	394	353
Indonesia	12,813	19,216	—	—	4,019	10,432	—	—	37	34	16,869	29,681
Jamaica	—	—	—	—	—	—	—	—	719	680	719	680
Japan	—	—	(3)	2	—	—	2,815	6,201	—	—	2,815	6,203
Kazakhstan	—	—	—	—	—	—	1,897	3,423	—	—	1,897	3,423
Mexico	1,992	2,355	105	155	37,067	71,871	3,638	6,864	12,988	19,159	55,790	100,404
Netherlands	—	—	3	8	—	—	518	1,046	268	652	788	1,706
Panama	—	—	—	—	—	—	—	—	500	786	500	786
Peru	55	65	—	—	10,313	21,731	10,496	20,003	147	126	21,011	41,925
Portugal	3,223	4,905	—	—	—	—	—	—	—	—	3,223	4,905
Russia	—	—	—	—	1,856	3,506	36	74	—	—	1,892	3,580
Spain	—	—	—	—	1,222	2,104	—	—	1,409	2,185	2,631	4,289
United Kingdom	—	—	—	—	(3)	2	(3)	6	1,071	2,454	1,071	2,462
Venezuela	—	—	—	—	—	—	—	—	1,372	1,486	1,372	1,486
Zaire	—	—	—	—	2,003	4,244	12,963	26,841	—	—	14,967	31,084
Other	4	7	1	48	125	280	268	600	1,538	1,798	1,936	2,732
Total[1]	36,958	46,223	2,301	2,429	97,604	201,017	343,375	669,466	45,772	74,079	526,009	993,215

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

[2] C.i.f. value at U.S. port.

[3] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS FOR CONSUMPTION OF COPPER SEMIMANUFACTURES, BY COUNTRY

	Pipes and tubing		Plates, sheets, foil, and bars		Bare wire, including wire rod[1]		Wire and cable, stranded		Oxides and hydroxides	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992	6,080	$23,306	48,314	$206,244	8,293	$30,926	869	$4,243	3,951	$10,785
1993:										
Australia	—	—	78	233	2	19	—	—	2,412	6,057
Austria	—	—	2	6	23	294	(2)	5	—	—
Belgium	1	8	353	3,187	6	25	—	—	—	—
Brazil	—	—	521	1,408	18	104	—	—	—	—
Canada	4	41	10,831	32,588	16,780	34,967	110	1,390	—	—
Chile	2	5	1,284	3,460	—	—	—	—	—	—
China	—	—	97	138	8	36	1	15	12	41
Finland	—	—	3,034	10,968	286	1,918	—	—	—	—
France	—	—	84	301	111	1,794	16	112	—	—
Germany	1	67	6,349	21,656	468	3,103	4	21	250	705
India	—	—	142	172	—	—	—	—	(2)	2
Israel	—	—	—	—	783	4,528	—	—	—	—
Italy	—	—	43	135	7	82	27	328	1	1
Japan	28	333	12,764	68,532	77	3,598	39	428	10	88
Korea, Republic of	—	—	95	645	2	9	(2)	5	21	37
Luxembourg	—	—	1,140	10,434	—	—	—	—	—	—
Macedonia	—	—	115	283	—	—	—	—	—	—
Mexico	(2)	2	817	2,533	782	1,857	58	164	509	1,127
Netherlands	2	35	90	258	107	448	—	—	—	—
Norway	—	—	—	—	—	—	—	—	54	128
Peru	—	—	819	1,519	—	—	—	—	—	—
Poland	—	—	177	301	—	—	—	—	—	—
Singapore	—	—	133	1,312	—	—	—	—	—	—
Spain	—	—	50	186	—	—	—	—	—	—
Sweden	(2)	3	10,767	38,363	8	24	—	—	—	—
Switzerland	(2)	7	14	119	34	122	—	—	—	—
Taiwan	1	12	26	330	36	262	21	88	—	—
Turkey	—	—	—	—	101	341	267	988	—	—
United Kingdom	13	78	104	656	20	208	2	39	125	310
Venezuela	10	29	—	—	—	—	59	163	—	—
Other	1	16	41	182	26	183	(2)	15	61	114
Total[3]	63	635	49,968	199,907	19,684	53,920	604	3,762	3,455	8,612

[1] Total imports of wire rod for 1992 were 6,644 tons, valued at $17,562,325 and 1993 were 16,582 tons, valued at $34,357,387.
[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
COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Albania	[r][e]14.0	[r]11.5	[r]6.1	[r]3.9	3.9
Argentina	.7	[r].4	.4	[r][e].3	.4
Armenia	—	—	—	[r]2.0	.5
Australia	[r]295.0	[r]327.0	[r]320.0	[r]378.0	[2]337.0
Bolivia	.3	.2	[e](3)	[r].1	.1
Botswana[4]	21.7	20.6	20.6	[r]20.4	20.0
Brazil	47.4	36.4	37.9	[r][e]38.0	38.0
Bulgaria	38.8	32.9	47.2	[r][e]36.0	36.0
Burma	5.1	4.4	5.7	4.8	3.0
Canada:					
By concentration or cementation	719.1	790.0	[r]807.8	[r]765.5	[2]730.9
Leaching (electrowon)	4.0	3.7	[r]3.3	3.1	[2]2.7
Chile[5]	1,609.3	1,588.4	1,814.3	[r]1,932.7	[2]2,050.4
China[e]	276.0	[r]285.0	[r]304.0	[r]334.2	340.0
Colombia	—	.3	3.6	3.9	4.0
Cuba	1.8	[e]2.8	[e]3.0	2.5	2.5
Cyprus[6]	[r].7	.5	.2	.2	.1
Czechoslovakia[7][8][9]	[r]4.6	3.3	2.6	[e]2.5	—
Ecuador[e]	.1	.1	.1	.1	.1
Finland	14.5	12.6	11.7	[r]9.3	9.2
France	[r].3	[r][e].3	[e].3	[r].1	.1
Georgia	—	—	—	[e]6.0	5.0
Germany:					
Eastern states	7.9	3.6	—	—	—
Western states[7]	.1	(3)	—	—	—
Total	8.0	3.6	—	—	—
Honduras	2.4	1.4	[e]1.0	[r]1.6	1.5
India	57.4	[r][e]58.2	55.4	[r][e]55.0	58.2
Indonesia[7]	144.0	164.1	211.7	280.8	298.6
Iran	[r]67.0	[r]78.6	[r]105.4	[r][e]105.0	86.6
Japan	14.7	12.9	12.4	12.1	10.2
Kazakhstan	—	—	—	[r][e]230.0	210.0
Korea, North[e]	[r]12.0	15.0	15.0	16.0	16.0
Korea, Republic of	(3)	.1	(3)	(3)	(3)
Macedonia	—	—	—	[r][e]7.2	7.0
Malaysia	23.8	24.3	25.6	28.6	[2]25.2
Mexico:					
By concentration or cementation	[r][e]250.0	[r]307.2	[r]299.0	[r]266.2	[2]301.2
Leaching (electrowon)	10.3	26.9	32.1	[e]40.0	40.0
Mongolia	123.6	123.9	90.1	105.1	[2]95.0
Morocco	16.0	16.4	15.8	[r]14.3	14.0
Mozambique[e]	.1	(3)	—	—	—
Namibia	[e]32.8	[e]32.5	33.9	34.6	33.1
Nepal	(3)	(3)	(3)	(3)	(3)
Norway	16.5	19.7	17.4	12.7	9.0
Oman	16.6	14.0	14.0	[r]13.6	12.0
Papua New Guinea	204.0	170.2	204.5	193.4	201.0

See footnotes at end of table.

TABLE 16—Continued

COPPER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Peru:[10]					
By concentration or cementation	368.2	317.7	382.0	[r]369.4	369.5
Leaching (electrowon)	19.7	16.3	17.9	[r]19.0	19.0
Philippines	[r]193.1	[r]182.3	148.3	[r]123.5	[2]136.3
Poland	[r]401.0	[r]370.0	[r]359.0	[r] [e]360.0	350.0
Portugal[10]	103.7	162.9	164.8	[r]147.7	160.0
Romania[7]	[r] [e]47.0	[r]32.0	[r]27.2	[r]25.0	27.0
Russia	—	—	—	[r] [e]590.0	540.0
Saudi Arabia	.8	.9	.9	.9	.9
Serbia and Montenegro	—	—	—	[r]90.0	85.0
Slovakia[9] [11]	—	—	—	—	.5
South Africa, Republic of[7]	181.9	178.7	184.6	[r]176.1	165.0
Spain	28.5	10.9	[r]7.7	[r]9.8	3.8
Sweden	69.5	74.3	81.6	[r]88.6	[2]88.7
Turkey[12]	[r]38.2	[r]39.8	[r] [e]40.0	[r] [e]32.0	28.0
U.S.S.R.[e] [13]	1,000.0	950.0	900.0	—	—
United Kingdom	0.5	1.0	.3	—	—
United States:[7]					
By concentration or cementation	1,185.6	1,194.3	1,189.8	[r]1,263.2	[2]1,310.9
Leaching (electrowon)[14]	311.9	393.5	441.2	[r]501.6	[2]490.5
Uzbekistan	—	—	—	[e]80.0	80.0
Yugoslavia[15] [16]	138.9	140.1	[e]138.0	—	—
Zaire:[17]					
By concentration or cementation	185.4	143.7	[e]70.5	[e]30.9	18.5
Leaching (electrowon)	280.8	229.1	[e]180.0	[r]111.0	50.0
Zambia:[18]					
By concentration or cementation (smelted)	345.5	331.7	300.3	[r]356.4	320.0
Leaching (electrowon)	120.8	104.6	109.9	[r]107.7	97.0
Zimbabwe[e] [7]	16.4	[2]14.7	14.4	[r]10.1	9.0
Total	[r]9,090.0	[r]9,077.9	[r]9,280.5	[r]9,452.7	9,352.1

[e] Estimated. [r] Revised.

[1] Data represent copper content by analysis of concentrates produced except where otherwise noted. Table includes data available through Aug. 10, 1994.

[2] Reported figure.

[3] Less than 50 tons.

[4] Copper content of pelletized nickel-copper matte produced in smelter.

[5] Reported by Comision Chilena del Cobre (COCHILCO). Includes recoverable copper content of nonduplicative mine and metal products produced from domestic ores and concentrates, and leach production for electrowinning.

Mine production data reported by Servicio Nacional de Geologia y Mineria (SERNAGEOMIN) were as follows, in thousand metric tons: 1989—1,628.3; 1990—1,616.3; 1991—1,855.0 (revised); 1992—1,967.0 (revised); and 1993—2,000.0 (estimated).

[6] Copper content of cement copper. Includes copper content of pyrite for 1989.

[7] Recoverable content.

[8] Dissolved Dec. 31, 1992.

[9] Production in Czechoslavakia from 1989-90 came from the Czech Republic and Slovakia, all production from 1991-92 came from Slovakia.

[10] Recoverable copper content by analysis of concentrates for export plus nonduplicative total of copper content of all metal and metal products produced indigenously from domestic ores and concentrates; includes leach production for electrowinning in Portugal.

[11] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[12] Excludes copper content of pyrite.

[13] Dissolved in Dec. 1991.

[14] Includes electrowon from concentrates roast-leached.

[15] Dissolved in Apr. 1992.

[16] Copper content by analysis of ore mined.

[17] Recoverable content of blister, black copper, and Sodimiza concentrate.

[18] Data are for fiscal years beginning Apr. 1 of year stated. Zambian-mined copper reported recovered during smelting and electrowinning.

TABLE 17

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Albania, primary	15.3	1.6	4.8	0.2	0.2
Australia:					
Primary	[r]203.0	192.0	[r]195.0	[r]304.0	223.0
Secondary[e]	10.0	10.0	10.0	10.0	52.0
Total[e]	[r]213.0	202.0	[r]205.0	[r]314.0	275.0
Austria, secondary	39.1	41.0	44.8	49.5	52.0
Belgium:[e]					
Primary	[r]—	[r]1.5	[r]1.0	[r].8	1.0
Secondary	[r]93.4	[r]103.0	105.0	87.4	102.0
Total	[r]93.4	[r]104.5	[r]106.0	[r]88.2	103.0
Brazil, primary	153.4	152.1	141.4	[e]145.0	145.0
Bulgaria:[e]					
Primary	57.2	29.3	26.8	24.0	24.0
Secondary	2.0	1.0	1.0	1.0	1.0
Total	59.2	30.3	27.8	25.0	25.0
Canada:					
Primary	462.3	475.6	[r]505.4	[r]515.0	[3]535.9
Secondary	37.8	47.4	[r]27.8	[r]37.4	[3]40.4
Total[4]	500.2	523.0	[r]533.2	[r]552.4	[3]576.3
Chile, primary[5]	[r]1,048.3	[r]1,206.4	[r]1,176.0	[r]1,191.0	[3]1,234.0
China, primary[e]	[r]450.0	[r]559.0	[r]600.0	[r]700.0	730.0
Czech Republic,[6] primary	—	—	—	—	.5
Czechoslovakia:[7]					
Primary[e]	5.0	5.0	5.0	5.0	—
Secondary[e]	3.0	3.2	3.0	3.0	—
Total	8.0	8.2	8.0	[e]8.0	—
Finland:					
Primary	79.5	90.2	90.1	[r]121.9	120.0
Secondary[e]	12.0	12.0	12.0	12.0	12.0
Total[e]	91.5	102.2	102.1	[r]133.9	132.0
France, secondary[e]	8.4	6.6	5.8	[r]6.1	6.2
Germany:					
Primary:					
Eastern states	[e]20.1	[e]14.0	—	—	—
Western states	176.9	183.6	—	—	—
Total primary	197.0	197.6	[e]171.9	[r e]211.1	175.0
Secondary:					
Eastern states[e]	[r]—	[r]—	—	—	—
Western states	[r]79.0	[r]70.9	—	—	—
Total secondary	[r]79.0	[r]70.9	70.0	70.0	70.0
Total[e]	[r]276.0	[r]268.5	241.9	[r]281.1	245.0
Hungary, secondary[e]	.1	.1	.1	.1	.1
India, primary	42.5	40.7	47.0	[e]50.0	43.3
Iran:[8]					
Primary	[r]72.3	[r]87.6	[r]119.6	[r]121.6	133.0
Secondary	3.8	[r]4.6	[r]6.3	[r]6.4	7.0
Total	[r]76.1	[r]92.2	[r]125.9	[r]128.0	140.0
Japan:					
Primary	882.3	893.2	967.7	1,046.2	[3]1,091.2

See footnotes at end of table.

TABLE 17—Continued

COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Japan—Continued:					
Secondary	123.2	147.4	117.7	128.7	[3]72.9
Total	1,005.5	1,040.6	1,085.4	1,174.9	[3]1,164.1
Kazakhstan:[e]					
Primary	—	—	—	[r]270.0	250.0
Secondary	—	—	—	40.0	40.0
Total	—	—	—	[r]310.0	290.0
Korea, North:[e]					
Primary	[r]25.0	[r]25.0	20.0	21.0	23.0
Secondary	[r]5.0	[r]5.0	5.0	5.0	5.0
Total	[r]30.0	[r]30.0	25.0	26.0	28.0
Korea, Republic of, primary	[r]159.7	[r]160.5	[r]148.6	[r]170.1	142.0
Mexico, primary	174.3	175.4	182.6	[r]228.2	181.0
Namibia, primary	38.0	33.2	32.9	[r]37.5	34.8
Norway, primary	35.0	36.5	38.4	39.3	40.0
Oman, primary	15.2	12.1	12.2	15.0	[3]27.7
Peru, primary	[r]241.4	195.5	268.8	253.9	253.9
Philippines, primary	156.3	153.5	167.5	[r]168.8	168.0
Poland:					
Primary[e]	[r]376.0	[r]331.4	[r]353.1	[r]363.0	360.0
Secondary[e]	20.0	20.0	20.0	20.0	20.0
Total	[r]396.0	[r]351.4	[r]373.1	[r][e]383.0	380.0
Portugal:[e]					
Primary	[r]—	[r]—	[r]—	[r]—	[r]—
Secondary	2.0	2.0	2.0	[r]1.0	1.0
Total	[r]2.0	[r]2.0	[r]2.0	[r]1.0	1.0
Romania:					
Primary[e]	[r]38.0	27.3	[r]27.8	[r]23.4	23.0
Secondary[e]	[r]1.5	1.0	1.0	1.0	1.0
Total	[r]39.5	28.3	[r]28.8	[r]24.4	24.0
Russia:[e]					
Primary	—	—	—	[r]620.0	590.0
Secondary	—	—	—	50.0	50.0
Total	—	—	—	[r]670.0	640.0
Serbia and Montenegro:[e]					
Primary	—	—	—	90.0	90.0
Secondary	—	—	—	40.0	40.0
Total	—	—	—	130.0	130.0
Slovakia,[6] primary[e]	—	—	—	—	3.0
South Africa, Republic of, primary	184.8	176.0	[r]164.7	[r]152.8	143.0
Spain:[e]					
Primary	120.0	110.0	111.1	110.0	110.0
Secondary	32.3	[r]40.3	38.0	40.0	40.0
Total	152.3	[r]150.3	149.1	150.0	150.0
Sweden:					
Primary	70.0	76.4	68.1	77.8	76.3
Secondary	24.6	31.6	29.4	20.6	22.1
Total	94.6	108.0	97.6	98.4	98.4
Taiwan, primary	43.2	16.1	—	—	—

See footnotes at end of table.

TABLE 17—Continued
COPPER: WORLD SMELTER PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Turkey:					
Primary	[r]25.0	[r]25.2	[r]32.4	[r]31.6	39.6
Secondary	.2	.2	.2	.2	.2
Total	[r]25.2	[r]25.4	[r]32.6	[r]31.8	39.8
U.S.S.R.:[e] [9]					
Primary	1,200.0	1,100.0	950.0	—	—
Secondary	150.0	130.0	120.0	—	—
Total	1,350.0	1,230.0	1,070.0	—	—
United States:					
Primary[10]	1,120.4	1,158.5	1,123.0	1,180.3	[3]1,265.2
Secondary	359.1	[r]304.9	364.3	393.6	[3]414.7
Total	1,479.5	[r]1,463.4	1,487.3	1,573.9	[3]1,679.9
Uzbekistan:[e]					
Primary	—	—	—	75.0	75.0
Secondary	—	—	—	10.0	10.0
Total	—	—	—	85.0	85.0
Yugoslavia:[11]					
Primary	101.6	105.9	105.0	—	—
Secondary	71.4	68.3	50.0	—	—
Total	173.0	174.3	155.0	—	—
Zaire, primary:					
Electrowon	280.8	229.1	180.0	[r]111.0	50.0
Other	[r]153.4	[r]117.2	[r]52.5	[r]19.9	10.0
Total	[r]434.2	[r]346.3	[r][e]232.5	[r]130.9	60.0
Zambia, primary:[12]					
Electrowon	75.4	51.9	64.5	[r]64.0	57.0
Other	345.5	331.7	300.3	[r]356.4	320.0
Total[4]	420.8	383.7	364.9	[r]420.4	377.0
Zimbabwe, primary[13]	15.8	14.1	13.8	[r]9.7	8.2
Grand total[4]	[r]9,740.7	[r]9,644.8	[r]9,502.6	[r]9,957.4	9,856.4
Of which:					
Primary:					
Electrowon	356.2	281.0	244.5	[r]175.0	107.0
Other	[r]8,306.6	[r]8,313.3	[r]8,224.6	[r]8,749.4	8,689.8
Secondary	[r]1,077.9	[r]1,050.6	[r]1,033.4	[r]1,033.0	1,059.6

[e] Estimated. [r] Revised.

[1] This table includes total production of copper metal at the unrefined stage, including low-grade cathode produced by electrowinning methods. The smelter feed may be derived from ore, concentrates, copper precipitate or matte (primary), and/or scrap (secondary). To the extent possible, primary and secondary output of each country is shown separately. In some cases, total smelter production is officially reported, but the distribution between primary and secondary has been estimated. Table includes data available through June 30,1993.

[2] Argentina presumably produces some smelter copper utilizing its own small mine output together with domestically produced cement copper, and possibly using other raw materials including scrap, but the levels of such output cannot be reliably estimated.

[3] Reported figure.

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

[5] Data revised to exclude high-grade electrowon production. Data include low-grade electrowon which is re-refined.

[6] Formerly part of Czechoslovakia.

[7] Dissolved Dec. 31, 1992.

[8] Data may be for year beginning Mar. 21 of year stated. Only estimated production data are available. Secondary production is estimated to be about 5% of total.

[9] Dissolved in Dec. 1991.

[10] 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: 1989—34,485; 1990—22,997; 1991—27,684; 1992—27,196 (revised); and 1993—19,043.

[11] Dissolved in Apr. 1992.

[12] For fiscal year beginning Apr. 1 of year stated. Electrowon is total electrowon production reported, less the quantity reported as "finished production, leach cathodes." (See table 38).

[13] Includes impure cathodes produced by electrowinning in nickel processing.

TABLE 18
COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Albania, primary[e]	[2]14.5	10.9	4.4	0.1	0.1
Argentina, secondary[e]	11.0	15.0	15.0	[r]15.0	15.0
Australia:					
Primary	[r]220.0	[r]250.0	[r]244.0	[r]271.0	275.0
Secondary	35.0	24.0	35.0	32.0	25.0
Total	[r]255.0	[r]274.0	[r]279.0	[r]303.0	300.0
Austria:					
Primary	7.2	8.7	8.1	[r]5.7	9.6
Secondary	39.1	41.0	44.8	[r]49.0	48.0
Total[3]	46.3	49.7	52.8	[r]54.7	57.6
Belgium:[4]					
Primary	[r]241.2	[r]229.9	[r]191.6	[r]204.2	203.0
Secondary	88.0	102.0	106.0	[r]102.0	102.0
Total	[r]329.2	331.9	[r]297.6	[r]306.2	305.0
Brazil:					
Primary	153.4	152.1	141.4	[e]145.0	145.0
Secondary	54.4	49.6	37.0	[r,e]38.0	38.0
Total[3]	207.8	201.7	178.5	[r,e]183.0	183.0
Bulgaria:					
Primary	45.8	14.3	[r]7.8	8.0	8.0
Secondary	10.0	10.0	5.0	5.0	5.0
Total	55.8	24.3	[r]12.8	13.0	13.0
Canada:					
Primary	477.4	468.4	503.8	508.2	520.0
Secondary	37.8	47.4	34.5	31.1	41.6
Total	515.2	515.8	538.3	539.3	[2]561.6
Chile, primary	1,071.0	1,191.6	1,228.3	[r]1,242.3	1,255.0
China:[e]					
Primary	400.0	400.0	400.0	[r]430.0	440.0
Secondary	140.0	160.0	160.0	[r]229.0	230.0
Total	540.0	560.0	560.0	[r]659.0	670.0
Czech Republic,[5] primary	—	—	—	—	.5
Czechoslovakia:[6]					
Primary[e]	10.0	8.0	10.0	8.0	—
Secondary[e]	[r]18.1	[r]17.4	[r]15.9	[r]20.6	—
Total	[r]28.1	[r]25.4	[r]25.9	[r]28.6	—
Egypt, secondary[e]	3.6	3.6	3.6	3.6	3.6
Finland:					
Primary	49.7	57.1	56.5	[r]68.9	69.0
Secondary[e]	6.0	8.0	8.0	[r]11.0	11.0
Total[e]	55.7	65.1	64.5	[r,2]79.9	80.0
France:					
Primary	[r]16.4	[r]18.0	[e]19.6	[r,e]27.7	26.3
Secondary[e]	[r]26.8	[r]26.0	30.0	29.0	27.0
Total[e]	[r]43.2	[r]44.0	49.6	[r]56.7	53.3

See footnotes at end of table.

TABLE 18—Continued
COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Germany:					
Primary:					
Eastern states[e]	62.0	39.9	—	—	—
Western states	[r]196.2	204.0	—	—	—
Subtotal	[r]258.2	243.9	[r]203.4	[r]236.1	[2]257.5
Secondary:					
Eastern states[e]	31.6	16.8	—	—	—
Western states	279.1	272.2	—	—	—
Subtotal[e]	310.7	289.0	[r]318.3	[r]345.4	375.0
Total:					
Eastern states[e]	93.6	56.7	—	—	—
Western states	[r]475.3	476.2	—	—	—
Grand total	[r,e]568.9	[e]532.9	521.7	[r]581.5	632.5
Hungary, primary and secondary	[r]13.1	[r]12.8	[e]12.0	[r,e]12.0	11.0
India, primary:					
Electrolytic	41.0	40.6	45.0	[e]45.0	35.0
Fire refined[e]	[2].8	1.0	1.0	1.0	.5
Total[e]	[2]41.8	41.6	46.0	46.0	35.5
Iran, primary[7]	[r]43.2	[r]58.2	[r]81.9	[r]86.4	85.0
Italy, primary and secondary	83.3	83.0	[r,e]82.5	[e]76.0	[2]86.0
Japan:					
Primary	882.3	893.1	967.7	1,046.2	1,050.0
Secondary	107.3	114.8	108.6	114.7	139.0
Total[3]	989.6	1,008.0	1,076.3	1,160.9	1,189.0
Kazakhstan:					
Primary	—	—	—	[r,e]225.0	225.0
Secondary	—	—	—	[r,e]25.0	25.0
Total	—	—	—	[r,e]250.0	250.0
Korea, North:[e]					
Primary	[r]25.0	[r]25.0	[r]19.0	20.0	22.0
Secondary	[r]10.0	[r]10.0	[r]5.0	5.0	5.0
Total	[r]35.0	[r]35.0	24.0	25.0	27.0
Korea, Republic of:					
Primary	178.7	[e]183.0	201.9	[r]209.0	218.0
Secondary[e]	[2]1.2	2.6	1.0	2.0	2.0
Total	179.9	185.6	202.9	[r]211.0	220.0
Mexico:					
Primary:					
Electrowon	10.3	26.9	32.1	[r]27.9	30.0
Other[e]	113.8	[2]104.7	107.0	[r]163.2	160.0
Secondary[e]	23.0	[2]31.0	[2]53.0	80.0	80.0
Total[3]	147.0	162.7	192.1	[r]271.1	270.0
Norway, primary[7]	35.0	36.5	38.4	39.3	40.0
Oman, primary	15.1	12.0	[r]11.4	[r]16.2	[2]20.5
Peru, primary	224.3	181.8	246.1	[r]251.1	251.1
Philippines, primary	132.2	125.9	[r]115.5	[r]145.7	172.0
Poland, primary[7]	390.3	[r]346.1	[r]378.5	387.0	[2]404.0

See footnotes at end of table.

TABLE 18—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Portugal, primary	6.0	[r]1.0	0.3	[r]—	—
Romania:[e]					
Primary	[r]42.0	[r]40.3	[r]29.8	[r]21.0	20.0
Secondary	[r]6.0	[r]4.0	[r]4.0	[r]3.1	3.0
Total	48.0	[r]44.3	[r]33.8	[r]24.1	23.0
Russia:					
Primary	—	—	—	[r][e]620.0	590.0
Secondary	—	—	—	[e]50.0	50.0
Total	—	—	—	[r][e]670.0	640.0
Serbia and Montenegro:					
Primary	—	—	—	[r]85.0	85.0
Secondary	—	—	—	[r]29.8	30.0
Total	—	—	—	[r]114.8	115.0
Slovakia,[5] primary and secondary	—	—	—	—	28.0
South Africa, Republic of, primary[7]	144.2	133.0	[r]127.0	[r]115.8	130.0
Spain:					
Primary	[e]115.7	[e]116.0	111.1	[r]134.3	135.0
Secondary	[e]50.0	[e]50.0	38.0	[r]44.8	45.0
Total	[e]165.7	[e]166.0	149.1	[r]179.1	180.0
Sweden:					
Primary	70.0	66.3	67.6	[r]71.6	76.3
Secondary[e]	[2]24.6	31.0	29.0	30.0	[2]22.5
Total	94.6	97.3	96.6	[r]101.6	[2]98.8
Taiwan:					
Primary	43.2	16.1	—	—	—
Secondary[e]	10.0	6.0	12.0	12.0	10.0
Total[e]	53.2	22.1	12.0	12.0	10.0
Turkey, primary[e]	86.4	84.2	[r]80.8	[r]93.5	[2]104.2
U.S.S.R.:[e] [8]					
Primary	1,200.0	1,100.0	950.0	—	—
Secondary	150.0	130.0	120.0	—	—
Total	1,350.0	1,230.0	1,070.0	—	—
United Kingdom:					
Primary	48.6	47.0	16.6	[e]10.4	10.0
Secondary	70.4	74.6	53.5	[e]31.7	36.0
Total	119.0	121.6	70.1	[e]42.1	46.0
United States:					
Primary:					
Electrowon	311.9	393.5	441.2	[r]501.6	[2]490.5
Other	1,164.9	1,183.2	1,136.2	[r]1,209.0	[2]1,302.2
Secondary	480.0	440.8	417.8	433.2	[2]459.8
Total[3]	1,956.8	2,017.4	1,995.2	2,143.8	[2]2,252.5
Uzbekistan:					
Primary	—	—	—	[e]75.0	75.0
Secondary	—	—	—	[e]10.0	—
Total	—	—	—	[e]85.0	75.0

See footnotes at end of table.

TABLE 18—Continued

COPPER: WORLD REFINERY PRODUCTION,[1] BY COUNTRY

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Yugoslavia:[9]					
Primary	101.9	102.2	107.2	—	—
Secondary	49.2	49.2	[e]27.0	—	—
Total[3]	151.0	151.4	134.2	—	—
Zaire, primary[10]	181.6	140.9	104.0	47.5	40.0
Zambia, primary:[11]					
Electrowon	45.4	52.7	45.4	[r]43.7	40.0
Other	418.1	385.4	357.1	[r]428.5	385.0
Total[3]	463.6	438.1	402.5	[r]472.2	425.0
Zimbabwe:[12]					
Primary	15.7	14.1	13.8	[r]9.7	[2]8.2
Secondary[e]	8.3	8.4	8.2	8.2	8.2
Total[e]	24.0	22.5	22.0	[r]17.9	16.4
Grand total[3]	[r]10,919.2	[r]10,805.0	[r]10,637.2	[r]11,162.8	11,375.2
Of which:					
Primary[3]	[r]9,052.2	[r]8,963.7	[r]8,852.6	[r]9,284.7	9,413.6
Secondary[3]	[r]1,770.5	[r]1,745.4	[r]1,690.1	[r]1,790.1	1,836.7
Primary and secondary, undifferentiated[3]	[r]96.4	[r]95.8	[r]94.5	[r]88.0	125.0

[e] Estimated. [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 Aug. 10, 1994.

[2] Reported figure.

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

[4] Includes leach cathode from Zaire, which is processed.

[5] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[6] Dissolved Dec. 31, 1993. Production in Czechoslovakia from 1989-92 came from the Czech Republic and Slovakia.

[7] May include secondary.

[8] Dissolved in Dec. 1991.

[9] Dissolved in Apr. 1992.

[10] Excludes leach cathode exported for reprocessing in Belgium.

[11] Data are for fiscal year beginning Apr. 1 of that stated. Electrowon covers only presumably high-grade electrowon cathodes reported as "finished production leach cathodes." Other, in addition to electrorefined cathodes, includes a smaller amount of "finished product shapes" presumably cast from electrorefined cathodes, high-grade electrowon cathodes, or any blister-anodes and low-grade electrowon cathodes that were furnace- or fire-refined.

[12] May not include copper-nickel matte (copper content more than 6,000 tons per year) imported from Botswana for toll refining.

FLUORSPAR

By M. Michael Miller

Mr. Miller, a physical scientist with 16 years of mineral experience with the Department of the Interior, has been the commodity specialist for fluorspar since 1989. Domestic survey data were prepared by Robin Richardson, statistical assistant; and international data tables were prepared by Harold Willis, international data coordinator. All units are in metric tons, unless otherwise noted.

Traditionally, fluorspar has been considered vital to the Nation for both national security and economic reasons. It is used directly or indirectly to manufacture products such as steel, aluminum, refrigerants, insulating foams, uranium fuel, and gasoline.

In the United States, three producers supplied about 13% of the Nation's fluorspar requirements. This included fluorspar processed from mined ore, fluorspar processed from National Defense Stockpile material, fluorspar shipped from stocks, and fluorspar processed from imported ore. Supplementing fluorspar as a domestic source of fluorine was byproduct fluorosilicic acid production from some phosphoric acid producers. According to the Bureau of the Census, imports of fluorspar were essentially unchanged compared with the 1992 revised figures. Hydrofluoric acid (HF) imports were about 6% lower than those reported in the previous year.

DOMESTIC DATA COVERAGE

Domestic production and consumption data for fluorspar were developed by the U.S. Bureau of Mines from voluntary surveys of U.S. operations. Surveys were conducted to obtain fluorspar mine production and shipments and fluorosilicic acid production. The latter was formerly termed fluosilicic acid, but as a result of an international effort to standardize nomenclature, its name has been changed to fluorosilicic acid. Of the four fluorspar mining operations to which a survey request was sent, four responded, representing 100% of known domestic shipments. Actual production quantities and values in table 1 are withheld to protect company proprietary data, but an estimate of total shipments is provided. Of the 11 fluorosilicic acid operations surveyed, 8 respondents reported production, representing 100% of the quantity reported. The consumption survey was sent to 58 operations quarterly and to 28 additional operations annually. Of the operations surveyed quarterly, 80% responded. Of the operations surveyed on an annual basis, 96% responded. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Technically, pure fluorspar, or the mineral fluorite, contains 51.1% calcium and 48.9% fluorine. Natural fluorite is commonly associated with other minerals such as quartz, barite, calcite, galena, siderite, celestite, sphalerite, chalcopyrite, other sulfides, and phosphates. It occurs in well-formed isometric crystals, in massive and earthy forms, and as crusts or globular aggregates with radial fibrous texture. In crystalline form, it can be colorless or may exhibit a wide range of colors, including yellow, blue, purple, green, rose, red, bluish and purplish black, and brown. It has a hardness of 4 on the Mohs scale, a specific gravity ranging from 3.01 to 3.60, and a melting point of 1,378° C.

Three principal grades of fluorspar are available commercially: acid, ceramic, and metallurgical. Although the specifications for individual grades are generally well defined, some variation is permitted to satisfy the requirements of individual consumers.

In the United States, acid-grade fluorspar (acidspar) contains in excess of 97% CaF_2. Some manufacturers of hydrofluoric acid in the United States and Europe can use 96% CaF_2 or slightly lower if the remaining impurities are acceptable. User specifications may impose limits on silica, calcium carbonate, sulfide or free sulfur, calcite, beryllium, arsenic, lead, phosphates, and other constituents. Moisture content of the dried material is preferably 0.1% or less. Particle size and distribution are sometimes specified for proper control of the rate of chemical reaction and stack losses. Very few reserves in the world can be used to produce acid-grade fluorspar without flotation processing.

Ceramic-grade fluorspar is generally marketed as No. 1 ceramic, containing 95% to 96% CaF_2, and No. 2 ceramic, containing 85% to 90% CaF_2. An intermediate grade of about 93% to 94% CaF_2 is also available. Specifications on impurities vary, but may allow a maximum of 2.5% to 3.0% silica, 1.0% to 1.5% calcite, 0.12% ferric oxide, and trace quantities of lead and zinc. Shipments of ceramic-spar are usually tailored to the specific need of individual consumers.

Traditionally, metallurgical-grade fluorspar (metspar) has contained a minimum of 60% effective CaF_2, with effective CaF_2 units calculated by subtracting 2.5 times the silica content of the metspar from its total CaF_2 content. More recently, there has been much less emphasis on effective CaF_2 units and more emphasis simply on total CaF_2

content. Today, the term "metspar" is usually used to refer to material with a minimum content of 85%, but is sometimes used for material as high as 96%, which includes what is technically ceramic grade. Metspar is commonly traded as lump or gravel that must meet physical requirements similar to those of the National Defense Stockpile purchase specifications discussed below.

According to the current National Defense Stockpile purchase specifications (P-69b-R3), which were determined by the Federal Interagency Committee for Stockpile Purchase Specifications and Special Instructions in consultation with U.S. steel producers, metallurgical-grade fluorspar must contain a minimum of 70% by weight effective CaF_2. Specifications for maximum allowable impurities are as follows: sulfur = 0.10%, lead = 0.25%, arsenic = 0.01%, barium = 0.01%, zinc = 0.01%, phosphorus = 0.25%, tin = 0.02%, antimony = 0.02%, and copper = 0.10%. Physical requirements are that all metallurgical-grade fluorspar shall be in the form of gravel and, after washing, shall pass a 75-millimeter (3-inch) sieve, and not more than 10% by weight shall pass a 9.5-millimeter (3/8-inch) sieve.

In the domestic steel industry, various shapes and sizes of briquets or pellets are being used. Generally made to consumer specifications, briquets contain varying quantities of fluorspar mixed with binders, fillers, and fluxing agents. Typically made on roll presses and ranging in size from that of a peach seed to a 5-centimeter square, briquets contain 25% to 90% CaF_2 and steel mill waste ingredients, such as mill scale, flue dust, shredded scrap, iron ore fines, and manganese ore fines. The most popular binders are molasses and lime, which do not require baking ovens. Imported briquets are often made from fines accumulated during metspar preparation and from flotation concentrates. Pellets have been made on balling machines using sodium silicate binder.

Geology-Resources[1]

Fluorspar occurs in a wide variety of geological environments, which indicates that deposition takes place in a number of different ways. From an economic standpoint, seven of the most important modes of occurrence are as follows:

1. Fissure vein deposits commonly occur along faults or shear zones and are the most readily recognized form of fluorspar occurrence in the world. Although the vein structure may be persistent, the fluorspar mineralization commonly occurs as lenses or ore shoots separated by barren zones. Fissure veins occur in igneous, metamorphic, and sedimentary rocks.

2. Stratiform, manto, or bedded deposits occur as replacements in carbonate rocks. Some beds are replaced adjacent to structural features such as joints and faults. Frequently, there is a capping of sandstone, shale, or clay.

3. Replacement deposits in carbonate rocks along the contact with acidic igneous intrusives are another common type of deposit. Deposits do not have to be the result of contact metamorphism, but may be introduced later, following the contact zone as a conduit and replacing the limestone.

4. Stockworks and fillings in shear and breccia zones are another form in which fluorspar occurs. The Buffalo deposit in the Transvaal consists of a network of fluorspar veinlets in sill-like bodies that are inclusions in the granite of the Bushveld complex.

5. Carbonatite and alkalic rock complexes may have fluorspar at their margins. Fluorspar grades are not usually sufficient to be economic, but the Okorusu deposit in Namibia is made up of a number of bodies of fluorspar in limestones, quartzites, and related rocks that have been intruded and metamorphosed by an alkaline igneous rock complex.

6. Residual deposits of fluorspar are formed in clayey and sandy residuum that results from surficial weathering of fluorspar veins and replacement deposits. These deposits may be the sources of metallurgical-grade fluorspar. They include detrital deposits blanketing the apex of veins and the upper portions of the veins themselves that have been weathered to depths of 30 meters or more.

7. Fluorspar also may occur as a major gangue mineral in lead and zinc vein deposits. Two operations in the Parral area of Mexico have treated the tailings of lead-zinc mines to recover fluorspar from previously discarded gangue minerals.

Identified world fluorspar resources are approximately 430 million tons of contained fluorspar. As might be expected, the countries with the highest production have the largest fluorspar reserves, although their production ranking does not necessarily mirror their reserve ranking. World resources of equivalent fluorspar from phosphate rock are approximately 325 million tons, which includes about 32 million tons from domestic phosphate rock.

Technology

Mining.[2]—Mining methods vary according to geologic conditions at individual deposits around the world. Deep deposits usually require underground techniques, while wide, shallow deposits employ open pit methods. If the ground is unable to support underground mining, open pit methods may be used even though overburden removal might be substantial. In some cases, open pit methods are used until the mining reaches a practical production limit because of excessive waste removal. Mining operations then move underground.

Narrow vein mining is commonly done by shrinkage stoping and open stoping where strong walls occur, while stratiform or bedded deposits use room-and-pillar patterns. Replacement and fissure vein deposits are mined with shrinkage stoping or cut-and-fill methods if they are deep, narrow occurrences. They also may be mined by open pit or strip-mining techniques when they occur near the surface and have competent sidewalls. The replacement and stockwork deposits in the Republic of South Africa, the carbonatite deposit in Namibia, and most of the fissure veins in Thailand are mined with open pit methods. However, replacement deposits in Mexico are extracted by stoping or cut-and-fill methods.

Beneficiation.—Most fluorspar must be upgraded for marketing. Metspar is often produced by hand sorting of high-grade lump crude ore, followed by crushing and screening to remove most of the fines. In the case of fluorspar ores of lower grade and/or ores with relatively coarse interlocking of minerals, gravity concentration processes are used based on the specific gravity above 3.0 for spar and below 2.8 for most gangue minerals.

Heavy-media cone and drum separators are particularly effective in the 37.5- by 4.75-millimeter (1 1/2- by 3/16-inch) size range, either for producing metallurgical gravel or for preconcentrating crude ore for flotation feed. For the finer sizes, the heavy-media cyclone process is frequently used. The high capacity and low operating cost of heavy-media methods give very satisfactory results. Ores as low as 14% CaF_2 can be preconcentrated to yield a flotation feed of 40% CaF_2 or more. In the process, lead and zinc sulfides and barite concentrate with the fluorspar, which enriches the flotation feed with these valuable minerals. In some cases, washing plants are used prior to flotation to remove clay or manganese oxides (wad).

Ceramic and acid grades of fluorspar are produced by multistage froth flotation. Ore from the mine is crushed and ground to proper size; care is taken not to overgrind and cause fluorspar to be lost in the slimes. If lead and zinc sulfides are present, they are preferentially floated off with xanthate collector. After this process is completed, all the easy floating fluorspar is removed in a quick pass through a flotation circuit and sent on to the cleaner circuit. The tailings are discarded. The middling product is reground to separate the more finely interlocked grains of fluorspar and gangue and passed through one or more cleaner circuits. The final products generally comprise an acid-grade concentrate and, in some cases, one or more concentrates of lower grade, which are sold as ceramic grade, or pelletized and sold as metallurgical grade. Fatty acids are used as collectors for the fluorspar. Quebracho or tannin is used to depress calcite and dolomite; sodium silicate is used to depress iron oxides and silica; and chromates, starch, and dextrin are used to depress barite. Cyanide is used to depress any remaining sulfides. Lime, caustic, or soda ash can be used for acidity control. Flotation temperatures range from ambient to 80° C.

Economic Factors

Depletion allowances against Federal taxes of 22% and 14%, respectively, remained in effect for domestic and foreign production by U.S. companies.

Operating Factors

The United States is import dependent for the majority of its fluorspar supplies. Fluorspar products are transported to customers by truck, rail, barge, and ship. Most acidspar is shipped in the form of damp filter cake containing 7% to 10% moisture to facilitate handling and reduce dust.

Most acidspar imports come from China, the Republic of South Africa, and other overseas suppliers. Fluorspar is shipped by ocean freight utilizing the "Tramp" market for ships. Bulk carriers of 10,000 to 50,000 tons deadweight are normally utilized. Participants negotiate freight level, terms, and conditions. The main participants are *charterers*—generally the buyers or sellers, *ship owners*—who either own vessels or have them time chartered, *operators*—traders normally taking positions on either cargo or ships, and *brokers*—generally represent ship owners or charterers and act as go betweens. Ships are primarily owned by the following: privately held shipping companies, publicly held shipping companies, government-controlled companies, and groups of professionally managed fleets under varying ownership. The total number of ships in the 10,000- to 50,000-ton range is about 2,000, of which more than 60% is at least 15 years old. The rate of new ship construction is very low—less than 2% of the total fleet is on order. Factors or concerns currently affecting the shipping market are the age of the fleet, environmental safety and quality assurance, insurance rates, rising operating costs due to inflation, increasing port expenses, increased tax or tariffs relating to ship costs, and anticipated volatility due to changing world conditions.[3]

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency, Defense National Stockpile Center (DLA-DNSC), measures the fluorspar stockpile in standard dry tons (sdt), although actual sales are made in standard wet tons (swt). In 1993, it was authorized to sell 20,000 sdt (18,144 metric tons) of metspar and 20,000 sdt of acidspar during fiscal year 1993 (October 1, 1992, to September 30, 1993). During this period, the DLA-DNSC reported sales of 17,043 swt (15,461 metric tons) of metspar from stockpiles in Marietta, PA, and Hammond, IN; 720 swt (653 metric tons) of nonstockpile-grade metspar from a stockpile in Marietta, PA; and 7,257 swt (6,583 metric tons) of acidspar from stockpiles in Wilmington, DE. According to the DLA-DNSC's Fiscal Year 1994 Annual Materials Plan, there is an existing authority for the disposal of 20,000 sdt (18,144 metric tons) of metspar and 90,000 sdt (81,647 metric tons) of acidspar.

Owing to HF's acute toxicity, the Environmental Protection Agency (EPA) has listed it as an extremely hazardous substance with a threshold planning quantity of 100 pounds (45 kilograms), under Section 302 of the Emergency Planning and Community Right-to-Know Act. Local Emergency Planning Committees (LEPC's) are required by the act to develop comprehensive emergency plans to address facilities where HF is present in excess of it threshold planning quantity. In July 1993, EPA issued an HF Chemical Emergency Preparedness and Prevention Advisory for use by LEPC's. This advisory listed suggestions for hazards analysis and identification, recognizing HF's characteristics, vulnerability analysis, emergency planning, testing the plan, and communications. It also offered recommendations for HF facilities.[4]

The EPA continued to propose and finalize rules regulating ozone-depleting chemicals, as required by "Title VI—Stratospheric Ozone Protection" of the Clean Air Act Amendments of 1990 (CAAA). EPA finalized its regulations limiting emissions of ozone-depleting substances during their use and disposal. The regulations established a recycling program for ozone-depleting refrigerants recovered during the servicing and disposal of air-conditioning or refrigeration equipment. The regulations require persons servicing air-conditioning and refrigeration equipment to observe certain service practices that reduce refrigerant emissions and establish equipment and offsite reclaimer certification programs. In addition, EPA requires that ozone-depleting compounds contained "in bulk" in appliances be removed prior to disposal of the appliances.[5]

EPA finalized separate regulations to ban nonessential products releasing class I ozone-depleting substances consisting of chlorofluorocarbons (CFC's), halons, carbon tetrachloride, and methyl chloroform and class II substances consisting of hydrochlorofluorocarbons (HCFC's). The rulemaking prohibits the sale, distribution, or offer of sale or distribution in interstate commerce of certain products containing or produced with these substances after specified dates. There are, however, exceptions to these rulemakings for certain medical or industrial uses for which no suitable replacement has been found.[6]

EPA added 11 HCFC's to the list of toxic chemicals subject to reporting under the Emergency Planning and Community Right-to-Know Act of 1986. The rationale focused not on direct toxicity, but rather on the depleting effect HCFC's have on stratospheric ozone and the resulting increase in penetration of ultraviolet-B radiation, which is known to cause various adverse human health and environmental effects.[7]

As part of a project initiated in 1991, the U.S. Bureau of Mines, Minerals Availability Field Office continued to collect information on the fluorspar and HF industries for the purpose of addressing impacts on production costs and supply and demand resulting from regulatory requirements on the industries or new technologies to produce replacements for banned CFC's. A Network Flow Model and Supply Analysis Model will be developed for the fluorspar and HF industries to address material flow from the production of acid-grade fluorspar to HF plants and on to CFC consumers. Operating costs and transportation costs for each stage will be incorporated. During 1993, data were collected on eight European HF plants and work on the computer model began. The model is expected to be completed by the second quarter of 1994 and the final report published by the end of the year.

Issues

As required by Section 112(n)6 of Title III of the CAAA, EPA published the Hydrogen Fluoride Study Report to Congress. In the report, EPA was required to identify potential hazards to public health and the environment considering a range of events and to make recommendations for reducing hazards, if appropriate. The study determined that "owners/operators can achieve an adequate margin of protection both for their workers and the surrounding community by assiduously applying existing industry standards and practices, existing regulations, and future guidance and regulations applicable to various classes of hazardous substances in various settings."[8] The conclusions of this study should allay the concerns of producers and consumers of HF, who may have been required to spend large sums of money for new equipment and training. In particular, the petroleum refining industry estimated it could have cost $4 billion to replace HF alkylation units with sulfuric acid units.

EPA proposed rules for evaluating and regulating substitutes for ozone-depleting chemicals being phased out by the CAAA. EPA is authorized to identify and restrict the use of substitutes where other alternatives exist that reduce overall risk to human health and the environment. The program is known as the Significant New Alternatives Policy (SNAP) program. In the proposed rulemaking, EPA issued preliminary decisions on the acceptability of certain substitutes for refrigeration, foam blowing, solvents cleaning, fire extinguishing, tobacco puffing, adhesives, coatings and inks, aerosols, and sterilants.[9]

The publication of the preliminary substitute list helped allay uncertainty in the consumer markets, in particular the foam blowing, refrigeration, and air conditioning markets. Equipment manufacturers and consumers were faced with the very real uncertainty of redesigning equipment and selecting replacement compounds without knowing if the replacement compounds would be on the "approved list" or not.

In response to an animal study that detected a higher rate of bone tumors in male rats exposed to very high levels of fluoride and a few cases of skeletal fluorosis, EPA requested the National Research Council (NRC) to review available data on fluoride toxicity. The NRC is the operating agency of the National Academy of Sciences, which is chartered by Congress to conduct research for the Government. About one-half of the U.S. population drinks water from municipal supplies containing optimally 0.7 to 1.2 parts per million (ppm) fluoride, with an allowable ceiling of 4.0 ppm. The resulting report, "Health Effects of Ingested Fluoride," concluded that existing fluoride levels in drinking water do not pose a health risk for kidney failure, bone disease, or cancer. Further research was recommended on patterns of fluoride exposure from food and dental products. The findings were the result of a comprehensive review of publications and government databases. The fluoridation of drinking water has been a source of controversy and dispute since its beginning in the 1940's.[10]

Production

Illinois was the only State reporting mine production in 1993, although Nevada and Texas reported shipments from stocks and shipments of reprocessed material from Mexico, respectively.

These three sources accounted for 100% of all reported U.S. shipments. Data on shipments of fluorspar, by State and grade, are withheld to avoid disclosing company proprietary data.

Ozark-Mahoning Co., the Nation's largest fluorspar producer and a subsidiary of Elf Atochem North America Inc., operated three mines and a flotation plant in Pope and Hardin Counties, IL. Ozark-Mahoning also dried imported fluorspar and processed some material from the National Defense Stockpile to supplement its production. Seaforth Mineral & Ore Co. Inc. dried imported fluorspar at its facilities at Cave-In-Rock, IL, and East Liverpool, OH, for sale primarily to consumers in the ceramic industry. J. Irving Crowell, Jr., & Son shipped a small amount of fluorspar from stocks, but the Crowell-Daisy Mine in Nye County, NV, remained closed. Production Minerals Inc. reprocessed some fluorspar imported from Mexico at its mill in Marathon, TX.

Six companies operating eight plants processing phosphate rock for the production of phosphoric acid sold a reported 65,882 tons of byproduct fluorosilicic acid at a value of about $7.96 million. This was equal to 115,952 tons of 92% fluorspar equivalent. Because fluorosilicic acid is a byproduct of the fertilizer industry and is not manufactured for itself alone, shortages can occur when fertilizer demand goes down.

Consumption and Uses

Acid-grade fluorspar, containing greater than 97% calcium fluoride (CaF_2), was used primarily as a feedstock in the manufacture of HF. Ceramic-grade fluorspar, containing 85% to 95% CaF_2, was used for the production of glass and enamel, to make welding rod coatings, and as a flux in the steel industry. Metallurgical-grade fluorspar, containing 60% to 85% or more CaF_2, was used primarily as a fluxing agent by the steel industry. Fluorspar is added to the slag to make it more reactive. It increases the fluidity of the slag (by reducing its melting point) and thus increases the chemical reactivity of the slag. Reducing the melting point of the slag brings lime and other fluxes into solution to allow the absorption of impurities.

Reported domestic consumption by the HF industry in 1993 decreased by about 8%. Reported consumption by the steel industry in basic oxygen and electric arc furnaces decreased by about 14%, despite a 5% increase in U.S. raw steel production.

In the ceramic industry, fluorspar was used as a flux and as an opacifier in the production of flint glass, white or opal glass, and enamels. Fluorspar was used in the manufacture of aluminum, brick, cement, and glass fibers, and was also used in the melt shop by the foundry industry.

Three companies reported fluorspar consumption for the production of HF. The U.S. Department of Commerce, Bureau of the Census, reported that, based on its quarterly survey of anhydrous, technical, and aqueous HF, 100% basis, 158,988 tons was "produced and withdrawn from the system" for 1993, compared with the 1992 annual summary total of 164,562 tons.

The largest use of HF, accounting for 60% to 65% of HF withdrawn from the system, was for the production of a wide range of fluorocarbon chemicals, including fluoropolymers, CFC's, HCFC's, and HFC's. CFC's, HCFC's and HFC's were produced by six companies: Allied-Signal Corp., Ausimont USA Inc., E. I. du Pont de Nemours & Company Inc. (Du Pont), Elf Atochem North America Inc., I.C.I. Americas Inc., and La Roche Chemicals Inc. According to preliminary data from the U.S. International Trade Commission, production of trichlorofluoromethane (CFC-11) decreased by 28% to 32,803 tons and dichlorodifluoromethane (CFC-12) increased by about 16% to 83,701 tons compared with 1992 figures. Production of chlorodifluoromethane (HCFC-22) in 1993 was 132,164 tons. At present, no information is collected on production of the HCFC and HFC replacement compounds.

Some of the replacements for CFC's will be HCFC's 22, 123, 124, 141b, and 142b. These HCFC substitutes have ozone-depletion potentials much lower than that of CFC-11, CFC-12, and CFC-113, which in total have accounted for more than 90% of CFC consumption. Unfortunately, because of the recently agreed upon phaseout schedule for HCFC's and the likelihood that the schedule will be accelerated, the market for HCFC's will exist for only a relatively short time. Industry expects HCFC's to be produced and utilized at least through the end of this decade.

The HFC replacements have no ozone-depletion potential because they contain no chlorine atoms. The most promising HFC candidate is HFC-134a, which is already replacing CFC-12 in auto air conditioners and is expected to replace CFC-12 in medium-temperature range refrigeration systems. HFC's 125, 143a, and 152a also are being produced domestically, but in much smaller quantities. These four HFC's hold potential for use by themselves or more likely as blends for specific uses. In addition, some interim replacements may be mixtures of these compounds and HCFC's.

The manufacture of aluminum fluoride for use in aluminum reduction cells was a major use of HF. In the Hall-Héroult process, alumina is dissolved in a bath of molten cryolite, aluminum fluoride, and fluorspar to allow electrolytic recovery of aluminum. An estimated 20 to 30 kilograms of fluorine was consumed for each metric ton of aluminum produced. Aluminum fluoride was used by the ceramic industry for some body and glaze mixtures and in the production of specialty refractory products. It was used in the manufacture of aluminum silicates and in the glass industry as a filler.

HF was consumed in the manufacture of uranium tetrafluoride that was used in the process of concentrating uranium isotope 235 for use as nuclear fuel and in fission explosives. It was also used in stainless steel pickling, petroleum alkylation, glass etching, oil and gas well treatment, and as a cleaner and etcher in the electronics industry. It was used as the feedstock in the manufacture of a host of fluorine chemicals used in dielectrics, metallurgy, wood preservatives, herbicides, mouthwashes, decay-preventing dentifrices, plastics, and water fluoridation.

The byproduct fluorosilicic acid was used in water fluoridation (76%), either directly or after processing to sodium silicofluoride, to make aluminum fluoride for the aluminum industry (23%) and to make ammonia and magnesium fluorosilicates (1%). *(See table 2.)*

Stocks

Consumer stocks at yearend were 75,015 tons, an increase of 4% from the revised level reported in 1992. At yearend, the National Defense Stockpile fluorspar inventory had decreased from yearend 1992 and contained about 889,000 sdt (806,000 metric tons) of acid-grade material, about 282,000 sdt (256,000 metric tons) of metallurgical-grade material, about 900 sdt (816 metric tons) of nonstockpile, acid-grade material, and about 107,000 sdt (97,000 metric tons) of nonstockpile, metallurgical-grade material. The fluorspar stockpiles are at 22 sites across the country. The largest acid-grade stockpiles are in Wilmington, DE; Memphis, TN; and North Gate, CO. The largest metallurgical-grade stockpiles are in Large, PA; Warren, OH; and Pine Bluff, AR.

Prices

According to prices published by Industrial Minerals (Metal Bulletin PLC), no domestic price for fluorspar was available for 1993. Published yearend producer prices for Mexico decreased for both acid grade and metallurgical grade. South African prices for acid grade also decreased. Although no list prices for Chinese fluorspar were available, based on U.S. trade data, the prices for acid grade and metallurgical grade both decreased in 1993. *(See table 3.)*

Yearend price quotations from the Chemical Marketing Reporter (CMR) were unchanged at $0.6875 per pound for anhydrous HF and were unchanged at $52.00 per 100 pounds for aqueous HF, 70%, in tanks. These quotations were equivalent to about $1.52 per kilogram for anhydrous HF and $114.64 per 100 kilograms for aqueous HF, 70%, in tanks. The CMR yearend price quotation for hydrofluosilicic acid (fluorosilicic acid), 23% basis, in tanks, Midwest & East Coast terminals, was $165 per short ton (about $182 per metric ton). Prices of fluorosilicic acid were up in 1993, because several producers have either closed or ceased production. This tightened supplies and forced buyers to turn to higher cost producers. Rising rail and truck freight rates also caused upward pressure on prices.

Foreign Trade

According to the Bureau of the Census, U.S. exports of fluorspar decreased by about 7%. Because Ozark-Mahoning reported no foreign sales, all U.S. exports were reexports of material imported into the United States. *(See table 4.)*

Imports for consumption of fluorspar remained essentially unchanged when compared with those of the previous year, according to Bureau of the Census data and revisions made to 1992 data. In 1993, China was once again the largest supplier of fluorspar to the United States, followed by, in descending order, the Republic of South Africa and Mexico. China accounted for nearly 59% of U.S. fluorspar imports. The average c.i.f. unit value, in dollars per metric ton, was about $102 for acid grade and about $73 for subacid grade. *(See table 5.)*

The 13.5% ad valorem tariff on subacid-grade fluorspar imports went back into effect on January 1, 1993, and applied to both most-favored-nation (MFN) and non-MFN countries. The tariff on acid grade for MFN countries is $2.10 per long ton ($2.07 per metric ton) and for non-MFN countries $5.60 per long ton ($5.51 per metric ton).

Congress ratified the North American Free Trade Agreement (NAFTA) in November 1993 and the President signed the implementation bill in December 1993. NAFTA required the elimination of the 13.5% ad valorem tariff on subacid-grade imports from Mexico effective January 1, 1994. Under the Generalized System of Preferences, acid-grade imports from Mexico were already exempt from duty upon entering the United States, and under NAFTA, acid-grade imports will continue to receive duty-free treatment.

Imports for consumption of HF decreased by 6% to a quantity equivalent to approximately 94,000 tons of fluorspar. Imports of synthetic and natural cryolite decreased 7% to a quantity equivalent to approximately 4,540 tons of fluorspar. Imports of aluminum fluoride increased by 22% to a quantity equivalent to approximately 59,100 tons of fluorspar. *(See tables 6, 7, and 8.)*

World Review

World fluorspar consumption and production remained essentially unchanged compared with 1992 levels. In order of rank, China, Mexico, the Republic of South Africa, and Mongolia were the major producers. The international fluorspar industry experienced the continuing effects of major changes in the traditional markets of fluorochemicals, steel, and aluminum.

Brazil.[11]—The Brazilian mining company Paranapanema announced plans to move ahead with the development of a cryolite deposit in the State of Amazonas. Pending approval of necessary environmental permits, development would take place over a 2-year period and cost $20 million. The cryolite deposit was discovered in 1991 in the Pitinga tin mine belonging to Paranapanema. The mine is near the town of Joao Figueiredo. Reserves are estimated at 3 million tons and occur at a depth of 150 meters, below the cassiterite ore body. The project is expected to produce 25,000 tons per year of 99% purity concentrates for the domestic aluminum industry.

European Union.[12]—China's pricing practices continued to cause difficulties for other fluorspar producers. As a result, on September 1, 1993, the Commission of the European Communities imposed a provisional antidumping duty on imports of fluorspar originating in China. The duty was imposed on imports of fluorspar presented in filter cake form or in powder form, containing more than 97% calcium fluoride falling within harmonized code 2529.22.0000 or containing less than 97% calcium fluoride falling within harmonized code 2529.21.0000, originating in China. The duty was equal to the difference between a minimum price of ECU 93.40 per ton (dry net weight) and the net free at Community frontier price before customs clearance. The duty was to apply for a period of 4 months, unless the Council adopted definitive measures before the expiration of that period. This meant that acid-grade and ceramic-grade imports into the European Community from China were to be assessed a duty based on a minimum price of about $104 per ton.

Mexico.—Production figures for 1989-91 were revised in the world production table to reflect acidspar production incorrectly listed as submetallurgical grade.

Fluorita de Mexico S.A. had financial difficulties but continued production of acidspar. Applied Industrial Minerals Corp. (AIMCOR) announced plans to sell its Metals/Minerals, which included a 49% stake in Fluorita de Mexico. The stake in Fluorita de Mexico was included in the metals side of the group owing to AIMCOR's fluorspar marketing arrangements. Talks with prospective buyers were further advanced for the sale of the minerals side of the group.[13]

Mexico's largest fluorspar producer, Cia. Minera Las Cuevas S.A. de C.V., received ISO 9002 accreditation from the Bureau Veritas Quality International. The quality assurance approval applies to extraction, processing, and marketing of both acidspar and metspar.[14]

Grupo Industrial Camesa sold its chemical division, Fluorex S.A., to Norfluor U.S.A. Fluorex produced and marketed HF and inorganic fluorides from its 25,000-ton-per-year HF plant in Ciudad Juárez, Chihuahua.[15]

Namibia.[16]—Okorusu Fluorspar Ltd. received a loan from the European Union through the Namibian Government for $47 million. The loan is repayable at 6% per annum over 13 years. The company plans to use the money to continue its current program to expand and develop its processing plant in anticipation of recovery of fluorspar markets. Okorusu ships most of its product to Germany or the United States, although import data do not necessarily agree with the company's sales figures. One possible explanation is that, because ships carrying Kenyan and South African fluorspar stop at Namibia's Walvis Bay to load Okorusu's material, the trade importing country's statistics may confuse the origin of the shipments. For example, total U.S. imports from Namibia amounted to only 4,229 tons in 1990 and 4,614 tons in 1992.

Russia.[17]—Kirovo-Chepetsk Chemical Enterprise (KCCE) of Kirovskaya Oblast, Russia, and Du Pont formed a joint venture to market fluoropolymers worldwide. The new venture will be primarily targeting business opportunities in the former U.S.S.R., but also will export polytetrafluoroethylene to other countries. KCCE is the largest producer of fluoropolymers, fluoroelastomers, refrigerants, and fluorinated fluids in the former U.S.S.R.

United Kingdom.—In December 1993, Swan Industrial Minerals Ltd. went into receivership. Swan had acquired the Derbyshire mineral rights of fluorspar producer Deepwood Mining Co. Ltd. They also had acquired Matlock Barytes and Horace Taylor Minerals Ltd., the latter a grinding and concentrating facility. The company had refurbished and upgraded the processing facility, expecting an upturn in European metspar demand that never materialized. The processing plant was shut down indefinitely, but production and sales of raw materials were expected to continue, at least for a time, into 1994.[18]

British Nuclear Fuels (BNFL), a long-time producer of elemental fluorine for the production of uranium hexafluoride, has during the past 2 years expanded into the fluorochemicals business. In 1992, BNFL Fluorochemicals was set up to produce and market high value added fluorochemicals and shortly thereafter acquired Fluorochem Ltd., a supplier of fluorine compounds, mostly in research and development quantities. They extended their product line later in the year by acquiring the assets of Shell jv Yarsley Fluorochemicals Ltd. In 1993, the company acquired Rhône Poulenc's Flutec business, which produces fully saturated perfluorocarbons, containing only carbon and fluorine. BNFL Fluorochemicals also has an agreement with a Russian fluorochemical supplier for large quantities to develop their bulk and semibulk business.[19] *(See table 9.)*

Current Research

The 3M Specialty Chemicals Co., at the request of Magma Copper Co., developed a fluorochemical surfactant designed to improve acid/ore contact. Personnel at Magma Copper theorized that they could increase the rate of copper recovery by improved wetting of the ore with the acidic leach solution. The new product, called Fluorad FC-1129, improves the coverage and wetting action of the acid without affecting the subsequent solvent extraction process. Magma Copper reported a 5% increase in recovery through the addition of the new surfactant.[20]

Realizing the need to develop HFC replacements for HCFC compounds, Allied-Signal Inc. has identified four HFC compounds to possibly replace HCFC-141b for polyurethane foam-blowing applications. The four compounds are HFC-245ca, HFC-245eb, HFC-245fa, and HFC-356. A short-term toxicity testing protocol was begun to determine which compounds will require long-term testing. Short-term testing was expected to be completed by the first quarter of 1994.[21]

OUTLOOK

Consumption of metspar by the U.S. steel industry decreased again in 1993, despite a gain in raw steel production. The decreasing level of consumption is mainly a result of continuing changes in technology, improvements in efficiencies, and tighter raw material specifications. These factors indicate that U.S. consumption of metallurgical-grade fluorspar will continue to decrease through the 1990's.

The international market for metspar is still huge. Worldwide, the steel industry is still the largest consumer of fluorspar. However, with the spread of more efficient steelmaking processes, the unit consumption of fluorspar is expected to fall. This will probably offset overall gains in steel production, primarily in developing countries.

The aluminum industry consumes fluorine from different sources and in different forms. Although some acidspar is consumed directly, fluorine is also consumed in the form of synthetic or natural cryolite, but mainly as aluminum fluoride. Aluminum fluoride is manufactured either directly from acidspar, HF, or fluorosilicic acid.

U.S. consumption by primary aluminum producers is down owing to cutbacks in aluminum production necessitated by world oversupply. Aluminum Co. of America Inc., which manufactures aluminum fluoride from acidspar, cut capacity in 1993 and is expected to make additional capacity cuts in 1994. Demand for aluminum is expected to grow, on average, by only 2% per year over the rest of this decade. Consumption of fluorspar and fluorspar equivalent is expected to track aluminum demand.

Consumption of acidspar by the chemical industry for the production of HF is the largest market for fluorspar. The largest use of HF is in the manufacture of fluorocarbons (CFC's, HCFC's, and HFC's). The fluorocarbon market accounts for about 63% of HF demand and is thus the driving force in HF demand. Demand for fluorocarbons is expected to remain essentially unchanged in 1994 and then increase by 5% to 6% per year during the next 3 to 5 years. No significant growth is expected long term in the other smaller HF markets.

Prices are expected to move upward as a result of pressures on Chinese producers. In recent years, Chinese producers have closed mines, sold off inventories built up over a 2-year period, experienced rising production costs, and faced increasing inflation pressures.

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TABLE 1
SALIENT FLUORSPAR STATISTICS[1]

		1989	1990	1991	1992	1993
United States:						
Production:						
Finished (shipments)[e]	metric tons	66,000	63,500	58,000	[2]51,000	[3]60,000
Value f.o.b. mine	thousands	W	W	W	W	W
Exports	metric tons	5,134	14,921	73,943	13,646	12,739
Value	thousands	$694	$1,891	$16,424	$1,983	$2,126
Imports for consumption	metric tons	655,590	513,921	437,027	[r]407,239	398,322
Value[4]	thousands	$79,897	$65,938	$54,549	[r]$42,505	$38,761
Consumption (reported)	metric tons	641,882	564,545	483,589	485,442	447,392
Consumption (apparent)[5]	do.	698,255	581,806	500,720	[6]480,376	455,261
Stocks, Dec. 31:						
Domestic mines:						
Finished	do.	W	W	W	W	W
Consumer	do.	79,347	74,692	68,999	[r]71,954	75,015
World: Production	do.	[r]5,557,424	[r]5,123,772	[r]4,221,508	[r]4,053,955	[e]4,030,852

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

[1] Does not include fluorosilicic acid (H_2SiF_6) or imports of hydrofluoric acid (HF) and cryolite.

[2] Includes 2,700 tons of nonstockpile-grade metspar from the National Defense Stockpile beneficiated by Ozark Mahoning Co.

[3] Includes fluorspar from the National Defense Stockpile beneficiated by Ozark-Mahoning Co., Illinois, and Mexican fluorspar processed by Production Minerals, Inc., Texas, totaling 21,775 tons.

[4] C.i.f. value at U.S. port.

[5] U.S. primary and secondary production plus imports plus adjustments for Government and industry stock changes.

[6] Includes 907 tons of nonstockpile-grade metspar from the National Defense Stockpile.

TABLE 2
U.S. CONSUMPTION (REPORTED) OF FLUORSPAR, BY END USE

(Metric tons)

End use or product	Containing more than 97% calcium fluoride (CaF_2)		Containing not more than 97% calcium fluoride (CaF_2)		Total	
	1992	1993	1992	1993	1992	1993
Hydrofluoric acid (HF)	347,367	320,706	—	—	347,367	320,706
Basic oxygen furnaces	—	—	33,204	26,877	33,204	26,877
Electric furnaces	2,229	1,319	20,733	20,159	22,962	21,478
Iron and steel foundries	W	—	W	1,367	W	1,367
Other[1]	W	W	W	W	81,909	76,964
Total	W	W	W	W	485,442	447,392
Stocks, Dec. 31 (consumer)	[r]69,959	72,987	1,995	2,399	[r]71,954	75,015

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1] Includes aluminum fluoride, enamel, glass and fiberglass, open-hearth furnaces, primary aluminum, primary magnesium, and welding rod coatings.

TABLE 3
PRICES OF DOMESTIC AND IMPORTED FLUORSPAR

(Dollars per metric ton)

	1992	1993
Domestic, f.o.b., Illinois district, bulk, acid grade	190-195	NA
Mexican, f.o.b., Tampico:		
Acid grade, filtercake	122-127	100-110
Metallurgical grade	90- 95	80- 85
South African, f.o.b., Durban, acid grade, dry basis	110-115	90- 95
U.S. Gulf port, dry bulk, acidspar	NA	95-100

NA Not available.

Source: Industrial Minerals (Metal Bulletin PLC), No. 303, Dec. 1992, p. 86, and No. 315, Dec. 1993, p. 54

TABLE 4
U.S. EXPORTS OF FLUORSPAR, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value[1]	Quantity (metric tons)	Value[1]
Australia	38	$5,483	40	$7,951
Canada	10,745	1,638,883	11,069	1,893,911
Colombia	—	—	57	8,350
Honduras	24	3,528	—	—
Korea, Republic of	241	26,943	1,044	116,880
Mexico	2,509	288,891	212	23,674
Peru	—	—	27	3,952
Venezuela	89	19,612	290	71,746
Total	13,646	1,983,340	12,739	2,126,464

[1] F.a.s. value at U.S. port.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1992		1993	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
Canada: Detroit	48	$3	[2]10,000	[2]$600
China:				
Houston	32,075	3,631	47,463	5,391
New Orleans	106,642	10,057	149,663	13,288
Total	138,717	13,688	197,126	18,679
France:				
Cleveland	—	—	15	2
Philadelphia	54	26	18	8
Total	54	26	33	10

See footnotes at end of table.

TABLE 5—Continued

U.S. IMPORTS FOR CONSUMPTION OF FLUORSPAR, BY COUNTRY AND CUSTOMS DISTRICT

Country and customs district	1992 Quantity (metric tons)	1992 Value[1] (thousands)	1993 Quantity (metric tons)	1993 Value[1] (thousands)
CONTAINING MORE THAN 97% CALCIUM FLUORIDE (CaF_2)—Continued				
Mexico:				
Laredo	29,277	$3,619	27,115	$3,333
New Orleans	[r]6,456	796	1,431	140
Total	[r]35,733	4,415	28,546	3,473
Namibia: New Orleans	4,614	467	—	—
South Africa, Republic of: New Orleans	117,218	14,514	99,630	11,374
Grand total	[r]296,384	[r]33,113	335,335	34,136
CONTAINING NOT MORE THAN 97% CALCIUM FLUORIDE (CaF_2)				
China:				
Baltimore	6,000	440	—	—
New Orleans	53,130	4,093	36,397	2,509
Total	59,130	4,533	36,397	2,509
Mexico:				
Buffalo	499	50	—	—
El Paso	3,366	235	3,378	235
Laredo	308	29	591	31
New Orleans	47,552	4,545	22,621	1,851
Total[3]	51,725	4,859	26,590	2,115
Grand total[3]	110,855	9,392	62,987	4,625

[r] Revised.

[1] C.i.f. value at U.S. port.

[2] Data supplied by importer.

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

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF HYDROFLUORIC ACID (HF), BY COUNTRY

Country	1992 Quantity (metric tons)	1992 Value[1] (thousands)	1993 Quantity (metric tons)	1993 Value[1] (thousands)
Canada	6,302	$8,596	141	$299
Germany	61	166	91	214
Israel	4	64	—	—
Japan	263	537	153	471
Mexico	60,147	57,246	62,161	58,535
Sweden	—	—	37	56
United Kingdom	358	442	366	402
Total	67,135	67,051	62,949	59,977

[1] C.i.f. value at U.S. port.

Source: Bureau of the Census.

TABLE 7

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

Country	1992		1993	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	608	$347	551	$271
China	214	154	291	208
Denmark	1,846	2,043	552	490
Germany	887	820	1,531	1,214
Italy	18	13	428	496
Hungary	19	13	119	96
Japan	474	501	232	228
Other	[r]1	[r]6	76	66
Total	4,067	3,897	3,780	[2]3,070

[r] Revised.

[1] 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.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM FLUORIDE, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Canada	5,270	$4,547	5,391	$4,736
China	1,485	1,187	1,650	1,249
Italy	42	35	2,658	2,167
Japan	7,331	6,995	6,469	5,556
Mexico	15,900	14,503	16,258	12,116
Norway	1,656	1,559	6,149	4,651
United Kingdom	558	291	450	254
Other	33	152	372	391
Total[2]	32,274	29,268	39,397	31,119

[1] C.i.f. value at U.S. port.

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

Source: Bureau of the Census.

TABLE 9
FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1989	1990	1991	1992	1993[e]
Argentina	23,317	[r]23,727	[r]28,925	[r]23,157	20,000
Brazil (marketable):					
Acid grade	56,973	47,724	52,415	[r][e]54,000	52,000
Metallurgical grade	38,550	22,659	28,898	[r][e]32,000	29,000
Total	95,523	70,383	81,313	[r][e]86,000	81,000
Canada: Acid grade	[r]50,794	[r]21,400	—	—	—
China:[e]					
Acid grade	[r]700,000	[r]700,000	[r]700,000	[r]700,000	800,000
Metallurgical grade	[r]1,000,000	[r]1,000,000	[r]1,000,000	[r]1,200,000	1,300,000
Total	1,700,000	1,700,000	[r]1,700,000	[r]1,900,000	2,100,000
Czech Republic[4]	—	—	—	—	20,000
Czechoslovakia[5]	68,910	46,966	[e]40,000	[e]40,000	—
Egypt	1,721	1,249	1,790	[e]1,700	1,700
France:					
Acid and ceramic grades	[r]158,000	[e]145,000	[r][e]150,000	[r]118,000	100,000
Metallurgical grade	62,000	[r][e]113,000	[r][e]50,000	[r]15,000	25,000
Total	[r]220,000	[r]258,000	[r][e]200,000	[r]133,000	125,000
Germany:					
Eastern states	[r]93,762	[r]61,830	—	—	—
Western states (marketable)	74,500	[e]85,300	—	—	—
Total	[r]168,262	[r][e]147,130	[r][e]76,515	[r]53,051	50,000
Greece	450	[r]—	[r]—	[r]—	—
India:					
Acid grade	10,300	10,399	9,700	[e]10,000	10,500
Metallurgical grade	12,589	13,042	14,439	[e]15,000	9,500
Total	22,889	23,441	24,139	[e]25,000	20,000
Iran[6]	[e]6,000	4,767	12,260	[r]9,182	10,000
Italy:					
Acid grade	66,600	81,822	60,650	[r][e]35,000	50,000
Metallurgical grade	59,679	[r]40,661	37,868	[e]25,000	25,000
Total	126,279	[r]122,483	98,518	[r][e]60,000	75,000
Kazakhstan[7]	—	—	—	[e]100,000	90,000
Kenya: Acid grade	95,181	112,295	77,402	80,630	78,725
Korea, North: Metallurgical grade[e]	40,000	40,000	41,000	41,000	41,000
Korea, Republic of: Metallurgical grade	856	560	290	[r]70	100
Mexico:[8]					
Acid grade	[r]524,000	[r]428,000	[r]277,000	[r]220,000	250,000
Ceramic grade	27,000	11,000	—	—	—
Metallurgical grade	225,000	192,000	90,000	[r]87,000	117,000
Submetallurgical grade[e]	[r]3,000	[r]3,000	[r]3,000	[r]3,000	3,000
Total	779,000	634,000	370,000	[r]310,000	370,000
Mongolia:					
Acid grade	115,000	119,000	120,000	[e]97,100	80,000
Other grades[9]	586,000	495,000	250,000	[e]180,000	100,000
Total	701,000	614,000	370,000	[e]277,100	180,000

See footnotes at end of table.

TABLE 9—Continued

FLUORSPAR: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2] and grade[3]	1989	1990	1991	1992	1993[e]
Morocco: Acid grade	105,000	86,500	74,600	[r]85,500	70,000
Namibia: Acid grade	25,679	27,107	34,565	[r]37,176	[10]42,249
Pakistan	4,741	5,312	[e]5,300	[e]5,000	2,300
Romania: Metallurgical grade[e]	[r]18,000	[r]12,000	[r]12,000	15,000	15,000
Russia[7]	—	—	—	[e]100,000	70,000
South Africa, Republic of:[11]					
Acid grade[e]	310,000	262,000	240,000	230,000	195,000
Ceramic grade[e]	9,000	7,500	6,000	5,500	3,800
Metallurgical grade[e]	49,340	41,530	24,340	22,600	19,000
Total	368,340	311,032	270,341	258,105	[10]217,778
Spain:					
Acid grade	[r]162,741	144,010	107,000	[r]108,000	80,000
Metallurgical grade	[r]9,584	9,681	[e]5,000	[e]5,000	5,000
Total	[r]172,325	153,691	[e]112,000	[r] [e]113,000	85,000
Sweden[e]	150	—	—	—	—
Thailand:					
Acid grade (beneficiated low-grade)	—	—	1,450	4,863	—
Metallurgical grade	98,375	94,757	[r]60,617	[r]51,597	48,000
Total	98,375	94,757	62,067	56,460	48,000
Tunisia: Acid grade	53,575	40,974	37,580	[r]13,750	—
Turkey: Metallurgical grade[e]	13,000	[r]10,000	[r]5,000	[r] [10]3,074	3,000
U.S.S.R.[e] [12]	410,000	380,000	350,000	[r]—	—
United Kingdom	122,057	118,498	77,903	[r] [e]76,000	65,000
United States (shipments)[e]	66,000	63,500	58,000	51,000	60,000
Uzbekistan[7]	—	—	—	[e]100,000	90,000
Grand total	[r]5,557,424	[r]5,123,772	[r]4,221,508	[r]4,053,955	4,030,852

[e] Estimated. [r] Revised.

[1] Table includes data available through June 3, 1994.

[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] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved Dec. 31, 1992.

[6] Year beginning Mar. 21 of that stated.

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

[8] Data for 1989-91 are reported by Consejo de Recursos Minerales; but the production of submetallurgical grade and acid grade have been redistributed by the author based on industry data. Data for 1992 and 1993 are from an industry source.

[9] Principally submetallurgical-grade material.

[10] Reported figure.

[11] Data show estimated proportions of acid-grade, ceramic-grade, and metallurgical-grade fluorspar within the reported totals. Data may not add to totals shown because of rounded estimates.

[12] Dissolved in Dec. 1991.

GEMSTONES

By Gordon T. Austin

Mr. Austin, a physical scientist with more than 30 years of industry and Government experience, has been the gemstones commodity specialist since 1986. Ms. Kelly Dorney of the Branch of Data Collection and Coordination prepared the domestic production survey data.

Webster's dictionary defines a gem "as any jewel, whether stone, pearl or the like, having value and beauty that are intrinsic and not derived from its setting; a precious or, sometimes, a semiprecious stone cut and polished for ornament. A stone of value because it is carved or engraved, as a cameo or intaglio." Additionally, the dictionary states that gemstone or gem material is a stone or material from which a gem may be cut. So a gem, gemstone, or gem material may be described as inorganic or organic minerals used for personal adornment, display, or to manufacture objects of art because they possess beauty, rarity, and durability.

In 1993, the value of natural gemstones from deposits in the United States was $57.7 million, a decrease of 13% compared with that of 1992. Production of gemstones included faceting rough, lapidary rough, carving material, specimen material, natural and cultured freshwater pearls, mother of pearl, shell, fossil ivory, amber, and coral.

Laboratory grown synthetic gemstones have essentially the same appearance and optical, physical, and chemical properties as the natural material that they represent. Synthetic gemstones produced in the United States include alexandrite, coral, diamond, emerald, garnet, lapis lazuli, quartz, ruby, sapphire, spinel, and turquoise. Laboratory grown simulants have an appearance similar to that of a natural gem material but have different optical, physical, and chemical properties. The gemstone simulants produced in the United States include coral, cubic zirconia, lapis lazuli, malachite, and turquoise. Additionally, certain colors of synthetic sapphire and spinel, used to represent other gemstones, would be classed as simulants. Colored and colorless varieties of cubic zirconia are the major simulants produced. In 1993, the reported value of production of U.S. synthetic and simulant materials was $17.9 million, about a 5% decrease from that of 1992.

Wholesale and retail stores, gem and mineral shops, gem and mineral dealers, cutting factories, and jewelry manufacturers were the major purchasers of domestic gem materials.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines (USBM) estimates U.S. production from the "Natural and Synthetic Gem Material Survey," a voluntary survey of U.S. operations, and from USBM estimates of unreported production. Of the 387 operations surveyed, 84% responded, 84% of the natural gemstone producers and 95% of the synthetic and simulant producers.

The number of operations surveyed in 1993 was 3% less than the number surveyed in 1992. The response rate was about the same. The USBM estimated the production by nonresponding operations, by professional collectors, and by amateur or hobbyist collectors. The basis for these estimates was information from published data, conversations with gem and mineral dealers, analyses of gem and mineral shows and sales statistics, and from information informally supplied by collectors.

BACKGROUND

The history of production and preparation of gemstones begins with the wearing of items for personal adornment in prehistoric times; this preceded even the wearing of clothes. Amber was mined in the Baltic countries for use as a gem material before 25000 B.C. Later, the Phoenicians in their writings described their trade routes to the Baltic for amber and to areas in Asia and Africa for other gemstones. The voyages of Columbus brought increased interest in gemstone deposits, especially emerald, in South America. The discovery of diamond in Africa in 1859 focused major interest on Africa. More recently, the discovery of diamond in Western Australia in 1967 resulted in the development of the largest known diamond deposit in the world.

Commercial mining of gemstones is extensive in the United States but not as large-scale operations. More than 60 different gemstones have been produced commercially from small domestic sources. Often, production rests in the hands of hobbyists and members of mineralogical and lapidary clubs. The Crater of Diamonds State Park near Murfreesboro, AR, is open to the public on a fee-per-day basis, as are many gemstone deposits throughout the United States. Each year many gem-quality stones are found at these locations.

Definitions, Grades, and Specifications

The gemstones data include information on select rocks, certain varieties of mineral specimens, and some organic materials, such as pearl, amber, jet, and coral. Customarily, diamond, ruby, sapphire, and emerald are the major gems.

The most important qualities of gemstones are beauty, durability, uniqueness, and rarity. Beauty, indicated as splendor, purity, or attractiveness, is according to the taste of the beholder and includes such appearances as luster, transparency, brilliance, and color. Luster of a mineral or stone is independent of color and is the surface appearance in reflected light. Apart from materials that have a metallic luster, the chief contributors to luster are transparency and refractive index. In cut gems, the perfection of the polish enhances the luster. Visible imperfections impair the luster of transparent stones. Yet, defects, described as "jardens" or "inclusions," may enhance the beauty and value of natural rubies, emeralds, and other gemstones. Sometimes these inclusions may be used to identify the country and even the mine from which the stone came. Durability is the resistance of a stone to abrasion, pitting, chipping, or splitting. Resistance to abrasion is correlated with relative hardness, but intrinsic brittleness and toughness suggest resistance to wear in other aspects. Rarity is an essential qualification and is more important for some stones in determining their value than their physical characteristics.

Of the approximate 2,900 mineral species, only about 100 possess all the attributes required of a gem. Collectors of gems may not require that a gem be durable because the stone is for display and is not to be worn. Therefore, the number of species of gemstones may be greater than the 100 that meet all the requirements.

Silicates furnish the greatest number, including such minerals as beryl, topaz, tourmaline, and feldspar. Oxides such as corundum (ruby and sapphire) and quartz (amethyst, agate, etc.) comprise the second largest group. Sulfides, carbonates, and sulfates are of small importance; the phosphates yield primarily turquoise and variscite. An exception is pearl, essentially calcium carbonate, which ranks high as a gem. Diamond, the best known gem, is an isometric crystalline form of the element carbon.

Gemstones are classified the same as minerals; that is, into group, species, and variety. Group refers to two or more gem materials that are similar in crystal structure and physical properties but have different chemical properties. Each member of the group is 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 grossular species of the garnet group.

Products for Trade and Industry

Cutting of gems from gemstones is to obtain the most effective display of the material. No significant change is made in the fundamental properties, and the preparation is to enhance the desirable characteristics that are present initially. Gemstones are cut into gems in three main styles: faceted, cabochons, and baroque.

Facet cutting usually is on transparent gemstones to increase brilliancy and appearance. Often it is confined to the harder materials. Softer materials may be faceted, but extreme care must be exercised in cutting and polishing the stones and in their use in jewelry. Often the softer gems are only for display and not for making jewelry. The "round brilliant" cut, most commonly used in faceting, has 58 facets, 33 above the circle "girdle" and 25 below it, arranged in eightfold symmetry. The "round brilliant" and other common cuts are illustrated in figure 1. *(See figure 1.)*

Cabochons are cut in four operations: sawing, grinding, sanding, and polishing. Sawing, the first step in cutting, customarily is done with a diamond saw to obtain a slab or slice of the desired size and thickness from the rough gemstone. The cabochon outline is scribed onto a flat surface, using a template for making a standard size for jewelry mountings. Rough grinding of the stone may be by metal-bond diamond, electroplated diamond, silicon carbide, or aluminum oxide wheels or coated abrasive disks. In grinding, the hardness of the gemstone determines the grit and hardness of the abrasive used. Multiple grinding steps starting with 80- to 100-mesh (grit) through 600-mesh abrasives are used. The scratches left by grinding are removed by progressively finer grinding and sanding. Disk or belt sanders use abrasives bonded to cloth, waterproof reinforced paper abrasives, or cloth charged with abrasive pastes. The final polish is on hard felt, wood, or leather laps, with various polishing agents such as fine diamond compound, tin oxide, tripoli, chromium oxide, cerium oxide, alumina, or rouge.

Polished irregular shapes are baroque gems. An inexpensive method of polishing baroque gems is to tumble them in rubber-lined drums, using a grinding and polishing medium with or without water.

Industry Structure

The Central Sales Organization (CSO), the marketing arm of De Beers Centenary AG, highly controls the world market for rough diamonds. It is by far the most controlled of the world's commodity markets. The CSO markets about 80% of the world's gem and natural industrial diamond. The marketing through the CSO is by the Diamond Trading Co. Ltd. and Industrial Distributors Ltd. The CSO sells uncut gem diamonds for De Beers and most other major producers at sights (approved bidder viewings) in London, England, and Lucerne, Switzerland. There are 10 such sights each year.

Diamonds reach the CSO sights through three channels—De Beers owned and operated mines, contracts sales by mine owner and operators, and open-market competitive sales.

The distribution of rough diamonds in the Republic of South Africa is by the South Africa Diamond Board. A new agreement was reached between De Beers Consolidated Mines Ltd., its customers, and the Government of South Africa on the method of domestic rough diamond distribution. In the past, all categories of rough diamonds that could be processed economically in South Africa must first be offered to local manufacturers. Rough could be exported duty free only if it had first been offered to the local market, otherwise a 15% duty was charged. Now, all rough will be shipped to London and mixed with diamonds from the other producers. Rough for South African cutters is then drawn from the world rough supply.

The CSO has been extremely successful at maintaining the rough diamond market for more than 50 years. In modern times there has never been a decrease in CSO's price of rough diamonds. *(See tables 1 and 2.)* The compounded effect over 44 years of these increases is a price increase of about 1,800%. Thus, a piece of rough that sold for $100 in August 1949 would sell for about $1,830 in February 1993.

For more than 30 years, the major diamond cutting and polishing centers of the world were in Belgium and Israel, with a certain amount of the larger stones being cut in the United States. In the early 1980's, the development of a large cottage industry in India—today there are more than 500,000 cutters—made a major impact on world diamond trade. India consumes most of the world's small-gem, cheap-gem, and near-gem rough material in the manufacture of small stones, which resulted in annual cut-stone exports worth billions of dollars. These small stones averaged less than one-fifth of a carat (0.20 carat). The availability of small inexpensive stones resulted in substantial changes in the design of jewelry. The utilization of small cut diamond stones (usually 0.07 to 0.14 carats each, called melee) to create a pavé effect (set close together to conceal the metal base) is but one example.

Estimates are that Russia's diamond cutting industry employs about 16,000 workers. The eight Krystall factories at Moscow, Smolensk, Kiev, Barnaul, Vinnitsa, Yerevan, Kusa, and Gomel employ fewer than 8,000, with the Moscow plant having about 900 workers. The workers at the various factories may be paid by different methods.

The workers at the Moscow plant are paid by the piece according to its size and difficulty of the cut. At Kiev, those workers whose work is not subject to inspection receive a 50% higher salary. Some Krystall factories have an incentive program for workers producing stones of 0.3 carat and larger. The incentive is a bonus of 5% of the added value that is paid to each 20-worker team and is shared by the team.

The diamond cutting and polishing factory at Nur Adjen, Armenia, produced about $60 million of income per year. The factory works at full capacity even in the winter because of its priority for electricity and heat. The factory's 1,800 workers are not allowed to drink at lunch (unlike Russian and Ukrainian diamond factory workers), have high morale, and comparatively high salaries; these factors resulted in high-quality production.

Annual cut diamond production depends on the number of workers in the industry and their productivity. If it is assumed that the industry has a production rate of 20 carats of finished goods per month per worker and that polished yields are less than 40%, then the industry's consumption of rough and yield of finished goods can be estimated. It is estimated that during a year, the Russian diamond cutting industry processes about 3.8 million carats of rough that yields about 1.6 million carats of polished goods. The polished goods would be worth between $500 million and $550 million on the world market.

During 1991, Leo and Schachter & Co. opened the newest, largest, and most modern U.S. diamond polishing factory in New York. The factory is computerized to track every diamond from rough to finished stone. The computer predicts the cash return from each piece of rough based on estimates of the rough's color, clarity, yield, and make; estimates are reported to be within 2% of actuals. The factory employs 40 polishers.

Cutting and polishing of colored, synthetic, and simulant gemstones are centered in, listed according to importance, Thailand, India, Hong Kong, Republic of Korea, China, and Brazil, where cheap labor and favorable export laws ensure the lowest total costs for finished gems.

Geology-Resources

Gemstones form in a large variety of igneous, metamorphic, and sedimentary deposits, usually as a small fraction of the total deposit. The origins are as varied as the deposits. Gemstones form primarily by precipitation from watery solutions, by crystallization from molten rock, and by metamorphic processes. Approximately one-third of gemstones is silicate minerals, about one-fifth alumina-silicates, and almost one-seventh 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 one line item in table 3. *(See table 3.)*

There are no large resources of major gem materials defined in the United States. North Carolina has emerald, ruby, and sapphire deposits. Historically, sapphires have been mined in Montana, and commercial mining is underway again. Many other domestic deposits of gemstones are known and have been mined for many years. Still, there are no systematic evaluations of the magnitude of these deposits, and no statements can be made about their reserve or the size of the resource.

Occasional finds of diamond have been made, but no great diamond pipes or alluvial deposits similar to those of Africa have been reported. Diamond exploration is underway by several companies in the Colorado-Wyoming State line area, and in Michigan, Minnesota, Wisconsin, and Arkansas. Diamond-bearing kimberlites have been located and bulk samples have been processed for diamond recovery.

World resources of gemstones are nearly all unevaluated. However, world gem diamond reserves are estimated to be about 300 million carats, including near-gem and cheap-gem qualities. Nearly all the reserves are in, listed in order of size, Australia, Africa and Russia. The estimates for diamond reserves are of limited value because data needed for reliable estimates are not available from the producers. Reserve data on other gemstones are even less available than for diamond.

Technology

Synthetic Gems.—Synthetic gemstone producers use many different methods, but they can be grouped into one of three types of processes: melt growth, solution growth, or extremely high-temperature, high-pressure growth.

The year 1902 saw the first production of synthetic ruby using the Verneuil flame-fusion process. Later, sapphire, spinel, rutile, and strontium titanate were grown with this technique. In this process, a single crystal, called a boule, forms in the flame of a simple, downward-impinging oxygen-hydrogen blowtorch. Pure oxides of aluminum (in the cases of ruby, sapphire, and spinel) or titanium (rutile and strontium titanate) are poured into the top of a small furnace and melted. Other oxides are added as needed for process control and to obtain the specific color desired. The melted material solidifies as a boule on a rotating fire-clay peg as the peg is slowly withdrawn.

A boule has a very characteristic shape, with a rounded end, a long, cylindrical body, and a tapering end. It is usually about 13 to 25 millimeters in diameter, 50 to 100 millimeters long, and weighs 75 to 250 carats (a carat is 200 milligrams). Under controlled conditions, a boule about 5 millimeters in diameter and more than 890 millimeters long can be produced for the manufacturing of jewel bearings.

Another melt technique is the Bridgman-Stockbarge solidification method, named for an American, P.W. Bridgman, and a German, D.C. Stockbarge, who, aided by three Russians, J. Obreimov, G. Tammann, and L. Shubnikov, discovered and perfected the process between 1924 and 1936. Currently, the method is used primarily for growing nongem halide, sulfide, and various metallic oxide crystals, one of the metallic oxides being aluminum oxide or sapphire.

The Bridgman-Stockbarge process uses a specially shaped crucible, which is a cylindrical tube open at one end and capped at the other by a small, pointed cone. The crucible is filled with the powdered chemicals necessary to grow a specific crystal and is lowered slowly through a furnace. The small, pointed end of the cone cools first because it is the first part of the crucible that moves from the hottest part of the furnace into cooler regions and it is the first part to emerge from the furnace. As the crucible cools, the molten materials solidify, hopefully in a single crystal, in the point of the crucible. The crystal then acts as a seed around which the remainder of the molten material solidifies until the entire melt has frozen, filling the container with a single crystal.

This process is simple, and crystals of various sizes can be grown. The crystals are typically about 51 millimeters in diameter and 15 millimeters in length, but large ones exceeding 890 millimeters in diameter and weighing more than 1 metric ton have been grown. The crystals have the same shape as the crucible.

The Czochralshi pulled-growth method is used for ruby, sapphire, spinel, yttrium-aluminum-garnet (YAG), gadolinium-gallium-garnet (GGG), and alexandrite. Czochralshi developed his method about 1917 while working with crystals of metallic nutrients.

In the Czochralshi method, ingredient powders—nutrients—are melted in a platinum, iridium, graphite, or ceramic crucible. A seed crystal is attached to one end of a rotating rod, the rod is lowered into the crucible until the seed just touches the melt, and then the rod is slowly withdrawn. The crystal grows as the seed pulls materials from the melt, and the material cools and solidifies. Yet, because of surface tension of the melt, the growing crystal stays in contact with the molten material and continues to grow until the melt is depleted.

Typically, the seed is pulled from the melt at a rate of 1 to 100 millimeters per hour. Crystals grown using this method can be very large, more than 51 millimeters in diameter and 1 meter in length, and of very high purity. Each year this method grows millions of carats of crystals for use as gems, laser rods, windows for special scientific or technical applications, and for other industrial applications.

Certain gemstones pose unique problems when attempting to grow them. The problems arise because certain materials are either so reactive that they cannot be melted even in unreactive platinum and iridium crucibles or they melt at higher temperatures than the crucible materials can endure. Therefore, another melting system must be used, called the skull melting system. Cubic zirconia, because of its high melting point (2,700 ° C) must be grown using the skull melting method.

The "skull" is a hollow-walled copper cup. Water is circulated through the hollow walls to cool the inside wall of the skull. The cup is filled with powdered ingredients and heated by radio frequency induction until the powders melt. Because the water cools the walls of the skull, the powdered materials next to the walls do not melt, and the molten material is contained within a shell of unmelted material. Therefore, the reactive or high-temperature melt is contained within itself. When the heat source is removed and the system is allowed to cool, crystals form by nucleation and grow until the entire melt solidifies. Crystals grown using this system vary in size, depending on the number of nucleations. In growing cubic zirconia, a single skull yields about 1 kilogram of material per cycle.

Solution techniques for making synthetic gems include flux methods for emerald, ruby, sapphire, spinel, YAG, GGG, and alexandrite. The other solution method is the hydrothermal method, often used for growing beryl (emerald, aquamarine, and morganite) and quartz.

Quartz crystals are grown in a hydrothermal solution in large pressure vessels known as autoclaves. Careful control of temperature and pressure in the different areas of the autoclave result in the feed material, known as lascas, dissolving in the hotter portion. The material redeposits on seed crystals, located in the cooler portion, forming synthetic quartz crystals. The process usually takes 30 to 60 days for the crystals to reach the desired size. The process can produce rock crystal, amethyst, or citrine.

The same system is used to grow beryl crystals. Beryl seed crystals are suspended in the cooler upper portion of an autoclave. Nutrient materials dissolve in the hotter, lower portion of the autoclave and, because of the temperature and pressure gradients, migrate to the cooler seeds and are deposited.

Other techniques involve solid- or liquid-state reactions and phase transformations for jade and lapis lazuli; vapor phase deposition for ruby and sapphire; ceramics for turquoise, lapis lazuli, and coral; and others for opal, glass, and plastics.

The Verneuil, Czochralshi, and scull melting processes are the melt techniques most often used for gem materials. *(See table 4.)*

Enhancement of Gemstones.—Enhancement of gemstones through chemical and physical means has become much more commonplace in the past few years and includes a wider variety of materials. Irradiation by electromagnetic spectrum (X-rays, gamma rays, etc.) and by energetic particles (neutrons, electrons, alphas, etc.) is used to enhance or change the color of diamonds, topaz, tourmaline, quartz, beryl, sapphire, zircon, scapolite, and pearls. Nearly all blue topaz is irradiated, but this does not imply that these gem materials are irradiated regularly.[1]

Many gemstones can be enhanced by chemical treatment or impregnations. The treatments may alter the bulk of the gem material or only penetrate the surface. This includes bleaching, oiling, waxing, plastic impregnations, color impregnations, and dyeing. The treatments that alter only the surface of the material include surface coatings of various types, interference filters, foil backings, surface decoration, and inscribing. Chemical treatment is more widespread than just the common dyeing of quartz, treatment of turquoise, and oiling of emeralds. Chemical treatment and impregnations have been used to enhance amber, beryl, chalcedony, coral, diamonds, emerald, ivory, jade, lapis lazuli, opal, pearl, quartz, ruby, sapphire, tiger's eye, and turquoise.[2]

In recent years the bleaching and impregnating of jadeite jade have become much more common. Investigators at gem laboratories estimate that as much as 90% of the jadeite sold in Taiwan is bleached; this includes both high- and low-quality material. The treatment is a two-step process where the jadeite is first chemically bleached using hydrochloric acid, nitric acid, or sodium compounds. The bleaching can take several hours to several weeks. The jadeite is then impregnated with a polymer, wax, or resin.[3]

Since about 1987, fractures, cleavages, and other void-type imperfections that reach the surface in diamonds have been filled using a process developed by Mr. Zvi Yehuda, of Ramat Gan, Israel. This treatment can enhance that apparent clarity of treated faceted diamonds; examples are available that show SI stones enhanced to VS and I_1 improved to SI_2. Yehuda also had developed a similar treatment for emeralds.

The oldest and most common method of gemstone enhancement is heat treating. Heat treatment of gem materials was used in Greece and Rome well before the Christian Era. Heat treatment can cause color change, structural change, and improve clarity. In the past, heat treatment was common for quartz and gem corundum. Today, materials that are heat treated to enhance their appearance include amber, beryl, diamond, quartz, ruby, sapphire, topaz, tourmaline, zircon, and zoisite.[4]

An additional type of treatment for sapphire and ruby is diffusion treatment, a chemical-heat treatment. In this process a thin layer of color is diffused into the surface of the gem. The color may be diffused as little as 0.1 millimeter or as much as 0.4 millimeter into the gem. The treatment is a long process of heat treatment in a bath of chemicals containing the proper proportions of titanium and iron. The American Gem Trade Association (AGTA) adopted a policy for the disclosure of diffusion treated gems. The policy is "If the color of a gemstone is confined to an area near the surface so that the color of the stone would be visibly affected by recutting or repolishing then the following statement must also appear: Although the color induced in the diffusion treated gems is permanent, it remains confined to a shallow surface layer." Therefore, recutting or repolishing is not recommended.[5]

Exploration.—Gemstone exploration should be undertaken in much the same manner as any other mineral exploration program. Historically, this has not been the case, except for diamond exploration. Exploration for diamonds starts with an area analysis to determine favorable geologic settings. The analysis is followed by on-the-ground regional reconnaissance and mapping. Airborne geophysical surveys may be completed before or after the regional reconnaissance work. Followup geologic work on the ground is used to determine the presence of kimberlite or lamproite host rock. If a host rock is present, then drilling and sampling determine if diamonds are present and in what quantity and quality.

Historically, most gemstone deposits have been found by following float material to the source or by alluvial sample collected while searching for some other mineral, usually gold. One of the largest Maine tourmaline deposits was found when tourmaline crystal were found in the roots of an overturned tree. In the future, gemstone exploration will be conducted in a more businesslike and scientific manner. Successful exploration for gemstone deposits begins with the selection of target areas based on the presence of known favorable host rocks. Geologic studies and maps, topographic maps, and aerial photographs are used to identify favorable metamorphic, igneous, alluvial, or eolian geological formations.

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

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

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

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

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

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

Mining.—Gemstone mining operations can range from the most primitive to the most sophisticated. In hard rock, at shallow depths, an operation by one, two, or three persons may be mined by prybar, pick, shovel, and buckets or baskets for carrying material; drilling and blasting may be employed. A larger operation includes drilling, blasting, and minimum timbering. Mechanized hauling and hoisting is done only at the larger mines.

Diamond mining in the kimberlite pipes of Africa and Russia and the lamproite pipes of Australia represent the ultimate in that huge quantities of ore must be mined to extract small quantities of diamond (as few as 20 to 30 carats per 100 tons of ore) produced at as low a cost as possible.

Placer mining for gemstones ranges from small-scale, simple procedures to huge, complicated operations. In some areas, digging is by hand, and sorting and recovery is by panning, screening, or sluicing. Diamond miners in the larger placer operations use bucket dredges and heavy-duty excavating equipment, as, for example, in Australia, Brazil, Namibia, the Republic of South Africa, and Russia.

Processing.—Most gemstone ores are broken or crushed where necessary and concentrated by various combinations of hand picking, washing, screening, or jigging. In large-scale operations, mineral beneficiation methods are mechanized and employ the latest technology in each step from primary crushing and screening to the final recovery processes. Diamond recovery, in particular, makes use of standard gravity methods, grease belts, electrostatic separation, skin-flotation, magnetic separation, separation by X-ray luminescence, and separation by optical sorting.

ANNUAL REVIEW

Production

In 1993, all 50 States produced at least $1,000 worth of gem materials. Ten States accounted for 93% of the total value of production of natural gemstones. The States, in order of declining value of production, were Tennessee, Maine, Arizona, Arkansas, Alabama, Kentucky, Oregon, Utah, California, and Nevada. These States accounted for about 93% of the total value of U.S. production of natural gemstones. Certain States were known best for the production of a single gem material (i.e., Tennessee for freshwater pearls and Arkansas for quartz). Other States produced a variety of gemstones. Tennessee, Arkansas, Alabama, and Kentucky, in declining order of value of production, were the major producers of freshwater mussel shell and pearl. Arizona produced the greatest variety. Production included agate, amethyst, antlerite, azurite, chrysocolla, fire agate, garnets, jade, malachite, obsidian, onyx, peridot, petrified wood, precious opal, shattuchite, smithsonite, and turquoise. California, Idaho, Montana, and North Carolina also produced a variety of gemstones. Historically, North Carolina is the only State to have produced all four of the major gems: diamond, emerald, ruby, and sapphire.

The reported value of synthetic and simulant gemstone production was $17.9 million in 1993, a decrease of 5% over that of 1992. Fourteen firms, four in California; four in Arizona; and one each in Massachusetts, Michigan, New Jersey, North Carolina, Ohio, and Washington, produced synthetic and simulant gem material. Production during 1993 included the manufacture of amethyst, azurite/malachite, cubic zirconia, emerald, lapis, ruby, sapphire, and turquoise. The materials were made by

10 plants operating in 8 States. The States, in descending order of value of production, were California, Massachusetts, New Jersey, Washington, Arizona, Michigan, New Mexico, and Ohio.

Arizona is known for its variety of gemstones that include agate, amethyst, antlerite, azurite, chrysocolla, fire agate, fluorite, garnet, jade, jasper, malachite, obsidian (Apache tears), onyx, peridot, petrified wood, precious opal, shattuchite, smithsonite, and turquoise. Yet, turquoise, peridot, petrified wood, and azurite-malachite accounted for more than 90% of the total value of gem material produced. Arizona was the largest domestic producer of azurite, fire agate, peridot, petrified wood, and turquoise. Also, it is estimated that Arizona was the world's largest producer of peridot, turquoise, and petrified wood and a significant producer of pyrope garnet. Many gem and mineral dealers believe that the value of mineral specimens produced from Arizona deposits is equal to, if not greater than, the value of gemstone produced. The USBM does not survey the production of mineral specimens, but its gemstones survey does capture data on that portion of the mineral specimens that are gemstones. The mineral specimen information collected is for gemstones that are used as specimen, because the value of the specimen is in the total value of production of the individual gemstone. This is particularly true for the production of Arizona's petrified wood. Additionally, four manufacturers of synthetic or simulant gem materials in Arizona produced about $0.3 million worth of material.

Arkansas continued to be the State with the greatest value of quartz production. At least four firms produced significant amounts of gem and specimen rock crystal from deposits in the areas around Hot Springs, Mt. Ida, and Jessieville. As stated earlier, the rivers, lakes, and reservoirs of Arkansas continued as the second largest source of U.S. freshwater mussel shell and pearl. Arkansas also produces several different mineral specimens other than rock crystals, but only the rock crystal specimen production is in the gemstone production numbers.

During 1993 at Crater of Diamonds State Park, Murfreesboro, AR, visitors reported finding 800 diamonds that totaled 144.44 carats. Crater of Diamonds State Park is the only location in the United States to have reported sustained production of diamonds for any appreciable length of time. Diamonds are found by visitors to the State park who pay a daily fee to hunt for diamonds using only handtools. It is possible that 1993 could be the last year that Arkansas has the only operating diamond mine. Mining tests were underway during late 1993 and early 1994 on two diamond properties in the Colorado-Wyoming Stateline Mining District. Since 1972, hobbyists have found from 300 to 1,500 diamonds per year at the Crater of Diamonds State Park. From 1906 to the present, it is estimated that production from the deposit is 100,000 to 150,000 carats; this amount of diamond production is insufficient to classify the United States as a diamond-producing country. Still, the potential to become a diamond producer may be there, and efforts were underway to evaluate this potential more fully.

Gemstone production from California includes a variety of materials almost a large as Arizona's. Tourmaline production from the State is significant, and California has the only producer of benitoite. Additionally, deposits in the State produce agate, alabaster, beryl, dumortierite, fire agate, garnet, gem feldspar, jade, jasper, kunzite, lepidolite, obsidian, quartz, rhodonite, topaz, and turquoise. Yet, even with this long list of gemstones, most people think of California in terms of its State gem benitoite, its high-quality tourmalines, and its fine orange spessartine garnets.

The State also has a freshwater culture pearl farm at Marysville, but it did not harvest shell or pearls during 1993. The farm uses animals imported from Tennessee and other southeastern States. Production includes pearls, shell, and finished nucleus for cultured pearl implants.

California also has four manufacturers of synthetic or simulant gemstones. The value of production from the State is the largest of any State for synthetics and simulants.

Colorado is not known as a gemstone-producing State, but it does hold some gemstone honors. It has the only commercially mined deposit of lapis lazuli in the United States and one of the few fee-for-dig topaz deposits currently operating. Additionally, the State was the first to produce turquoise commercially, and it still has commercial turquoise mines. It also produced the United States' finest gem-quality rhodochrosite and a quantity of high-quality rhodonite.

During 1993, two diamond deposits in the Colorado-Wyoming State Line diamond district were tested by bulk sampling. Reports in the International California Mining Journal, February 1994, issue indicated that the Kelsey Lake project of Colorado Diamond Corp., project manager for Redaurum Red Lake Mines Ltd., collected several bulk samples from the alluvial deposits associated with the Kelsey Lake kimberlites. A 6.2-carat, gem-quality diamond was recovered from one sample and a 1.1-carat stone from another. To date, sampling of the Kelsey Lake projects has yielded 268 stones larger than 2 millimeters, of which 60% was gem quality and 25% was more than 1 carat. Plans have been completed and activities are underway for a 100,000-ton test mining program. On May 31, 1994, the Denver Post reported the underground mining test by Royal Star Resources Ltd., a Canadian company, of the Sloan Ranch kimberlite deposit 40 kilometers northwest of the town of Fort Collins. Samples totaling 1,200 tons were processed and yielded more than 3,500 diamonds, the largest a 5.51-carat stone. Additional kimberlite will be mined and processed before a decision can be made about the economic feasibility of mining diamonds from the Sloan Ranch kimberlite.

Many locations in the State produce small quantities of aquamarine, the Colorado State gemstone. The best locations and the locations with the longest history of continued production (since about 1884) are Mount Antero and White Mountain in Chaffee County. Mount Antero, at 4,349 meters, may be the highest gemstone location in the United States. White Mountain, separated from Antero by a small saddle, is only slightly lower at 4,237 meters.

Star garnet, the Idaho State gemstone, and other gem-quality garnet lead the list of gemstones produced in the State. Idaho is one of two places that produce significant amounts of star garnet; India is the other. These almandite garnets are translucent, purplish-red stones that show four- or six-ray stars when cabochon cut or are transparent deep red stones that can be faceted. The primary sources of Idaho star garnet are the placer deposits on the East Fork of Emerald Creek and its tributary gulches in Benewah County. Additionally, the placers of Purdue Creek in Latah County yield star garnets. Currently, garnets that do not cut stars are mined commercially from areas in Clearwater County. These garnets range from purplish rose-red to a highly prized "special pink." Gem-quality garnets are found at several other locations in Idaho and are mined periodically by hobbyists or professional collectors for the gemstone market.

Opal is the second largest contributor to the total value of gemstone production in Idaho. The varieties produced include precious, yellow, blue, pink, and common. The Spencer opal mine is the largest producer. At the Spencer Mine, precious opal occurs as one or more thin layers within common opal that have partially filled gas cavities within a rhyolite-obsidian flow. About 10% of the material is thick enough to cut into solid gems; the remainder is suitable for making doublets and triplets. The Spencer Mine is also the source of the pink opal, which occurs as either pink common opal or pink-bodied precious opal.

Maine and tourmaline are almost synonymous in the gemstone industry. In 1822, Maine's Mount Mica was the site of the first gemstone production in the United States. In 1993, Plumbago Mining Corp. was actively mining the Mount Mica pegmatite for gem material and mineral specimens. Over the years, production from Mount Mica has included hundreds of kilograms of fine-quality gem and mineral specimen tourmaline. At least two deposits in the State produced significant quantities of tourmaline during the year.

Mount Mica is not the only large producer of high-quality tourmalines. Dunton Mine of Newry Hill is the most prolific gem tourmaline producer in Maine. Since its discovery in 1898, the mine has produced tons of gem- and specimen-grade tourmaline. Other mines and quarries in a three-county area produce gem- and mineral specimen-grade tourmalines. These include the Bennett, BB #7, Emmons, Harvard, Tomminen, Waisenen, Black Mountain and Red Hill Quarries, and Nevel Mine in Oxford County. It also includes the Mount Apatite Quarries in Androscoggin County and the Fisher and Porcupine Hill Quarries in Sagadahoc County.

Production from Maine deposits also includes fine-quality beryls—aquamarine, heliodor, and morganite. Pegmatites in Oxford, Androscoggin, and Sagadahoc Counties regularly produce fine-quality blue and blue-green aquamarine, rich yellow- and gold-colored heliodor, and rose- and peach-colored morganite.

A new discovery of amethyst in an old producing area resulted in the production of a significant amount of faceting- and specimen-grade amethyst in 1993.

Montana produces many different gemstones, some suited for faceting, while others are suited for the cutting of cabochons, carvings, or objects-of-art. Montana is noted for the production of sapphires, Montana moss agate, and Dryhead agates. Yet, deposits in the State also produced amethyst, amazonite, azurite, covellite, cuprite, garnet, onyx, opal, petrified wood, rhodochrosite, rhodonite, smokey quartz, sphalerite, and wonderstone (banded rhyolite) for use as gemstones.

Sapphires have been produced from Montana deposits since 1865. In recent years, Montana sapphire has gained in popularity, and because of the improved popularity, production has increased significantly. Currently, commercial sapphire production is from deposits on the Missouri River in Lewis and Clark County, the Rock Creek area in Granite County, and from the Yogo Gulch area in Judith Basin County. Additionally, there are fee-for-dig sapphire operations on the Missouri River, Dry Cottonwood Creek, and Rock Creek.

Nevada has been a major producer of turquoise since the 1930's, and until the early 1980's, the State was the largest turquoise producer in the United States. Estimates show that over the years, 75 to 100 different mines or prospects produced sizable quantities of turquoise. The value of production varied from a few thousand dollars at some properties to more than $1 million at others. Estimates of total production to date are between $40 to $50 million.

Precious opal production from deposits in the Virgin Valley area began in about 1906. The opal from Virgin Valley is comparable to any in the world for its vivid play of color and is unsurpassed in terms of the size of material available. The material varies in color from deep pure black to brown to yellowish-white to white to colorless. The play of color includes all the colors common to precious opal—red, blue, green, yellow, orange, and so on. The opal forms primarily as replacement of wood, or sometimes, the replacement of cones of conifer trees. A severe crazing problem restricts the use of the opal. Currently, two mines in Virgin Valley are open on a fee-to-dig basis during the summer months. The operators of these mines also mine the deposits for their inventories.

North Carolina is the only State in the United States where all four major gem materials, diamond, ruby, sapphire, and emerald, have been found. During 1988 was the last time all four major gemstones were found in the same year. The diamond was from a gold placer mine, the rubies and sapphires were from the Cowee Valley, and the emeralds were from near Hiddenite and Little Switzerland.

Production of ruby and sapphire from deposits along the Cowee Valley in

Macon County began in 1895 when the American Prospecting and Mining Co. systematically mined and washed the gravels of Cowee Creek. Today ruby, sapphire, and fee-for-dig operations are in the Cowee Valley. Many people pay to dig or purchase buckets of gravel to wash to recover gem corundum, garnets, and other gemstones. During 1993, deposits in North Carolina also produced gem-quality garnets, kyanite, emerald, and aquamarine.

Historically, Oregon has been known for the production of various picture and scenic jaspers, agates, thundereggs, petrified wood, and to a certain degree, gem labradorite. Oregon's State rock, the "thunderegg," may be the best known gem material from Oregon. Graveyard Point, Priday, and Polka Dot are names that are associated uniquely with beautiful Oregon agates. The same is true for the relationships between the names Biggs, Deschutes, and Sucker Creek and picture or scenic jasper. Yet, gem labradorite (sunstone) is currently the largest single contributor to the value of annual gemstone production in Oregon. At least seven firms or individuals currently are producing sunstone from three different geographic areas.

The other gemstone to contribute significantly to the value of production from Oregon is opal. During 1988, the first significant, commercial mining and marketing of very fine-quality opals from Opal Butte began. The varieties include hyalite, rainbow, contra luz, hydrophane, crystal, fire, blue, and dendritic. Exquisite stones as large as 315 carats have been cut from contra luz rough from this deposit and the fire opal is as fine as the best from Mexico.

Tennessee has the largest U.S. production of freshwater mussel shells and pearls of the 11 producing States. There has been an established U.S. freshwater mussel fishing industry since the mid-1850's. The mussels are from the family Unioidae, of which about 20 different species are harvested commercially. During 1993, the value of U.S. mussel shell exports was more than $32 million.

Historically, freshwater pearls from the United States were a byproduct of the shell industry. With the coming of the freshwater cultured pearl farms in Tennessee and the increasing popularity of freshwater pearl jewelry with the U.S. consumer, this has changed. Since the technology for culturing freshwater pearls was proven in the late 1970's, six freshwater pearl farms have been established. These farms are the beginning and heart of the U.S. pearl industry.

In Wisconsin and Michigan, 12 kimberlite pipes have been identified on exploration holdings, 7 have yielded microdiamonds, and 3 have not been tested. Ashton Mining of Canada, Inc. announced that its Great Lakes project found a small kimberlite body in the Crystal Falls area of Michigan. The company also reported the possibility of additional kimberlite bodies in the Upper Peninsula of Michigan.

Utah topaz is not well suited for use as a gem, but it does make a fine mineral specimen. Topaz crystals have been collected from certain rhyolite flows in the Thomas Mountains and the Wah Wah Mountains. The crystals from the Thomas Mountains are predominately small, 10 to 20 millimeters long and 4 to 6 millimeters across, and crystals from the Wah Wah Mountains are even smaller. Occasionally, large gem-quality crystals are found. The color of the topaz varies from colorless, to light yellow, sherry brown, rose, or light pink. The light yellow to sherry brown color fades to colorless if exposed to sunlight or heat and rose or light pink colored crystals are rare. Because of the size of the crystals and problem with color fading, the material yields only small to very small colorless stones.

Another Utah gemstone is variscite, first produced in about 1893 near Fairfield. The latest recorded commercial production was from near Lucin during the summer of 1992. Variscite forms as fracture fillings or as nodules. The nodules may be solid, almost geode in nature, or fractured solid nodules that have undergone alteration. The color of the variscite varies from a shade of light to dark yellow-green, but can be a dark, nearly jade green and so pale as to appear almost white. It also can have black and brown spiderwebbing.

Another material from Utah is snowflake obsidian. Snowflake obsidian (also known as flower obsidian) earns its name from the bluish-white or grayish-white patterns of cristobalite included into the normally black obsidian. During 1992, two different firms produced this material commercially.

The red beryl from the Wah Wah Mountains is the most remarkable and desirable of Utah's gemstones. Bixbite, the variety name for red beryl, is found in rhyolites at several locations in the Thomas and Wah Wah Ranges. The beryl varies in color from a pink to bright red, with the bright red being what could be called strong raspberry-red. The material from most of the locations is not as spectacular, either in crystal size or color, as the crystals from the Violet claims in the Wah Wah's.

The Violet claims in the Wah Wah's are the only known location for commercial production of red beryl. In recent years, the claims have furnished a small but steady supply of materials for both mineral specimens and a few fine-quality gems. The crystals average about 10 millimeters in length, and most are flawed. Because of the size of the crystals and flaws, finished stones only average about 0.40 carat with few more than 1 carat. The largest finished stone to date is about 10 carats. The material is expensive, but justifiably so, because of its beauty and rarity.

Certain other States produce a single gem material of note, they are: Alaska with its two jade mines; Florida's agatized coral; New York reported significant quartz production (herkimer diamonds) from the Herkimer-Middleville area and a small amount of almandite garnet production from the North Creek area; New Mexico reported production of agate, turquoise, copper minerals, and gem feldspar; both Alaska and Hawaii reported the production of gem-quality coral; Minnesota reported production of thomsonite and agate; Ohio reported production of flint; and South Dakota produced rose quartz.

The value of 1993 production by individual gemstone can be reported for those materials that have three or more producers and if one producer does not account for more than 75% of the total or if two do not account for 95% or more of the production. *(See table 5.)*

Consumption and Uses

Consumption of domestic gemstones was in the manufacture of jewelry; for exhibit in gem and mineral collections; for decorative purposes in statuettes, vases, and other art objects; and for certain industrial applications.

Frequently, tourmaline is used as a standard for calibrating piezoelectric manometers and testing devices. It is also a control substance in boron experiments because it is itself an inert boron-containing compound. Tourmaline is the standard used in tests to check possible effects of water-soluble boron in fertilizers.

Many scientific and industrial instruments use tourmaline. One such use is tourmaline tongs, a simple laboratory instrument that shows the polarization of light. Because tourmaline is both pyroeletric and piezoelectric, meaning it generates electricity when heated or compressed, it is a component of instruments for measuring high pressures and fluid compressibility. Thermal dosimeters, which were early instruments that measured the intensity of radium emanations, depended upon tourmaline's pyroelectric properties.

Once the mark of a top-rated watch or timepiece was that it was Swissmade and had 18 or 21 ruby or sapphire jewel bearings. Originally, these jewel bearings were made from natural ruby and sapphire. Later, the availability of inexpensive synthetic gemstones allowed the natural materials to be replaced in the manufacture of jewel bearings.

Why are ruby and sapphire used as bearings? Because ruby and sapphire, color variations of the mineral corundum, are second only to diamond in hardness; they have no cleavage (cleavage being the tendency for a crystallized mineral to break in certain definite directions, showing a minimum value of cohesion in the direction of easy fracture) and thus they are very durable; they have a very low coefficient of friction when highly polished; they are chemically inert; and they can be cut and polished without great difficulty.

Watches were not the only instruments in which sapphire and ruby bearings were used. Most precision gauges in aircraft and boats depend upon jewel bearings, as do many gauges, meters, and other instruments in manufacturing and chemical plants. The military is still highly dependent on jewel bearings for many of its high-tech weapons systems. Another use for one type of jewel bearing is as connectors for optical fibers.

In recent years, technological advances allowed the growth of large, high-quality synthetic ruby crystals, called laser ruby, for the manufacture of laser rods. Several other synthetic gemstones also are produced for lasers, including chromium-doped chrysoberyl (dope being an element added to the crystal growing nutrients to get a particular color), synthetic alexandrite, and varieties of doped YAG.

Lasers require high-purity, optically perfect crystals. The crystal must be large enough so that a laser rod can be cut from the raw crystal, and the mineral or material must have the correct physical properties to allow light amplification without the necessity of excessive energy. Synthetic ruby, sapphire, and YAG have these characteristics.

Over the years, both natural and synthetic corundum have been ground and graded as an abrasive. Corundum was the major compound used in the polishing of eyeglass lenses. Although industrial diamond has replaced much of the corundum used in the lens-polishing industry, some still use corundum for specialized lenses.

Other gem materials have enjoyed limited uses in nongem applications. The abrasive and ceramic industries use topaz as a raw material because of its hardness and chemical features. Once, lenses for eyeglasses were made from gem-quality beryl—if the morganite variety of beryl was used, one would truly be looking at the world through rose-colored glasses. Mortar and pestle sets, knife edges for balances, textile rollers, and spatulas are some nongem uses of agate.

Some industrial applications requiring clean homogeneous stones used low-quality gem diamond. The quantity of natural and synthetic industrial-grade diamonds used in the United States each year is 12 to 15 times greater than the amount of diamonds consumed by the jewelry industry.

The 1993 estimated value of U.S. apparent consumption of gems and gemstones was $4,266 million, up about 24% from that of 1992. In 1993, the value of U.S. estimated apparent consumption of diamonds increased about 29% to $3.6 billion. The 1993 estimated apparent consumption of colored stones, led by emerald, ruby, and sapphire, was valued at $517 million, an increase of 30%. The estimated apparent consumption of pearls—natural, cultured, and imitations—was $18 million, a 6% decrease. Estimated apparent consumption of synthetic and imitation gemstones decreased about 13% to $102.3 million.

Prices

Demand, beauty, durability, rarity, freedom from defects, and perfection of cutting decide the value of a gem. In establishing the price of gem diamond, the CSO's control over output and prices of diamond rough also is a major factor.

The average U.S. wholesale asking price of the top 25 grades (D through H color and IF through VS_2 clarity) of a 1-carat diamond fluctuated between $7,200 and $7,300, and was about $7,300 at yearend. The average value per carat of all grades, sizes, and types of gem-quality diamond imports was $444, essentially the same as that of 1992. The average yearend wholesale purchase price of a fine-quality 1-carat ruby, paid by retail jewelers on a per stone or memo basis, was $3,900, the same as that of 1992. The average value of ruby imports decreased 15% to $25.14 per carat.

The average yearend wholesale purchase price of a fine-quality 1-carat sapphire, paid by retail jewelers on a per stone or memo basis, was $1,400, the same as that of 1992. The average value of sapphire imports decreased 5% to $15.46 per carat.

The average yearend wholesale purchase price of a fine-quality 1-carat emerald, paid by retail jewelers on a per stone or memo basis, was $2,750, the same as for 1992. The average value of emerald imports decreased 38% to $44.83 per carat. *(See tables 6 and 7.)*

Foreign Trade

The value of all diamond exports plus reexports increased 10% to $1.50 billion. The quantity of cut diamonds exported and reexported decreased 10% to 911,419 carats, and the value of diamond exported and reexported increased 9% to $1.44 billion.

The value of other precious stones, cut but unset or rough other than diamonds, pearls, and synthetics, exported and reexported decreased from $241.2 million to $103.1 million. The value of synthetic gemstone exports plus reexports decreased from $21.2 million to $19.3 million.

The value of natural, cultured, and imitation pearls, not set or strung, exports and reexports of pearls increased from $6.7 million to more than $7.3 million.

The value of gems and gemstones imported increased 18% to a record high $5,850.9 million. The value of imported gem diamonds accounted for about 86% of the total.

The value of imported gem diamonds increased 23% to a record high $5,096.3 million. The imports of cut diamonds increased 26% in quantity and 23% in value to 9.7 million carats and $4,486.3 million, respectively.

The value of imports of other gem and gemstones, led by emerald, ruby, and sapphires, was $754.5 million. Emerald imports increased 14% to $244.4 million. The value of ruby imports increased 16% to $90.6 million, but was less than the record-high value for the past 10 years of $98.4 million in 1990. The value of sapphire imports was $79.3 milion, an increase of 6% compared to that of 1992.

The value of imported gem materials other than diamond, emerald, ruby, and sapphire increased 35% to $327.7 million. *(See tables 8, 9, 10, 11, and 12.)*

World Review

Diamond sales by De Beers Centenary AG was $4.4 billion in 1993, an increase of 28% compared with 1992 sales of $3.4 billion. Sales during the first half of 1993 were $2.5 billion, 42% more than the $1.8 billion for the first half of 1992. Sales during the second half of 1992 were only $1.8 billion, but still 12% more than the $1.6 billion sales for the second half of 1992. A De Beers official stated that there were sharp sales gains in the Indian-type cheaper rough, but larger rough, more than 3 carats, was sold sparingly. De Beers controls about 80% of the rough, uncut diamonds sold in the world. Sales of colored stones remained strong. In February, De Beers increased the price of rough diamonds by an average of 1.5%. Not all prices went up 1.5%—some were unchanged while others increased as much as 8%.

Natural diamond production occurs in Africa, Asia, Australia, and South America. The principal producing localities are as follows: in Africa—Angola, Botswana, Namibia, the Republic of South Africa, and Zaire; in Asia—Russia (northeastern Siberia and in the Yakutia); in Australia; and in South America—Venezuela and Brazil. *(See table 13.)*

Foreign countries in which major gemstone deposits (other than diamond) occur are Afghanistan (beryl, kunzite, ruby, tourmaline); Australia (beryl, opal, sapphire); Brazil (agate, amethyst, beryl, kunzite, ruby, sapphire, tourmaline, topaz); Burma (beryl, jade, ruby, sapphire, topaz); Colombia (beryl, sapphire); Kenya (beryl, garnet, sapphire); Madagascar (beryl, rose quartz, sapphire, tourmaline); Mexico (agate, opal, topaz); Sri Lanka (beryl, ruby, sapphire, topaz); Tanzania (tanzanite, garnet, ruby, sapphire, tourmaline); and Zambia (amethyst, beryl).

Angola.—Odebrecht, a Brazilian company, purchased modular diamond recovery plants from Van Eck & Lurie for use on its diamond projects in Angola. Odebrecht is undertaking projects in Quango Province for Endiama, the Angolan state mining corporation.

Australia.—Argyle's diamond production of 42 million carats was another record year for the mine. Since the start of mining in 1983, more than 304 million carats of diamonds has been recovered from the AK-1 pipe and alluvial operations. Argyle's annual pink diamond sale saw a single buyer, a Geneva-based jeweler, buy the entire 46-stone, 41.48-carat offering for $2.25 million.

The Philips Range Joint Venture, a venture between Triad Minerals NL and Black Hill Minerals Ltd., both Australian companies, and the Canadian firm Cliff Resources Corp., has completed a drilling project on the Aries kimberlite pipe and has started a 100,000-ton bulk sampling of the overburden. The venture has processed 1,700 tons of overburden through its 100-tons-per-hour plant and recovered 69 diamonds that weighed 26.7 carats with five stones greater than 1 carat.[6] Ashton Mining Ltd. continued to explore the Merlin and adjacent Excalibur prospects in the Northern Territory. A 70-ton sample from Merlin produced 20 commercial-size stones; 20% were gem quality, 20% were near-gem, and the largest stone was 2.44 carats. On the Excalibur, a 60-kilogram sample produced 7 macrodiamonds and 92 microdiamonds. Many drill holes on the prospect have intercepted kimberlite down to 111 meters.

Botswana.—The largest diamond ever found in Botswana, 446 carats, was recovered at the Jwaneng Mine. The stone is currently being evaluated and no value has been set.

Preliminary exploration work is underway on the Gemsbok project to evaluate five diamond prospecting licenses. The licenses cover about 4,800 square kilometers. The project is a 50-50 joint venture between Scintilore Explorations and Fancamp Resources.

The $3 million diamond cutting and polishing factory jointly owned by Lazare Kaplan Botswana, a subsidiary of the U.S. firm Lazare Kaplan International, and the Government of Botswana is the newest cutting factory in Botswana. The factory was subsidized to train local cutters under Botswana's financial assistance policy for foreign investors. The factory will purchase rough from De Beers' CSO.

Brazil.—Southwestern Gold Corp. and Hillsborough Resources have had encouraging results from their joint-venture exploration on the 592,000-hectare Canabrava project in Minas Gerais. Sampling discovered kimberlite indicator minerals and stream samples contained diamonds. Diamonds from the stream samples contained one pink diamond.[7]

The KWG Resources and Diamond Co. Ltda. Charneca diamond property joint venture in Minas Gerais began production with a 750-cubic-meter-per-day washing plan and plans to add a second 300-cubic-meter-per-day plant. KWG, the operating partner, reported the recovery of 31 gem-quality diamonds weighing 79 carats during the first 19-days of operation. The joint venture controls two additional concessions in Minas Gerais—the Santo Antonio and Grupiaria.[8]

Burma (Myanmar).—The Burmese 30th Annual Gems, Jade, and Pearl Emporium attracted 654 buyers from 16 countries and accounted for a near record $14.7 million. Jade sales were $11.5 million; pearls, $0.6 million; and gems, $1 million. The gem sales were mostly cut rubies and sapphires. Some rough was offered as well as cut peridot, spinel, green tourmaline, danburite, almandine garnet, aquamarine, diopside, enstatite, zircon, colorless topaz, and scapolite. For the first time heat-treated rubies were offered for sale. The heat-treated material was all from the new Monghsu Mine.[9]

Canada.—Broken Hill Proprietary Co., an Australian company, and its Canadian partner Dia Met Minerals, Ltd. announced the start of work on the first diamond mine in Canada with their presentation of their mining plan to environmental authorities. The mine and other facilities would cost about $375 million and would be in full operation by 1997.

During 1993, diamond exploration activities were too extensive to be summarized in this limited space. It is recommended that interested individuals obtain copies of "Diamond in Canada: An Over View of Current Developments" by R. Irvine and M. Boucher, Industrial Minerals Division, Mineral Metal Commodities Branch Mineral Policy Sector, Energy, Mines and Resources Canada, Ottawa, Ontario; or "Mineral Exploration in Canada: Recent Developments and the Diamond Story" by J. M. Duke and B. A. Kjarsgaard, Geological Survey of Canada, Ottawa, Ontario.

China.—The New China News Agency announced a De Beers Chinese joint venture that includes equipment and technology for exploration and processing of diamond ore, assistance in training personnel, and the opening of a diamond cutting factory. The new factory will be in Shanghai, one of two major cities targeted by De Beers' recently announced $1.2 million marketing campaign to increase China's consumption of cut diamonds.

Ghana.—The Government of Ghana has agreed to sell 80% of the Government-owned Ghana Consolidated Diamond Mines, Ltd., 40% each to De Beers and Lazare Kaplan International. A new company, Birim River Diamonds Ltd., will operate the diamond mines with De Beers as the managing partner. Plans are for production to be increased to 0.4 million carats per year in 3 years; eventually production will increase to 1 million carats per year.

Greece.—In February, a new synthetic ruby, grown by a flux process, was announced to the industry at the Athens Jewelry Fair by J. and A. Douras, its producers. The material is grown in a plant in Piraeus. The Douros method grows crystals that are 20 to 50 grams and smaller that are almost identical in appearance to Ramaura material. The refractive indices, density, absorption spectrum, fluorescence, and dichroism of the new synthetic are the same as for natural ruby.

India.—India processed about 65% of the carats of the world's rough diamonds, accounting for a 45% share of the world trade in finished goods. While most of the finished goods were less than 20 points in size, the industry is increasing the amount of larger goods cut. The 11 million carats of cut diamonds exported accounted for 17% of the value of total exports from India.

Mali.—Mink Minerals Resources Inc., a Canadian firm, agreed to acquire 65% of Syndicat Diamat—the Mali diamond exploration and development company owned by the Governments of Mali and France—by spending more than $6 million over 3 years and additional amounts over 3 additional years. The Syndicat Kenieba district concession has 21 identified kimberlite pipes, 8 of which contain diamonds. Sampling of paleo placer deposits within the concession yielded more than 70 gem-quality diamond, many larger than 1 carat.

Namibia.—Namibian Minerals Corp. (Namco), a firm just listed on the Vancouver Stock Exchange, is undertaking a program to evaluate and develop two Namibian marine concessions covering 920 square kilometers. Detailed geophysical surveys and sampling are planned with the start of mining scheduled for early 1995. The concessions are off the coast for the port of Luderirz and Hottentots Bay in water 200 meters or more in depth. According to Namco, the concessions may contain as many as 27 million carats, and projections of production are 150,000 to 250,000 carats per year.

Russia.—The Russian diamond mining industry, with about 95% of production coming from five mines in Sakha—Udachny, Aikhal, Mir, International, and Sytykanskaya—is undergoing much change. Construction is underway on the Jubilee Mine that will begin production in 1994. Two deep vertical shafts have been completed at the International Mine, and plans are underway to convert the Mir from an open pit to underground mine. Additionally, efforts are underway to bring the five kimberlite pipes north of Archangel into production.

Current diamond exploration includes Ashton Mining's work in the Karelia area, work near Krasnovishersk in the Pern district, Kondor and Imperial, Inc. are exploring known pipes in Archangel, Gorizont Co. is exploring additional areas in Archangel, and geologists have discovered diamonds in the Khanka depression close to the city of Lesozavadsk near the Sino-Russian border.

Mr. Thomas Chatham, president of U.S.-based Chatham Created Gems, Inc., announced the formation of Chatham-Siberian Gem Co., based in Moscow. The company will grow and market synthetic white, yellow, and blue diamonds. The diamonds will be made using the high-temperature, high-pressure process. The new company plans to begin marketing about 100 carats of finished goods per month at a price that is 10% of that of equivalent natural diamonds.

In Moscow, J.V. Intertrade, a joint venture between the Moscow Municipality, the Russian Committee for Precious Stones and Metals, and Kaszirer Diamond and Oltusky—both Belgian firms—opened a diamond cutting factory. The Municipality provided land and construction. The committee is expected to insure a supply of rough, and the Belgians invested $6 to $7 million in funds. Ruisdiamond, an Israeli-Russian joint venture, also opened a new cutting factory in Moscow. It will use laser technology on types of rough that are difficult to cut. The newest cutting factory in Yakutia is in the city of Namtsy: It is the sixth factory to open in Yakutia during 1993, and an additional seven cutting factories have been announced.

Mr. Valerie Rudakov, president of Almazy Rossi-Sakha, the firm responsible for mining, sorting, pricing, and selling Russia's rough diamonds, announced the opening of an internal Russian Diamond Selling Center. Operating much like the CSO, the Selling Center will allocate diamonds to Russian cutting factories as if they were CSO sightholders. Almazy Rossi-Sakha is a joint stock company in which 32% is controlled by the governments of Russia and Sakha each, 8% by the eight regions of Sakha, 5% by the Guarantee Fund, and 23% by employees. The company's goals are to supply adequate rough diamonds at "world prices" to Russian cutting factories and to ensure the continued well being and growth of the Russian cutting industry.

South Africa, Republic of.—Diamond Field Resources (DFR), a Canadian company, purchased the Loxton Dan and Frank Smith diamond mines in the Kimberley area. The company reports that the mines have reserves sufficient for an additional 20 years of operation even at the increased rate plan. DFR plans to increase production from the mines to 100,000 carats per year. DFR also has a marine diamond concession off the coast of Luderitz in Namibia.

Tanzania.—During 1993, the Government of Tanzania lifted the restrictions on diamond sales and exploration to foreign investors. Because of these changes Dual Resources and Pue Gold Resources, both Canadian firms, each purchased 20% of Tanzania Diamond Mines' (TDM) diamondiferous kimberite project, two contiguous diamond lining leases, and three exploration licenses. East Africa Diamond Exploration, a wholly owned subsidiary of TDM, will manage the joint-venture project.[10]

European Ventures acquired a 50% interest in Tan Range Exploration Corp.'s 60-square-kilometer diamond concession; both firms are Canadian. European agreed to spend $300,000 on exploration over the next 2 years, and issued Tan Range 100,000 shares of European's common stock.[11]

Uruguay.—It is estimated that annual exports of amethyst are about 80 tons valued at more than $500,000. The amethyst is for mineral specimens, decorator pieces, and as gemstones.

Zaire.—Sediza, De Beers' Zairian diamond purchasing company, purchased a +770-carat top-colored, gem-quality rough diamond. It is reported that the firm paid an artisanal miner $7 million for the stone and paid the Government of Zaire a 10% fee to export it. Because of its shape, the rough will be sawed or cleaved into two pieces for cutting.

Zimbabwe.—The River Ranch Mine, operated by Auridiam Zimbabwe Ltd., a joint venture between the Canadian firm Cornerstone Investments Ltd. and Auridiam Consolidated NL of Australia, is expanding production from its current 50,000 carats per year to 130,000 carats per year and plan to produce 330,000 carats per year by 1995. Gem-quality stones account for about 60% of the production, and many of the stones are larger than 8 carats. During 1993, the mine produced two large fine stones—one was 29.6 carats and the other was 17 carats. Recovered fragments totaling 356.2 carats from one broken stone and 33.4 carats from another single stone suggest the presence of very large stones.

The joint venture between Reunion Mining and Argosy Mining Corp. has confirmed the discovery of a second kimberlite pipe on its Hwange project in western Zimbabwe. The pipe is about 10 kilometers from an earlier discovered pipe. The joint venture announced that additional exploration permits have been added to the venture to increase the Hwange project area.

OUTLOOK

World demand for gem diamond can be expected to rise because of increasing effective personal incomes and the populations of the United States and other industrialized countries. Also, demand will increase because of highly effective promotional efforts. These promotions are changing social customs in many eastern countries, particularly the use of diamond engagement rings. The changes are resulting in significant growth in the diamond market. Demand for other precious gems will continue to grow as diamonds become more expensive and the popularity and acceptance of colored gemstones increase. Demand for synthetic and simulant gemstones for both personal and industrial consumption is expected to increase. The diversity of sizes, types, uses, and values of gems and gemstones precludes any meaningful forecasting of future demand.

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Mineral Facts and Problems, 1985.

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Mineral Industry Surveys, Annual Advance Summary Supplement: An Overview of Gemstone Production in the United States.

TABLE 1

DE BEER'S CSO ROUGH DIAMOND PRICE INCREASES, BY PERCENTAGE

Sept. 1949	25.0	Nov. 1967	16.0	Aug. 1973	10.2	Sept. 1982	2.5
Mar. 1951	15.0	Sept. 1968	2.5	Dec. 1974	1.5	Apr. 1983	3.5
Sept. 1952	2.5	July 1969	4.0	Jan. 1976	3.0	Aug. 1986	7.5
Jan. 1954	2.0	Nov. 1971	5.0	Sept. 1976	5.8	Nov. 1986	7.0
Jan. 1957	5.7	Jan. 1972	5.4	Mar. 1977	15.0	Sept. 1987	10.0
May 1960	2.5	Sept. 1972	6.0	Dec. 1977	17.0	Apr. 1988	13.5
Mar. 1963	5.0	Feb. 1973	11.0	Aug. 1978	30.0	Mar. 1989	15.5
Feb. 1964	7.5	Mar. 1973	7.0	Sept. 1979	13.0	Mar. 1990	5.5
Aug. 1966	7.5	May 1973	10.0	Feb. 1980	12.0	Feb. 1993	1.5

TABLE 2

DE BEER'S CSO ROUGH DIAMOND SALES AND STOCKS

(Billions of dollars)

Year	Sales	Stocks
1984	1.61	1.95
1985	1.80	1.90
1986	2.56	1.85
1987	3.07	2.30
1988	4.17	2.00
1989	4.09	2.47
1990	4.17	2.68
1991	3.93	3.03
1992	3.42	3.36
1993	4.40	4.10

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[1] Nassau, K. Gemstone Enhancement. Buttersworth, 1984, pp. 46-60.

[2] Pages 61-78 of work cited in footnote 7.

[3] Bleached and Impregnated Jadeite, Jewelry News Asia, Issue 103, March 1993, pp. 118,120.

[4] Pages 25-44 of work cited in footnote 7.

[5] Rapaport Diamond Report. Colored Stones Section. V. 15, No 9. Mar. 6, 1992, p. 26.

[6] Industrial Minerals (London). No. 312, 1993, p. 13.

[7] Mining Journal (London). V. 321, No. 8247, 1993, p. 277.

[8] ———. V. 321, No. 8243, 1993, p. 209.

[9] Gemological Institute of America. Gems & Gemology. V. 29, No. 1. 1993, p. 64.

[10] Mining Journal (London). V. 320, No. 8227, 1993, p. 404.

[11] ———. V. 320, No. 8220, 1993, p. 276.

TABLE 3

GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with	Recognition characters
Amber	Hydrocarbon	Yellow, red, green, blue	Any	Low to medium	2.0-2.5	1.0-1.1	Single	1.54	Synthetic or pressed, plastics	Fossil resin, soft.
Beryl:										
Aquamarine	Beryllium aluminum silicate	Blue-green to light blue	Any	Medium to high	7.5-8.0	2.63-2.80	Double	1.58	Synthetic spinel, blue topaz	Double refraction, refractive index.
Bixbite	do.	do.	Small	Very high	7.5-8.0	2.63-2.80	do.	1.58	Pressed plastics, tourmaline	Refractive index.
Emerald	do.	Green	Medium	do.	7.5	2.63-2.80	do.	1.58	Fused emerald, glass, tourmaline, peridot, green garnet, doublets	Emerald filter, dichroism refractive index.
Emerald, synthetic	do.	do.	Small	High	7.5-8.0	2.63-2.80	do.	1.58	Genuine emerald	Flaws, brilliant, fluorescence in ultra-violent light.
Golden (heliodor)	do.	Yellow to golden	Any	Low to medium	7.5-8.0	2.63-2.80	do.	1.58	Citrine, topaz, glass, doublets	
Goshenite	do.	do.	Any	Low	7.5-8.0	2.63-2.80	do.	1.58	Quartz, glass, white sapphire, white topaz	Refractive index.
Morganite	do.	Pink to rose	Any	Low	7.5-8.0	2.63-2.80	Low	1.58	Kunzite, tourmaline, pink sapphire	Refractive index.
Calcite:										
Marble	Calcium carbonate	White, pink, red, blue, green or brown	Any	Low	3.0	2.72	Double (strong)	1.49-1.66	Silicates, banded agate, alabaster gypsum	Translucent.
Mexican onyx	do.	do.	Any	Low	3.0	2.72	do.	1.6	do.	Banded, translucent.
Chrysoberyl:										
Alexandrite	Beryllium aluminate	Green by day, red by artificial light	Russia (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.

See footnotes at end of table.

TABLE 3—Continued

GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with	Recognition characters
Corundum:										
Ruby	Aluminum oxide	Rose to deep purplish red	Small	Very high	9.0	3.95-4.10	Double	1.78	Synthetics, including spinel	Inclusions, fluorescence.
Sapphire	do.	Blue	Medium	High	9.0	3.95-4.10	do.	1.78	do.	Inclusions, double refraction, dichroism.
Sapphire, fancy	do.	Yellow, pink, white, orange, green, or violet	Medium to large	Medium	9.0	3.95-4.10	do.	1.78	Synthetics, glass and doublets	Inclusions, double refraction, refractive index.
Sapphire and ruby stars	do.	Red, pink, violet blue, or gray	do.	High to low	9.0	3.95-4.10	do.	1.78	Star quartz, synthetic stars	Shows asterism, color on side view.
Sapphire or ruby synthetic	do.	Yellow, pink, or blue	Up to 20 carats	Low	9.0	3.95-4.10	do.	1.78	Synthetic spinel, glass	Curved strae, bubble inclusions.
Diamond	Carbon	White, blue-white, yellow, brown, green, pink, blue	Any	Very high	10.0	3.516-3.525	Single	2.42	Zircon, titania, cubic zirconia	High index, dispersion, single refraction, hardness, cut, luster.
Feldspar:										
Amazonite	Alkali aluminum-silicate	Green	Large	Low	6.0-6.5	2.56	—	1.52	Jade	Cleavage, sheen, vitreous to pearly opaque, grid.
Labradorite	do.	Gray with blue and bronze sheen color play	do.	Low	6.0-6.5	2.56	—	1.56	do.	Cleavage, sheen, vitreous to pearly opaque, grid.
Moonstone	do.	White	do.	Low	6.0-6.5	2.77	—	1.52-1.54	Glass or white onyx	Blue sheen, opalescent.
Garnet	Complex silicate	Brown, black, yellow, green, ruby red, or orange	Small to medium	Low to high	6.5-7.5	3.15-4.30	Single strained	1.79-1.98	Synthetics, spinel, glass	Single refraction, anomalous strain.
Jade:										
Jadeite	do.	Green, yellow, black, white, or mauve	Large	Low to very high	6.5-7.0	3.3-3.5	Crypto-crystalline	1.65-1.68	Onyx, bowenite, vesu-vianite, 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.
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.
Peridot	Iron magnesium silicate	Yellow and/or green	Any	Medium	6.5-7.0	3.27-3.37	Double (strong)	1.65-1.69	Tourmaline chrysoberyl	Strong double refracation, low dichroism.

See footnotes at end of table.

TABLE 3—Continued

GUIDE TO SELECTED GEMSTONES AND GEM MATERIALS USED IN JEWELRY

Name	Composition	Color	Practical size[1]	Cost[2]	Mohs	Specific gravity	Refraction	Refractive index	May be confused with	Recognition characters
Quartz:										
Agate	Silica	Any color	Large	Low	7.0	2.58-2.64	—	—	Glass, plastic, Mexican onyx	Cryptocrystalline, irregularly banded, dendritic inclusions.
Amethyst	do.	Purple	do.	Medium	7.0	2.65-2.66	Double	1.55	do.	Refractive index, double refraction, transparent.
Cairngorm	do.	Smoky	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Citrine	do.	Yellow	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Crystal, rock	do.	Colorless	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Do.
Jasper	do.	Uniform or spotted red, yellow, or green	do.	Low	7.0	2.58-2.66	—	—	do.	Opaque, vitreous.
Onyx	do.	Many colors	do.	Low	7.0	2.58-2.64	—	—	do.	Uniformly banded.
Rose	do.	Pink, rose red	do.	Low	7.0	2.65-2.66	do.	1.55	do.	Refractive index, double refration, translucent.
Spinel	Magnesium aluminum oxide	Any	Small to medium	Medium	8.0	3.5-3.7	Single	1.72	Synthetic, garnet	Refractive index, single refraction, inclusions.
Spinel, synthetic	do.	Any	Up to 40 carats	Low	8.0	3.5-3.7	Double	1.73	Spinel, corundum, beryl, topaz, alexandrite	Weak double refraction, curved striae, bubles.
Spodumene:										
Kunzite	Lithium aluminum silicate	Pink to lilac	Medium	Medium	6.5-7.0	3.13-3.20	Double	1.66	Amethyst, morganite	Refractive index.
Hiddenite	do.	Yellow to green	do.	do.	6.5-7.0	3.13-3.20	do.	1.66	Synthetic spinel	Do.
Tanzanite	Complex silicate	Blue	Small	High	6.0-7.0	3.30	do.	1.69	Sapphire, synthetics.	Strong trichroism.
Topaz	do.	White, blue, green	Medium	Low to medium	8.0	3.4-3.6	do.	1.62	Beryl, quartz	Refractive index.
Tourmaline	do.	All, including mixed	do.	do.	7.0-7.5	2.98-3.20	do.	1.63	Peridot, beryl, corundum, glass	Double refraction, refractive index.
Turquoise	Copper aluminum phosphate	Blue to green	Large	Low	6.0	2.60-2.83	do.	1.63	Glass, plastics	Difficult if matrix not present, matrix usually limonitic.
Zircon	Zirconium silicate	White, blue, or brown, yellow, or green	Small to medium	Low to medium	6.0-7.5	4.0-4.8	Double (strong)	1.79-1.98	Diamond, synthetics, topaz, aquamarine	Double refraction, strongly dichroic, wear on facet edges.

[1] Small—up to 5 carats; medium—up to 50 carats; large—more than 50 carats.

[2] Low—up to $25 per carat; medium—up to $200 per carat; high—more than $200 per carat.

TABLE 4
SYNTHETIC GEMSTONE PRODUCTION METHODS

Gemstone	Production methods	Company	Date of first production
Ruby	Flux	Chatham	1950's
Do.	do.	Kashan	1960's
Do.	do.	Knischka	1980's
Do.	do.	J.O. Crystal (Ramaura)	1980's
Do.	do.	Douras	1990's
Do.	Zone melt	Seiko	1980's
Do.	Melt pulling	Kyocera (Inamori)	1970's
Do.	Verneuil	Various producers	1900's
Star ruby	do.	Linde (Div. of Union Carbide)	1940's
Do.	Melt pulling	Kyocera	1980's
Do.	do.	Nakazumi	1980's
Sapphire	Flux	Chatham	1970's
Do.	Zone melt	Seiko	1980's
Do.	Melt pulling	Kyocera	1980's
Do.	Verneuil	Various producers	1900's
Star sapphire	do.	Linde	1940's
Emerald	Flux	Chatham	1930's
Do.	do.	Gilson	1960's
Do.	do.	Kyocera	1970's
Do.	do.	Seiko	1980's
Do.	do.	Lennix	1980's
Do.	do.	Russia	1980's
Do.	Hydrothermal	Lechleitner	1960's
Do.	do.	Regency	1980's
Do.	do.	Biron	1980's
Do.	do.	Russia	1980's
Alexandrite	Flux	Creative crystals	1970's
Do.	Melt pulling	Kyocera	1980's
Do.	Zone melt	Seiko	1980's
Cubic zirconia	Skull melt	Various producers	1970's

TABLE 5
VALUE OF U.S. GEMSTONE PRODUCTION, BY GEMSTONE

(Thousand dollars)

Gem materials	1992	1993
Agate	548	843
Beryl	323	470
Coral (all types)	122	166
Garnet	108	233
Gem feldspar	1,042	701
Geode/nodules	260	207
Fire agate	45	40
Jasper	111	531
Obsidian	4	10
Opal	756	639
Peridot	1,306	1,520
Petrified wood	211	234
Quartz	638	1,036
Sapphire/ruby	895	313
Topaz	12	8
Tourmaline	82	9,534
Turquoise	1,994	3,035
Total	8,457	19,520

TABLE 6

PRICES OF U.S. CUT DIAMONDS, BY SIZE AND QUALITY

Carat weight	Description, color[1]	Clarity[2] (GIA terms)	Price range per carat[3] Jan. 1993-Jan. 1994	Average[4] July 1993
0.25	G	VS1	$1,400-$1,400	$1,400
.25	G	VS2	1,200- 1,200	1,200
.25	G	SI1	970- 970	970
.25	H	VS1	1,200- 1,200	1,200
.25	H	VS2	1,100- 1,100	1,100
.25	H	SI1	950- 950	950
.50	G	VS1	2,900- 3,050	3,050
.50	G	VS2	2,600- 2,700	2,700
.50	G	SI1	2,300- 2,400	2,400
.50	H	VS1	2,700- 2,800	2,800
.50	H	VS2	2,500- 2,600	2,600
.50	H	SI1	2,200- 2,300	2,300
.75	G	VS1	3,500- 3,650	3,650
.75	G	VS2	3,200- 3,350	3,350
.75	G	SI1	2,800- 2,950	2,950
.75	H	VS1	3,100- 3,250	3,250
.75	H	VS2	2,800- 2,950	2,950
.75	H	SI1	2,600- 2,750	2,750
1.00	G	VS1	4,600- 4,800	4,750
1.00	G	VS2	4,100- 4,250	4,200
1.00	G	SI1	3,700- 3,850	3,800
1.00	H	VS1	4,100- 4,250	4,200
1.00	H	VS2	3,900- 4,050	4,000
1.00	H	SI1	3,600- 3,750	3,700

[1] Gemological Institute of America (GIA) color grades: D—colorless; E—rare white; G-H-I—traces of color.

[2] Clarity: IF—no blemishes; VVS1—very, very slightly included; VS—very slightly included; VS2—very slightly included, but not visible; SI1—slightly included.

[3] Jeweler's Circular-Keystone. V. 165, No. 3, Mar. 1994, p. 146.

[4] Jeweler's Circular-Keystone. V. 164, No. 9, Sept. 1993, p. 114.

TABLE 7

PRICES OF U.S. CUT COLORED GEMSTONES, BY SIZE[1]

Gemstone	Carat weight	Price range per carat in 1993[2]	Average price per carat[2]	
			Jan. 1993	Jan. 1994
Amethyst	1	$8- $18	$13.00	$13.00
Aquamarine	1	75- 90	82.50	82.50
Emerald	1	2,000- 3,500	2,750.00	2,750.00
Garnet, tsavorite	1	600- 900	750.00	750.00
Ruby	1	3,000- 4,800	3,900.00	3,900.00
Sapphire	1	800- 2,000	1,400.00	1,400.00
Tanzanite	1	100- 185	130.00	150.00
Topaz	1	5- 9	7.00	7.00
Tourmaline, red	1	60- 125	92.50	92.50

[1] Fine quality.

[2] Jewelers' Circular-Keystone. V. 165, No. 3, Mar. 1994, p. 146. These figures represent a sampling of net prices that wholesale colored stone dealers in various U.S. cities charged their cash customers during the month for fine-quality stones.

TABLE 8

U.S. EXPORTS AND REEXPORTS OF DIAMOND (EXCLUSIVE OF INDUSTRIAL DIAMOND), BY COUNTRY

Country or territory	1992 Quantity (carats)	1992 Value[1] (millions)	1993 Quantity (carats)	1993 Value[1] (millions)
Exports and reexports:				
Australia	552	$1.7	585	$1.3
Belgium	r792,646	r322.3	443,623	363.9
Canada	r412,161	30.7	242,593	33.6
Germany	11,878	10.1	3,408	3.3
Hong Kong	r157,109	r311.3	232,487	333.5
India	101,717	15.4	128,675	15.8
Israel	r245,690	r250.3	320,100	286.7
Japan	r75,992	r121.4	88,756	144.5
Mexico	3,016	1.7	7,638	1.6
Singapore	r19,114	r30.7	14,604	35.7
South Africa, Republic of	928	1.7	1,276	2.0
Switzerland	r44,211	r146.2	36,605	160.4
Thailand	r17,369	r16.5	58,490	24.4
United Kingdom	r12,292	r50.8	13,925	43.5
Other	r29,903	r50.6	37,682	48.9
Total	r1,924,578	r1,361.4	1,630,447	1,499.1

rRevised.

[1] Customs value.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF DIAMOND, BY KIND, WEIGHT, AND COUNTRY

Kind, range, and country or territory of origin	1992		1993	
	Quantity (carats)	Value[1] (millions)	Quantity (carats)	Value[1] (millions)
Rough or uncut, natural:[2]				
Belgium	402,763	$81.9	143,860	$111.7
Brazil	26,867	1.4	55,214	4.7
Isreal	26,699	10.7	13,535	5.7
Netherlands	79,564	17.6	1,607	2.6
South Africa, Republic of	13,405	17.6	26,058	43.7
Switzerland	1,156	9.4	8,549	12.6
United Kingdom	685,544	189.1	1,127,237	229.3
Venezuela	318	.1	161	.1
Other	392,059	167.1	394,271	199.6
Total[3]	1,628,375	495.0	1,770,492	610.1
Cut but unset, not more than 0.5 carat:				
Belgium	795,348	270.5	951,502	315.7
Brazil	15,414	6.6	5,928	2.0
Canada	[r]6,552	2.1	5,709	1.5
Hong Kong	247,289	44.1	147,006	40.8
India	4,249,843	935.2	5,577,187	1,178.7
Israel	670,327	313.0	800,084	347.8
Netherlands	3,338	1.1	1,778	.4
South Africa, Republic of	7,263	6.3	5,658	5.4
Switzerland	11,055	4.6	8,357	2.8
United Kingdom	4,779	1.4	3,146	.6
Other	80,899	19.2	109,748	25.7
Total[3]	[r]6,092,107	1,604.2	7,616,103	1,921.4
Cut but unset, more than 0.5 carat:				
Belgium	589,036	776.2	676,500	912.2
Hong Kong	[r]14,886	30.8	33,037	44.6
India	30,634	18.0	100,209	63.4
Israel	915,487	973.8	1,161,760	1,255.7
Netherlands	3,928	18.9	2,177	6.8
South Africa, Republic of	5,706	22.4	11,788	34.4
Switzerland	10,712	95.1	11,678	114.1
United Kingdom	20,061	35.1	14,041	35.9
Other	41,319	74.3	75,940	97.7
Total[3]	[r]1,631,769	2,044.5	2,087,130	2,564.8

[r] Revised.

[1] Customs value.

[2] Includes some natural advanced diamond.

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

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GEMSTONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country or territory	1992 Quantity (carats)	1992 Value[1] (millions)	1993 Quantity (carats)	1993 Value[1] (millions)
Emerald:				
Belgium	4,381	$0.7	8,122	$2.1
Brazil	125,548	4.5	1,100,146	4.0
Colombia	403,988	92.4	581,333	118.9
France	3,753	4.1	490	1.0
Germany	149,870	4.3	66,929	2.3
Hong Kong	232,025	19.2	271,592	21.5
India	1,208,678	16.5	2,090,983	26.8
Israel	116,586	21.4	447,491	27.9
Switzerland	164,283	39.6	105,266	24.1
Taiwan	3,452	.3	581	2.5
Thailand	299,313	6.6	706,280	6.8
Other	[r]244,029	[r]4.0	72,928	6.5
Total	2,955,906	213.5	5,452,141	244.4
Jade:				
Brazil	NA	9.0	NA	7.3
Germany		15.7		13.8
Hong Kong		12.7		15.4
India		6.1		7.0
Israel		5.4		6.0
Taiwan		2.8		3.1
Thailand		47.5		17.5
Other		10.3		10.6
Total	NA	109.2	NA	80.7
Ruby:				
Belgium	9,065	1.1	4,932	.7
Brazil	6,793	.3	7,219	.1
France	790	.6	629	.7
Germany	17,677	1.1	101,945	1.2
Hong Kong	[r]99,823	[r]3.9	218,116	6.2
India	375,745	1.7	1,012,472	2.8
Israel	12,094	1.5	14,938	1.8
Switzerland	36,221	23.3	19,664	15.7
Thailand	2,008,030	39.1	2,181,489	47.9
United Kingdom	2,401	3.3	3,784	2.5
Other	[r]66,306	[r]2.0	39,175	10.3
Total	[r]2,634,945	[r]77.9	3,604,363	90.6
Sapphire:				
Australia	4,682	.1	12,377	.1
Beglium	6,744	.7	18,710	.8
Brazil	23,326	.2	2,585	.1
Canada	187,196	.5	48,593	.8
Germany	49,194	1.3	122,609	1.0
Hong Kong	[r]113,716	[r]3.9	202,914	3.7
Israel	28,987	1.2	30,554	1.0
Sri Lanka	85,218	3.5	196,128	4.5
Switzerland	27,608	13.6	32,786	7.8
Thailand	3,991,362	45.5	4,255,519	54.1

See footnotes at end of table.

TABLE 10—Continued

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GEMSTONES, OTHER THAN DIAMOND, BY KIND AND COUNTRY

Kind and country or territory	1992 Quantity (carats)	1992 Value[1] (millions)	1993 Quantity (carats)	1993 Value[1] (millions)
Sapphire—Continued:				
United Kingdom	4,210	$1.2	5,404	$0.8
Other	[r]88,663	[r]3.4	201,604	4.6
Total	[r]4,610,906	75.1	5,129,783	79.3
Other:				
Rough, uncut:				
Australia	NA	2.1	NA	2.6
Brazil	NA	30.2	NA	21.4
Colombia	NA	4.4	NA	6.1
Hong Kong	NA	1.0	NA	7.1
South Africa, Republic of	NA	.3	NA	2.4
Switzerland	NA	.7	NA	.3
Zambia	NA	1.0	NA	.8
Other	11,702,472	13.8	21,772,815	9.0
Total	41,130,452	53.5	56,187,445	49.7
Cut, set and unset:				
Australia	NA	3.8	NA	4.2
Brazil		9.0		7.2
China		.9		1.8
Germany		15.7		13.8
Hong Kong		[r]17.3		20.3
India		6.9		8.0
Japan		9.3		10.1
Switzerland		.8		1.2
Taiwan		3.1		3.5
Thailand		47.5		17.5
Other		17.1		16.6
Total	NA	131.5	NA	104.2

[r] Revised. NA Not available.

[1] Customs value.

Source: Bureau of the Census.

TABLE 11

VALUE OF U.S. IMPORTS OF SYNTHETIC AND IMITATION GEMSTONES, INCLUDING PEARLS, BY COUNTRY

(Million dollars[1])

Country or territory	1992	1993
Synthetic, cut but unset:		
Australia	1.9	3.4
Austria	6.3	3.7
Germany	[r]10.1	10.7
Hong Kong	2.9	2.0
Korea, Republic of	4.2	2.1
Switzerland	4.6	3.8
Thailand	23.2	12.5
Other	[r]4.8	5.9
Total	[r]58.0	44.1
Imitation:		
Austria	[r]69.9	45.9
Czechoslovakia	7.0	—
Germany	2.8	2.0
Japan	2.3	.7
Other	2.7	11.4
Total	[r]84.7	60.0

[r] Revised.

[1] Customs value.

Source: Bureau of the Census.

TABLE 12

U.S. IMPORTS FOR CONSUMPTION OF GEMSTONES

(Thousand carats and thousand dollars)

Stones	1992		1993	
	Quantity	Value[1]	Quantity	Value[1]
Diamonds:				
Rough or uncut	1,628	495,003	1,770	610,113
Cut but unset	7,724	[r]3,648,640	9,703	4,486,270
Emeralds: Cut but unset	2,956	213,497	5,452	244,356
Coral and similar materials, unworked	2,787	6,115	2,800	5,442
Jade: Cut and rough	NA	109,233	NA	80,679
Rubies and sapphires: Cut but unset	7,246	[r]153,059	8,734	169,934
Pearls:				
Natural	NA	3,896	NA	2,887
Cultured	NA	[r]18,195	NA	20,483
Imitation	NA	[r]3,698	NA	1,957
Other precious and semiprecious stones:				
Rough, uncut	408,236	41,446	558,900	38,378
Cut, set and unset	NA	[r]109,376	NA	80,825
Other	281	5,957	175	5,869
Synthetic:				
Cut but unset	[r]217,010	[r]57,950	163,423	44,107
Other	NA	[r]1,628	NA	1,523
Imitation gemstone	NA	[r]81,029	NA	58,071
Total	XX	[r]4,948,722	XX	5,850,894

[r] Revised. NA Not available. XX Not applicable.

[1] Customs value.

Source: Bureau of the Census.

TABLE 13
DIAMOND: WORLD PRODUCTION, BY TYPE AND COUNTRY[1]

(Thousand carats)

Country	1989				1990				1991			
	Natural			Synthetic[4]	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	1,165	80	1,245	—	1,060	73	1,133	—	899	62	961	—
Australia	17,540	17,540	35,080	—	17,331	17,331	34,662	—	17,978	17,978	35,956	—
Belarus	—	—	—	—	—	—	—	—	—	—	—	—
Botswana	10,680	4,570	15,252	—	12,150	5,200	17,352	—	11,550	4,950	16,506	—
Brazil	350	150	500	—	600	900	1,500	—	600	900	[e]1,500	—
Central African Republic	334	81	415	—	303	78	381	—	296	82	379	—
China[e]	200	800	1,000	15,000	200	800	1,000	15,000	200	800	1,000	15,000
Côte d'Ivoire[e] [6]	9	3	[7]12	—	9	3	12	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	—	—	—	—	—
Czechoslovakia[e] [9]	—	—	—	[r]10,000	—	—	—	[r]10,000	—	—	—	[r]10,000
France[e]	—	—	—	4,000	—	—	—	[r]5,000	—	—	—	4,000
Gabon[e]	400	100	500	—	400	100	500	—	400	100	500	—
Ghana[10]	[r]395	[r]99	494	—	[r]520	[r]130	650	—	[r]560	[r]140	700	—
Greece[e]	—	—	—	1,000	—	—	—	1,000	—	—	—	1,000
Guinea[e] [6]	137	10	147	—	119	8	127	—	91	6	97	—
Guyana	3	5	8	—	5	13	18	—	6	16	[r]22	—
India	[r]12	[r]3	15	—	[r]15	[r]3	18	—	[r]15	[r]3	18	—
Indonesia[e]	7	25	32	—	7	23	30	—	8	24	32	—
Ireland[e]	—	—	—	60,000	—	—	—	60,000	—	—	—	60,000
Japan[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	30,000
Liberia[e] [11]	[7]62	[7]93	[7]155	—	40	60	100	—	40	60	100	—
Namibia	910	20	927	—	750	15	763	—	1,170	20	1,187	—
Romania[e]	—	—	—	[r]5,000	—	—	—	[r]3,000	—	—	—	[r]3,000
Russia[e]	—	—	—	—	—	—	—	—	—	—	—	—
Serbia and Montenegro[12]	—	—	—	—	—	—	—	—	—	—	—	—
Sierra Leone[6]	90	39	129	—	66	12	78	—	160	83	243	—
Slovakia[9]	—	—	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of:												
Finsch Mine	1,600	3,000	4,610	—	1,480	2,700	4,178	—	1,200	2,280	3,483	—
Premier Mine	700	1,520	2,215	—	720	1,600	2,328	—	700	1,550	2,250	—
Venetia Mine	—	—	—	—	20	40	62	—	100	200	303	—
Other De Beers' properties[13]	1,350	530	1,880	—	1,200	460	1,652	—	1,500	400	1,897	—
Other	350	50	411	—	380	100	488	—	400	100	498	—
Total	4,000	5,100	9,116	[e]60,000	[r]3,800	4,900	8,708	[e]60,000	3,900	4,530	8,431	[e]60,000
Swaziland	33	22	55	—	25	17	42	—	34	23	57	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000	—	—	—	25,000
Tanzania	105	45	[e]150	—	60	25	85	—	70	30	100	—
U.S.S.R.[e] [14]	11,500	11,500	23,000	[r]120,000	12,000	12,000	24,000	[r]120,000	10,000	10,000	20,000	[r]120,000
Ukraine	—	—	—	—	—	—	—	—	—	—	—	—
United States	—	—	—	W	—	—	—	W	—	—	—	90,000
Venezuela	70	185	255	—	[r]85	[r]248	333	—	102	112	214	—
Yugoslavia[e] [15]	—	—	—	5,000	—	—	—	5,000	—	—	—	5,000
Zaire	[7]2,663	[7]15,092	17,755	—	[7]2,914	[7]16,513	19,427	—	3,000	14,814	17,814	—
Total	[r]50,665	[r]55,562	106,242	[r]325,000	[r]52,459	[r]58,452	110,919	[r]269,000	[r]51,090	[r]54,737	[r]105,832	[r]423,000

See footnotes at end of table.

TABLE 13—Continued

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

(Thousand carats)

Country	1992				1993[e]			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Angola[5]	[r]1,100	[r]80	[r]1,180	—	470	30	500	—
Australia	[r]17,750	[r]22,250	[r][e]40,000	—	19,000	23,200	42,200	—
Belarus	—	—	—	[e]30,000	—	—	—	30,000
Botswana	[r]11,160	[r]4,790	[r]15,946	—	12,000	5,000	17,000	—
Brazil[e]	[r]653	[r]665	[r]1,318	—	600	900	1,500	—
Central African Republic	[r]307	[r]107	[r]414	—	307	106	413	—
China[e]	200	800	1,000	15,000	230	850	1,080	15,500
Côte d'Ivoire[e] [6]	11	4	15	—	11	4	15	—
Czech Republic[8]	—	—	—	—	—	—	—	5,000
Czechoslovakia[e] [9]	—	—	—	[r]10,000	—	—	—	—
France[e]	—	—	—	[r]3,500	—	—	—	3,500
Gabon[e]	400	100	500	—	400	100	500	—
Ghana[10]	[r]570	[r]140	[r]710	—	600	150	750	—
Greece[e]	—	—	—	750	—	—	—	1,000
Guinea[6]	90	5	95	—	90	5	95	—
Guyana	[r]13	[r]32	[r][e]45	—	14	36	50	—
India	[r]15	[r]3	18	—	16	3	19	—
Indonesia[e]	6	21	27	—	7	20	27	—
Ireland[e]	—	—	—	60,000	—	—	—	66,000
Japan[e]	—	—	—	30,000	—	—	—	32,000
Liberia[e] [11]	[r] [7]62	[r] [7]93	[r] [7]155	—	60	90	150	—
Namibia	[r]1,500	50	[r]1,548	—	1,100	40	[7]1,139	—
Romania[e]	—	—	—	[r] [7]—	—	—	—	—
Russia[e]	9,000	9,000	18,000	80,000	8,000	8,000	16,000	80,000
Serbia and Montenegro[12]	—	—	—	5,000	—	—	—	5,000
Sierra Leone[6]	[r]200	[r]96	[r]296	—	90	68	[7]158	—
Slovakia[9]	—	—	—	—	—	—	—	5,000
South Africa, Republic of:								
Finsch Mine	1,200	2,250	3,446	—	700	1,300	[7]2,012	—
Premier Mine	740	1,700	2,444	—	500	1,100	[7]1,596	—
Venetia Mine	660	1,200	1,868	—	1,750	3,200	[7]4,969	—
Other De Beers' properties[13]	1,350	500	1,849	—	900	350	[7]1,249	—
Other	450	100	549	—	450	100	550	—
Total	[r]4,400	[r]5,750	[r]10,166	[e]60,000	4,300	6,050	10,324	75,000
Swaziland	36	24	[r]51	—	27	18	45	—
Sweden[e]	—	—	—	25,000	—	—	—	25,000
Tanzania	[r]48	[r]20	[r]68	—	48	20	68	—
U.S.S.R.[e] [14]	—	—	—	—	—	—	—	—
Ukraine	—	—	—	[e]10,000	—	—	—	10,000
United States	—	—	—	90,000	—	—	—	103,000
Venezuela	[r]302	[r]176	[r]478	—	335	200	535	—
Yugoslavia[e] [15]	—	—	—	—	—	—	—	—

See footnotes at end of table.

TABLE 13—Continued

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

(Thousand carats)

Country	1992				1993[e]			
	Natural			Synthetic[4]	Natural			Synthetic[4]
	Gem[2]	Industrial	Total[3]		Gem[2]	Industrial	Total[3]	
Zaire	[r] [7]8,934	[r] [7]4,567	[r]13,501	—	9,500	5,500	15,000	—
Total	[r]56,757	[r]48,773	[r]105,521	[r]419,250	57,205	50,390	107,620	456,000

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

[1] Table includes data available through June 8, 1994. Total natural diamond output (gem plus industrial) for each country actually is reported, except where indicated by a footnote to be estimated. In contrast, the detailed separate production data for gem diamond and industrial diamond are U.S. Bureau of Mines estimates except Brazil (1989-90), and the Central African Republic (1989-90), for which source publications give details on grade as well as totals. The estimated distribution of total output between gem and industrial diamond is conjectural, and for most countries, is based on the best available data at time of publication.

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

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

[4] Includes all synthetic diamond production.

[5] Figures do not include smuggled artisanal production.

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

[7] Reported figure.

[8] Formerly part of Czechoslovakia.

[9] Dissolved on Dec. 31, 1992.

[10] "Gem" vs. "Industrial" diamond breakdown has been revised to reflect the value of near-gem material, classified as industrial prior to 1991, but which was ultimately being sold for well above industrial prices.

[11] Data for 1989 do not include smuggled production. Data for 1990-92 are estimates of artisanal production, likely smuggled out of Liberia, but which are comparable to that hitherto reported to the Government.

[12] Formerly part of Yugoslavia.

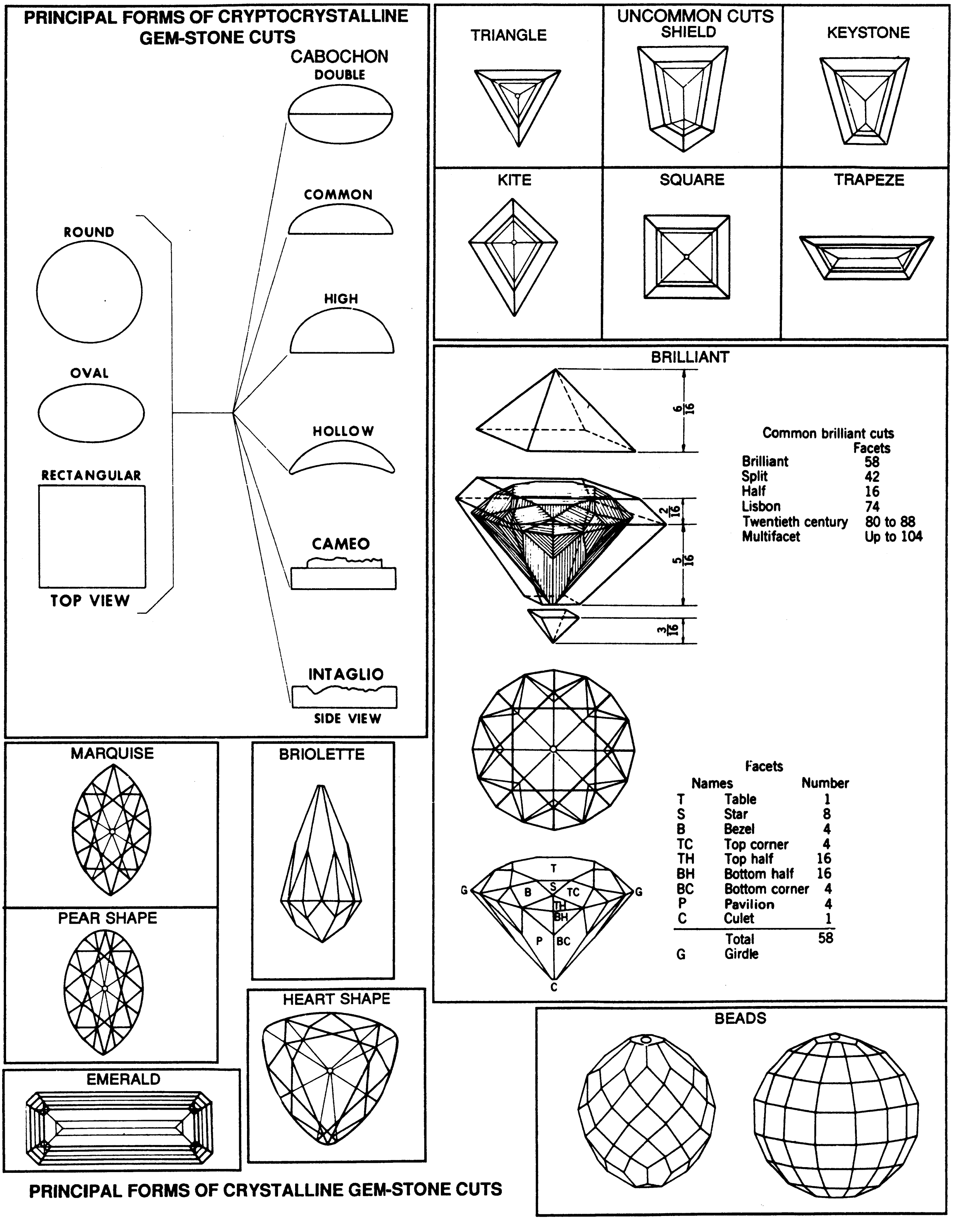
[13] Other De Beers' Group output from the Republic of South Africa includes Kimberley Mines, Koffiefontein Mine, and Namaqualand Mines.

[14] Dissolved in Dec. 1991.

[15] Dissolved in Apr. 1992.

FIGURE 1

PRINCIPAL FORMS OF CRYPTOCRYSTALLINE AND CRYSTALLINE GEM STONE CUTS



Common brilliant cuts

	Facets
Brilliant	58
Split	42
Half	16
Lisbon	74
Twentieth century	80 to 88
Multifacet	Up to 104

Facets

Names		Number
T	Table	1
S	Star	8
B	Bezel	4
TC	Top corner	4
TH	Top half	16
BH	Bottom half	16
BC	Bottom corner	4
P	Pavilion	4
C	Culet	1
	Total	58
G	Girdle	

GOLD

By John M. Lucas

Mr. Lucas, a geologist with more than 30 years of experience in the mining industry, has been the U.S. Bureau of Mines commodity specialist for gold since 1980. While with private industry, Mr. Lucas was involved in exploring for a wide variety of commodities, including gold, in the United States as well as Australia, Brazil, and Canada. Domestic survey data were prepared by Dwayne E. Penn, and Lisa P. Conley, statistical assistants. International data tables were prepared by Audrey D. Wilkes, international data coordinator.

Domestic gold mines continued to produce at record levels in 1993, thereby maintaining the United States' position as the world's second largest gold-producing nation after the Republic of South Africa. Domestic production continued to be dominated by Nevada and California, where combined mine output accounted for nearly 75% of the U.S. total. Gold was produced at about 200 lode mines, nearly all in western States; a dozen or more large placer mines, nearly all in Alaska; and numerous small placer mines, mostly in Alaska and western States. About 14,700 people were employed in gold mines and mills. A small amount of domestic gold was recovered as a byproduct of processing base metals, chiefly copper. Twenty-five mines yielded 80% of the gold produced. The value of 1993 mine production was more than $3.8 billion.

Environmental pollution abatement continued to be of concern to domestic gold producers, especially in Alaska, where there are many small placer mines. Provisions for reclamation of mined land was an integral part of an increasing number of gold mine plans.

The trend in gold exploration activity, which peaked about 1988, continued to decline in 1993 as North American exploration companies sought unexplored territory and improved business and regulatory climates elsewhere. The principal focus remained on several Latin American nations where favorable geology, combined with recently liberalized mining regulations, held the promise of greater long-term success and reduced risk to limited investment capital.

Conversion of gold scrap to refined gold provided nearly 66 metric tons (2.1 million troy ounces[1]) of metal to the market, a quantity equivalent to about 70% of domestic gold consumption. The balance of secondary production, 85 tons, was from prompt industrial scrap, partly toll refined.

Commercial-grade refined gold came from about two dozen producers. A few dozen companies, out of several thousand companies and artisans, dominated the fabrication of gold into useful products. Nearly all jewelry manufacturing was centered in the New York, NY, and Providence, RI, areas. Estimated uses in 1993 were as follows; jewelry and arts, 71%; industrial (mainly electronic), 22%; and dental, 7%.

The Engelhard Industries/London daily price of gold ranged from a low of $327 per troy ounce on March 10, to a high of $407 on August 2. The average for the year was $361.

Gold was mined in nearly 80 countries, of which the top 5 accounted for about two-thirds of the world total of more than 2,330 tons (74.9 million ounces). The Republic of South Africa was the largest producer, with 27% of the world total, followed by the United States (14%), Australia (11%), Canada (7%), and China (7%).

Identified world gold resources at yearend 1993 were estimated by the U.S. Geological Survey at 75,000 tons, of which 15% to 20% was byproduct resources. The reserve base was estimated by the U.S. Bureau of Mines (USBM) at 57,000 tons and reserves at 42,000 tons. The Republic of South Africa had about one-half of the resources and reserve base and 43% of the reserves. The United States had about 12% of world resources, 9% of the reserve base, and 11% of the reserves.

Of an estimated 114,000 tons of gold mined in historical times through 1993, about 15% is believed to have been lost, used in dissipative ways, or otherwise unrecoverable or unaccounted for. Of the remaining 97,000 tons, an estimated 35,000 tons is official stocks held by central banks and about 62,000 tons is privately held as coin, bullion, and jewelry.

DOMESTIC DATA COVERAGE

Domestic mine production data for gold are developed by the USBM from two separate, voluntary surveys of U.S. operations. One of these surveys is the lode-mine production survey of copper, gold, lead, silver, and zinc mines. Of the lode gold producers in operation to which a survey request was sent, 216 responded, representing 98% of the total lode-mine production of gold shown in tables 4 and 5. Production for the nonrespondents was estimated using reported prior-year production levels, adjusted by trends in employment, and other guidelines such as company annual reports, the news media, and State agency reports.

ANNUAL REVIEW

Production

The individual company production

and performance data in this report were derived from published sources such as company annual reports.

Alaska.—According to a summary of 1993 Alaskan mining activity prepared by the Alaska State Division of Geology and Geophysical Surveys (DGGS),[2] production data collected by the DGGS indicated a substantial decline in gold production from that of the previous year. Gold production amounting to about 2,777 kilograms (kg) (89,283 ounces) was reported to the USBM. However, the annual survey conducted informally by the DGGS suggests that a total of about 5,946 kg (191,200 ounces) of both lode and placer gold was produced during the year; the comparable total for the previous year was 8,163 kg (262,530 ounces). Despite the sharp decline in overall production, which, to a large extent reflects the early 1993 closure of Greens Creek Mining Co.'s Greens Creek underground polymetallic mine on Admiralty Island, Alaska's approximately 198 placer mines benefitted from improved gold prices and a long, warmer-than-average mining season.

Alaska Gold Co., a subsidiary of Mueller Industries Inc., continued to operate its two Yuba class bucketline stacker-dredges on its properties in the Nome area and along the Hogatza River.

Production at Alaska's largest placer mine, Cambior Alaska Inc.'s Valdez Creek Mine, was 1,106 kg (35,560 ounces) of gold compared with more than 2,676 kg (86,052 ounces) recovered during 1992.

In addition to Cambior Alaska, Greens Creek, and Alaska Gold, the State's top 10 gold producers, according to the DGGS, included Polar Mining Inc. near Fairbanks, Alaska Placer Development near Livengood, Thurmond Oil and Mining in the Eureka District, GHD Resources in the Tofty District, Cooks Mining east of Fairbanks, Green Mining and Exploration near Ruby, and Paul and Co. in the Circle district. In the State's northern region, Silverado Mines Ltd. reported year-round production at its Nolan gold mine, inside the Arctic Circle 288 kilometers (km) (180 miles) north of Fairbanks.

Gold mines undergoing exploration and development during the year included Echo Bay Mines Ltd.'s Alaska Juneau (AJ) Mine, a large former producing mine on the edge of Alaska's capital city of Juneau, and its Kensington joint-venture project, 115 km (72 miles) north of Juneau.

Amax Gold Inc.,'s 96%-owned operating subsidiary, Fairbanks Gold Inc., continued development work on its Fort Knox Project 24 km (15 miles) northeast of Fairbanks.

Arizona.—Economic ore reserves at Cyprus Gold Co's. Copperstone Mine, in LaPaz County, were exhausted and mining ceased in late 1992. Milling and processing of stockpiled low-grade material at the plant site was completed during the second quarter of 1993. The cessation of production at Copperstone was reflected in a sharp 29% decline in 1993 Arizona gold production from that recorded during 1992 when the Copperstone operation was the State's largest gold-producing property. Most of the gold production reported during 1993 was derived as a byproduct of Arizona's numerous copper mines.

California.—The State of California was again the Nation's second largest gold-producing State during 1993, a position held since 1987.

In mid-1993, the Mesquite Mine in Imperial County was acquired by Santa Fe Pacific Gold Corp. (SFPG) as part of an asset swap between SFPG and Hanson Natural Resources Co. Homestake Mining Co.'s McLaughlin Mine, near Lower Lake, processed oxide and sulfide ore mined by open pit methods to recover a record 9.5 tons (305,312 ounces) of gold during 1993. Near Ogilby, in Imperial County, the American Girl Mine, operated by the American Girl Mining Joint Venture, produced nearly 2,200 kg (69,200 ounces) of gold. In eastern Imperial County, Glamis Gold Ltd. produced gold at its open pit and heap-leaching Picacho Mine. Production also continued at the company's two Kern County mines.

Viceroy Gold Corp. completed its first full year of metal production in February at its new Castle Mountain Mine, in eastern San Bernardino County. The mine produced an estimated 4,000 kg (128,000 ounces) of gold during the year. Nearby, Lac Minerals Ltd. recovered 843 kg (27,131 ounces) of residual gold from its recently depleted Colosseum Mine. Reclamation of the site was nearly completed by yearend.

In the Mother Lode country of Tuolumne County, Sonora Mining Corp. continued mining operations at its Jamestown Mine. During 1993 the mine owners celebrated the recovery of the 500,000th ounce (15.6 tons) of production. On December 26, 1992, a large pocket of gold was discovered at workings on the mine's Crystalline-Alabama claims. Color photographs of the more spectacular specimens were published in California Geology.[3]

In Calaveras County, 65 km (40 miles) east of Stockton, FMC Gold Co. produced about 1,710 kg (55,000 ounces) at its Royal Mountain King Mine.

In June, following 1 year of operation, Lassen Gold Mining Inc., a subsidiary of Amax Gold Inc., placed the mill at its Hayden Hill Mine on standby and temporarily stopped production. The Lassen County operation was later reconfigured to heap leaching only.

Colorado.—The State's largest gold mine, Battle Mountain Gold Co.'s (BMG's) San Luis Mine in Costilla County, increased production by about 31% over production achieved during the previous year. The increased production largely reflects the resolution of operational problems encountered during the mine's startup in 1991 and later in 1992. In Teller County, the Cripple Creek and Victor Gold Mining Co. (CC&VGMC) produced about 1,533 kg (49,310 ounces) of gold, an increase of about 16% over 1992 production.

Other Colorado operations reportedly producing gold during the year included Solution Gold Ltd.'s reclamation mining and leaching project in Gilpin County; Franklin Consolidated Mining Co.'s

Franklin Mine near Idaho Springs, in Clear Creek County; and ASARCO Incorporated's Black Cloud Mine southeast of Leadville, in Lake County, where gold is recovered as a byproduct of lead mining operations.

Idaho.—In January, Pegasus Gold Inc. completed its first full year of metal production at its Black Pine Mine near Bridge, 40 km (25 miles) north of the Idaho-Utah border. The mine was Idaho's largest gold producer in 1993.

Production at the open pit DeLamar Mine in Owyhee County amounted to a record 1,340 kg (43,094 ounces). The DeLamar's new owners moved toward a mid-1995 startup at the Stone Cabin property, 8 km (5 miles) from the DeLamar site.

Idaho Gold Corp. reportedly conducted secondary leaching of low-grade ore at its Champagne Mine 32 km (20 miles) east of Arco in Butte County. Reclamation was underway near yearend at the site, where mining was completed in 1992.

Seasonal mining and heap-leach operations continued at the Stibnite Mine near Yellow Pine in Valley County. The mine is wholly owned by MinVen Corp., which changed its name in September to Dakota Mining Corp. Also in Valley County, USMX acquired an interest in the Dewey-Sunnyside Mine properties.

On Jordan Creek in Custer County, Hecla Mining Co. moved forward with plans to develop its Grouse Creek property in the Yankee Fork Basin. In Lemhi County, Meridian Gold Co., a subsidiary of FMC Gold Co., continued to defer development at its fully permitted Beartrack property, 18 km (11 miles) northwest of Salmon.

Montana.—Mining and mineral developments in Montana during 1993 were summarized in a report prepared by the Montana Bureau of Mines and Geology (MBMG).[4] With four separate open pit gold mines, Pegasus Gold Inc. was again Montana's leading gold producer in 1993. Pegasus' Basin Creek Mine, placed on care and maintenance in 1991, produced residual gold from existing test heaps at the Lewis and Clark County mine site. The company's Zortman-Landusky Mine, in Phillips County, the State's largest gold mine, yielded nearly 3,400 kg (108,500 ounces), or 4% less than in the previous year. The decline was attributed to an extremely wet summer. Gold was recovered at Pegasus' Montana Tunnels Mine, a gold, lead, silver, and zinc mine in Jefferson County. Despite a wet operating season, production at the company's Beal Mountain Mine increased. Pegasus also began mining at its newly permitted south Beal property in late 1993.

Open pit mining operations at Placer Dome's wholly owned Golden Sunlight Mine near Whitehall in Jefferson County yielded 2,818 kg (90,612 ounces) in 1993. At Jardine, in Park County, TVX Gold Inc. produced about 1,350 kg (43,300 ounces) of gold at its underground Mineral Hill Mine. Permitting work was continued by Crown Butte Resources Ltd. at its New World gold, copper, and silver project near Cooke City in eastern Park County. Plans call for processing not involving heap leaching or the use of cyanide.

Gold production at Canyon Resources Corp.'s open pit Kendall Mine near Lewiston amounted to nearly 1,700 kg (54,203 ounces) during 1993. Canyon continued exploration at the McDonald gold deposit, the smaller Seven-Up Pete deposit, and the nearby Keep Cool mineralized area in Lewis and Clark County.

Exploration activity in Montana continued to decline, and many companies closed their exploration offices. The MBMG estimated that the quantity of gold recovered at the State's numerous small placer mining operations was impacted severely by the extremely wet operating season.

Nevada.—Gold production in Nevada, the Nation's dominant gold-producing State, increased for the 14th consecutive year. Output during 1993 represented a 27-fold increase over production achieved in 1979.

Newmont Gold Co. (NGC), with gold mining operations generally centered in Eureka and Elko Countries, was again Nevada's and the Nation's largest gold producer. NGC's operations consisted of five active surface mines, five mills, and three heap-leaching facilities. Total production during 1993 amounted to 51.8 tons (1.67 million ounces). As an extension of its current leaching operations, NGC conducted successful field tests confirming the commercial viability of a patented bioleaching process to recover gold from low-grade sulfide-bearing materials that previously could not be treated economically.

Trailing behind NGC, Barrick Goldstrike Mines Inc., a wholly owned subsidiary of American Barrick Resources Corp., recovered 44.8 tons (1.4 million ounces) of gold from its Betze-Post Mine in Eureka County. The Betze-Post operation is part of the company's Goldstrike property. Development work at the company's underground Miekle Mine, north of the Betze-Post Mine, continued during the year. Production was expected to begin at the Miekle property in late 1996.

At the Jerritt Canyon Mine, northwest of Elko, Independence Mining Co. and FMC Gold Co. produced about 11.2 tons (360,000 ounces) of gold, an increase of about 13% over production achieved during the previous year. Plans were to shift the mine's operations from surface mining to underground mining—the New Deep Mine. Independence also continued gold mining operations at its nearby Big Springs open pit.

In eastern Humboldt County, Santa Fe Pacific Gold Corp. (SFPG), through an exchange of mineral assets with Gold Fields Operating Co., acquired Gold Fields' Chimney Creek Mine. Following the exchange, mining operations at Chimney Creek and Rabbit Creek were combined to form a single operation renamed the Twin Creeks Mine. SFPG's other Humboldt County gold mine, the Lone Tree Mine, located near Valmy, produced nearly 5 tons (160,000 ounces) of gold by heap leaching during the year. Nearby FirstMiss Gold Inc. began underground development at its open pit Getchell Mine where the company first began heap leaching in 1985 and expanded to include milling and autoclave pressure oxidation in 1988. Cumulative production near yearend amounted to almost 1 million ounces (31 tons). Other operating gold mines in Humboldt County included the Crowfoot/Lewis Mine, Marigold Mine, Pinson Mine, and Sleeper Mine.

Mining operations at the Battle Mountain Complex, in Nye County, were cut back in early 1993 following depletion of the high-grade ore at Battle Mountain Gold Co.'s Fortitide deposit. The company continued to move forward with the design and permitting of its new 1,560-kg-per-year (50,000-ounce-per-year) Reona heap-leach project. Work was continued at its recently discovered Phoenix mining project.

South of Battle Mountain's operations, the McCoy/Cove gold and silver property of Echo Bay Mines Ltd. achieved another year of record production for both metals. Gold production rose 31% to 12.3 tons (395,608 ounces). Exploration during the year replaced 86% of the reserves that had been mined during the year.

Along the Lander County/Eureka County line southeast of McCoy/Cove, the Cortez Gold Mine Joint Venture produced about 2,080 kg (66,852 ounces) of gold at its Cortez Mine. The partners also completed a feasibility study of the Pipeline gold deposit and continued exploration at the nearby South Pipeline project. Discovery of the Pipeline deposit sparked a flurry of exploration and claim staking in the Crescent Valley area.

At Round Mountain in north-central Nye County, Round Mountain Gold Corp. produced nearly 11.7 tons (374,696 ounces) of gold at its open pit and heap-leaching operations. A small amount of gold, about 0.5% of the total, was recovered at the Manhattan mine and mill site at the nearby town of Manhattan.

At Lac Minerals Ltd.'s wholly owned Bullfrog Mine near Beatty in southern Nye County, 11 tons (354,887 ounces) of gold was mined during 1993, a nearly 10% increase over that of the previous year. Bullfrog's new underground mine reached full production in early 1993.

In Mineral County, mining was completed at Corona Gold Inc.'s Santa Fe Mine. Limited residual metal production from the heap leach was expected in 1994 and reclamation was expected to be completed in 1996. Nearby, Kennecott Rawhide Mining recovered about 3,300 kg (105,000 ounces) of gold at its Denton Rawhide Mine. Other Mineral County gold mines include Nevada Goldfields Inc.'s Aurora Mine and Minerex Resources Ltd.'s Aurora Partnership Mine. Respective production at these two operations amounted to about 270 kg (8,600 ounces) and 940 kg (30,120 ounces) in 1993.

South Carolina.—Three out of four gold mines brought into production in South Carolina over the past decade produced gold during 1993. Two mines recovered gold from ore mined during the year, and the third, the Brewer Mine in Chesterfield County, produced some residual gold from ore mined prior to the suspension of mining operations in late 1992. Operations at the State's fourth gold mine, the Haile Mine in Lancaster County, were suspended in mid-1991 to allow time to develop a new mine plan.

South Carolina's largest gold mine in 1993 was Kennecott Ridgeway Mining Co.'s Ridgeway Mine, an open pit and milling operation in Fairfield County. Ridgeway mined 4,260 kg (137,000 ounces) of gold during 1993. At the Barite Hill Mine in McCormick County, surface mining and heap-leaching operations recovered nearly 30% more gold than during the previous year. The mine, owned and operated by Consolidated Nevada Goldfields Corp., yielded 623 kg (20,044 ounces) of gold during the company's fiscal year ending June 30. The company estimated that the property will be mined out during fiscal year 1995. Plans for a safe and effective site decommissioning had begun.

Exploration was continued at the Haile Mine. During the year, the Haile Mining Venture conducted drilling, engineering, and environmental studies. Gold mining has been conducted intermittently on the Haile property since 1829.

South Dakota.—The Nation's largest underground mine was the Homestake Mine at Lead, SD. During the year, this 116-year-old operation produced nearly 14 tons (447,593 ounces) of gold, a 13% increase over 1992 production. According to Homestake Mining Co., the increase was due primarily to higher grades of ore mined and by employing selective mining techniques. Homestake also began expanded and accelerated stripping operations at its Open Cut surface mine to provide its uninterrupted feed to the mill. The Open Cut is a pit developed on the site of the original 1876 Homestake gold strike.

Wharf Resources Ltd. operates South Dakota's second largest gold mine, the Wharf Mine, west of Lead. This wholly owned operation produced a record 3,200 kg (102,381 ounces) of gold during 1993. Regulatory approvals were received in early 1993 to increase the mine's annual open pit mining rate to about 4.1 million tons. The company's 60%-held Gold Reward open pit mine adjacent to the Wharf Mine produced about 1,100 kg (35,549 ounces) of gold. Dakota Gold Mining Inc. a subsidiary of Dakota Mining Corp., (formerly MinVen Gold) holds the remaining 40% interest in the Golden Reward property.

At Dakota Mining's Gilt Edge Mine, open pit mining of permitted oxide ore reserves was completed; leaching of ore already on the pad continued through the year, yielding nearly 300 kg (9,423 ounces) of gold.

At the Richmond Hill Mine, Lac Minerals Ltd. continued leaching ore mined prior to a State Department of Environment and Resources-mandated cessation of mining in July 1992. The termination of mining coincided approximately with the depletion of minable ore reserves, and leaching operations ceased permanently in December. Total gold production for the year amounted to about 330 kg (10,716 ounces).

Utah.—Kennecott Corp.'s Bingham

Canyon Mine, where gold is produced as a byproduct of copper mining operations, has long been Utah's largest gold producer as well as one of the Nation's leading gold-producing mines. During 1993, Kennecott mined 16 tons (516,000 ounces) of gold from Bingham Canyon. Kennecott also operated the nearby Barneys Canyon Mine, in Salt Lake County, where production during the year amounted to about 3,330 kg (107,000 ounces) of gold.

Utah's largest primary gold mine, American Barrick's Mercur Mine in Tooele County, produced about 3,570 kg (114,761 ounces) during the year, a decline of about 5% from that of the previous year. Other producing gold mines in Utah during 1993 included USMX's Goldstrike Mine in Washington County where, despite severe winter conditions, about 990 kg (31,984 ounces) of gold was recovered, and North Lily Mining Co.'s Silver City Joint Venture, a heap-leaching operation in Juab County.

Washington.—In terms of value and the number of people employed, gold was Washington State's most important metallic mineral commodity. USBM data of gold production in the State as well as the Washington State Division of Geology and Earth Resources (DGER), in its annual review of Washington's mineral industry,[5] indicated that combined gold production by Washington's three major gold mining operations—the Cannon Mine, the Kettle River Project, and the Republic Unit—amounted to about 7,100 kg (228,509 ounces) during 1993. When compared with similar data for 1992, a decline of nearly 20% was indicated.

The Cannon Mine in Chelan County was again the State's largest gold producer. According to the DGER, this underground facility, at Wenatchee, produced 3,280 kg (105,477 ounces) of gold during 1993.

At Hecla Mining Co.'s Republic Unit near Republic in Ferry County, gold production for the year amounted to about 1,543 kg (49,601 ounces). Most of the production came from the Mine's Golden Promise deposit, which is scheduled for depletion in early 1995 unless more ore is discovered. The Republic Unit, formerly known as the Knob Hill Mine, has been producing gold and silver for nearly 60 years.

Also in Ferry County, Echo Bay produced about 2,280 kg (73,431 ounces) of gold at it wholly owned Kettle River Project. The property was developed around five separate deposits, four of which have been mined to date, with one, the Overlook deposit, scheduled for further work in 1994. The Key East and Key West deposits were mined out in 1993 as planned, and land reclamation programs were under way at both by yearend. A fifth deposit, the Lamefoot, was being developed for production in 1994 together with a small area of high-grade ore discovered near the Key West pit.

In Okanogan County, near Chelan, Battle Mountain Gold, the operator, and Crown Resources Group continued development at their Crown Jewel property.

Wisconsin.—Kennecott Corp., through its wholly owned subsidiary Flambeau Mining Co., opened its new Flambeau Mine near Ladysmith in Rusk County, WI. The new copper mine will produce gold and silver as byproducts. All metal values were recovered from concentrates processed in Canada.

World Review

World gold mine output continued to increase, with 1993 marking the 15th consecutive year of growth. Gold Fields Mineral Services Ltd. (GFMS),[6] in its latest annual statistical review of world gold supply and demand, noted that the 1993 increase in Western World mine production represented the lowest rate of increase since production started to rise in 1980. The report revealed that the strongest rate of production growth was seen shifting toward nations in the developing world, especially Asia and Latin America where modernization of mining codes, the greater availability of relatively unexplored land, and increasingly attractive investment climates have enticed increased funds for exploration and development. Data on other components of supply, including old gold scrap and net sales of gold to the market from Western World central banks, also registered increases, with improved, albeit volatile, metal prices after the first quarter of the year as the principal stimulant. Despite a substantial increase in gold demand for investment purposes, GFMS data indicated a 7% overall decline in gold used in fabricating jewelry products, the first decline since 1986. Moderate increases of 9% and 11%, respectively, were registered for the use of gold in electronics and for other industrial or decorative uses, including the increased use of gold in official coins, where a 34% increase was largely attributed to a special issue in Japan of 2 million gold coins commemorating the wedding of the Crown Prince.

Australia.—For the second consecutive year, Australia was the world's third largest gold-producing nation behind the Republic of South Africa and the United States. Australia's largest gold-producing State was Western Australia, where numerous gold mines, generally situated within three principal goldfields developed around and west of Kalgoorlie, produced about 183 tons (5.9 million ounces) of gold during 1993.

In midyear, the 7th Australian Gold Mining Conference was held at the Kalgoorlie School of Mines, in Kalgoorlie. The conference celebrated the July 1893 discovery of gold in Western Australia. The Super Pit at Kalgoorlie, Australia's largest gold mine, incorporates the workings of several previously separate mines into one large operation.

Other Australian gold-producing States and Territories, in descending order of output, were Queensland, the Northern Territory, New South Wales, Victoria, Tasmania, and South Australia. During 1993 several new gold mines reportedly began production, including the Kanowna Belle Mine near Kalgoorlie, Zapopan N.L.'s Mount Todd Mine, 290 km (180 miles) south of Darwin in the Northern Territory, and Reynolds Metals Co.'s new underground mine at its Boddington operations southeast of Perth, Western Australia.

Canada.—A review of Canadian gold developments was prepared by the Canadian Department of Energy, Mines and Resources (EMR).[7] There were about 50 primary gold mines in Canada at the end of 1993, and these mines, along with placer operations, accounted for 89% of the gold produced. The remaining 11% of production was gold derived from base metal mines. Six gold mines began or resumed operations during the year, including the Keystone Mine in the Province of Manitoba and the following five mines in the Province of Quebec: Astoria, Casa Berardi Est, Granada, Portage, and Rand. Two gold mines in Quebec were closed during the year owing to exhaustion of reserves.

Canada's dominant gold-producing jurisdiction was again the Province of Ontario, which produced about 28% of the nearly 153 tons (4.9 million ounces) of total Canadian production. Three large underground mines in the Hemlo area accounted for nearly 50% of the Ontario total. Other Canadian Provinces and Territories producing gold in 1993 were, in decending order of output, Quebec, British Columbia, Northwest Territories, Yukon, Manitoba, New Brunswick, and Alberta. Gold also was produced in Newfoundland and Saskatchewan; however, data on production in these Provinces were withheld to avoid disclosing company proprietary data.

Latin America.—Over the past 4 or 5 years there has been an increasing level of interest in Latin American and Caribbean nations. In many Latin America countries, the recent ongoing liberalization of mining codes and the lowering or removal of political and economic barriers have increasingly served to attract foreign mining interests. Many of the companies involved in the exploration, acquisition, and development of Latin American and Caribbean gold projects, or seeking opportunities there, are based in North America. Two studies released during the year examined the reasons behind this recent surge in activity as well as various factors leading to the successful entry of foreign corporations into the region.[8]

Areas of Latin American receiving much of the attention in recent years have been Chile, Mexico, Peru, and the Guyanan Shield area of Guyana and Venezuela, especially around the "Kilometer 88" area of eastern Venezuela. In Esequibo County in western Guyana, commercial production was begun at Cambior Inc.'s 60%-held Omai Mine. Annual production at the new open pit operation is expected to be about 8.7 tons (280,000 ounces) of gold.

In May, the President of Argentina signed that nation's new Federal Mining Agreement. North American companies initiating gold exploration or mine development projects in Argentina during the year included Crown Resources Corp., of Golden, CO; San Francisco-based American Resources Corp.; and International Musto Exploration Ltd. of Toronto, Canada.

Brazil is Latin America's largest gold-producing nation. Reflecting the apparent exhaustion of easily worked surface and placer gold by independent gold miners, or "garimpeiros," production declined in 1993.

In Bolivia's Altiplano, southwest of La Paz, Empresa Mineral Inti Rami began production at its newly expanded Kori Kolo Mine. Annual gold production is expected to be about 7.6 tons (245,000 ounces).

Gold production in the Caribbean area was limited to that produced by Rosario Dominicana S.A. at its Pueblo Viejo Mine in the Dominican Republic. Exploration for gold in the Caribbean region in 1993 was conducted largely in the Republic of Cuba, the Dominican Republic, Jamaica, and the Commonwealth of Puerto Rico. Various nations in Central America continued to produce small amounts of gold, and exploration and mine development activities continued to be pursued, particularly in Costa Rica and Panama.

Gold production in Chile increased for the sixth consecutive year. In early 1993, Amax Gold Inc. began production at its newly expanded Guanaco Mine. Commercial production at the expanded operation was expected to yield up to 2,500 kg (80,000 ounces) per year. El Indio, Chile's largest gold mine, 83%-owned by Lac Minerals Ltd., produced about 6,232 kg (200,355 ounces) of gold during the year.

In early 1993, a landslide struck the remote gold rush town of Nambija, in the Loja Province of Ecuador, killing or injuring many of the residents. An estimated 2,000 to 3,000 unregulated gold miners operate mines at the remote site, about 390 km (240 miles) south of Ecuador's capital city of Quito.

In Mexico, at least two new gold mines were opened and two more reached the final stages of development. In late 1993, Exall Resources Ltd. reportedly began placer gold mining operations on its Rio Yaqui projects on the Yaqui River in the State of Sonora. Later, Australian-based Walhalla Mining Co. dedicated its new Amelia Mine, an open pit and heap-leaching operation, also in Sonora. Construction at two other open pit and heap-leaching mines in Sonora, Eldorado Corp. Ltd.'s La Colorada Mine and Hecla Mining Co.'s La Choya Mine, was nearly complete at yearend.

Estimated gold production in Peru, as shown in table 11, was revised substantially to reflect more reliable information on the performance of the formal and informal mining sectors. In late 1993, Newmont Mining Corp.'s Minera Yanacocha Mine near Caja Marca began production at a rate of about 6,842 kg (220,000 ounces) annually. Yanacocha was Peru's second largest gold-producing mine during 1993. Peruvian Government efforts to attract foreign investment in mining as well as privatization of Government-owned mining interests accelerated during the year.

Production was begun at American Resources Corp.'s Mahoma gold mine and milling operation in Uruguay. The new open pit operation, about 100 km (62 miles) northwest of Montevideo, is expected to recover about 1,244 kg (40,000 ounces) of gold per year.

Oceania.—Following three successive years of increased gold production, Papua New Guinea's 1993 production declined 15% from production achieved during the previous year. Sharp declines in production, apparently a reflection of lower grades of ore processed, were registered at Placer Pacific Ltd.'s Porgera Mine in Enga Province and its Misima Mine in Milne Bay Province. Production increased at the Ok Tedi copper-gold mine and at the Mount Kare alluvial mine, both in Enga Province. Development of the large Lihir Island project off the east coast of New Ireland continued, while exploration moved ahead at various exploration projects such as Tolukuma, Woodlark Tabar Island, Wild Dog, and others. The giant Bougainville copper and gold mine on Bougainville Island remains closed. Law and order problems continued to plague some remote exploration projects.

In West Irian, on the Indonesian side of the island of New Guinea, Freeport Indonesia, Inc. recovered 24.5 tons (786,700 ounces) of byproduct gold at its large Grasberg/Ertsberg copper and gold deposit, an increase of 23% over that of the previous year. Ongoing exploration and project expansion continued to enhance prospects for increased production. In the Province of East Kalimantan, PT Kelian Equatorial Mining's Kelian open pit mine completed its first full year of production and recovered about 14.4 tons (464,000 ounces) of gold. Newmont Indonesia continued exploration projects on the Island of Sulawesi and on the Island of Sumbawa. Raw gold as well as gold jewelry fabricated by a growing domestic manufacturing sector continued to be important Indonesian export products.

In addition to three large New Zealand gold mines—the Golden Cross and Waihi Mines on North Island and the largest mine, the Macraes Mine on South Island—a new placer mine, the Island Block Mine, began production in late 1993 in the central Otago region of South Island.

Other Asia.—Gold production in the Philippines declined 36% from that of the previous year. The Philippine's oldest company, the Benguet Corp., following suspension of operations at its Paracale gold operations in southern Luzon, began a previously announced phased shutdown of its underground Acupan and Balatoc Mines in northern Luzon. Atlas Consolidated Mining and Development Co. ceased operations at its Masbate Mine on Masbate Island. Philex Mining Corp. continued development at its Bulawan gold project on Negros Island where production is set to begin in early 1995.

Interest in gold in China continued to increase during the year. New laws were prepared to encourage participation by foreign companies. Twice during the year the Chinese Government increased the official price paid to Chinese gold miners for their product. The increases were reportedly aimed at helping mines meet rising production costs and to discourage smuggling and sale of gold outside official channels. There are reportedly about 500 gold mines in China. Shandong Province is the largest gold producer, accounting for about 25% of current production.

The emergence of China as a large gold-consuming nation increasingly favors the development of a domestic jewelry industry where Chinese mined products such as gold, diamonds, and colored stones plus a skilled work force and low wage rates have been combined to produce products for domestic and international consumption. An overview of the Chinese jewelry industry focusing on the potentials and pitfalls of foreign participation was published in 1993.[9]

To encourage local jewelry production, Malaysia abolished its 5% import duty on gold bullion and coins.

Gold exploration activity continued to expand throughout much of Asia during 1993 and included reports of activity in the nations aforementioned as well as other nations such as Burma, Japan, and Laos.

Russia and the Former U.S.S.R.—At least seven independent countries resulting from the dissolution of the U.S.S.R. in late 1991 were gold producers in 1993. Russia continues to be the dominant gold-producing country in the former U.S.S.R., with much of the gold production originating from mines in Magadan-Chukotski Peninsula region of eastern Russia. According to Gold Fields,[10] despite an increase during 1993 in the official price paid for domestic production, extended delays in payment by the state resulted in greater quantities of gold being sold outside of state-administered markets.

A report documenting the significant mineral deposits of the Russian Northeast and their relationship to similar deposits to the east in Alaska was released in 1993.[11] Foreign corporate mining interest in exploring and developing gold properties in the former U.S.S.R. continues to build. In late 1993, the Zarafshan-Newmont Joint Venture broke ground at its new gold recovery project in the Republic of Uzbekistan. In early 1993, MK Gold Co. formed a joint venture with the Republic of Kyrgystan to develop the Jerooy Gold Project in the Talas region of the republic. Later, Cyprus Amax Minerals Co. formed a joint venture with Russian partners to develop the Kubaka gold field in the Magadan region of eastern Russia.

South Africa, Republic of.—Despite earlier predictions of declining South African gold mine performance, production increased for the third consecutive year. The increase, albeit marginal at about 1%, again was attributed to an improvement in the average recovery grade of ore mined from 5.37 grams per ton (0.157 ounce per short ton) in 1992 to 5.56 grams per ton (0.162 ounce per short ton) during 1993. The tonnage of ore milled by the nearly three dozen mines representing the membership of the Chamber of Mines of South Africa declined about 3% during 1993 to about 103 million tons. This was the fourth consecutive year in which a decline in the volume of ore milled was registered.

The South Africa gold mining industry is dominated by six major corporate groups or "houses." Listed on the basis of 1993 production they were as follows: the Anglo American Corp. of South Africa Ltd. (AAC), Gold Fields of South Africa Ltd., Gencor Ltd., Johannesburg Consolidated Investment Co. Ltd., Anglovaal Ltd., and Rand Mines Ltd. Anglo American, the largest of the corporate groups, produced 267 tons (8.6 million ounces) of gold from seven separate mining operations, including its large Freegold Mine, South Africa's largest gold mine, which produced about 122 tons (nearly 4 million ounces) of gold and the nation's second largest gold mine, AAC'S Vaal Reefs Mine, where 80 tons (2.6 million ounces) of gold was recovered during 1993. During the year, underground mining operations were terminated at Gencor's Bracken Mine in the Evander area of the Orange Free State.

The number of workers employed at South African gold mines continued to decline during the year, reportedly reaching 360,000 by yearend. The work force numbered about 535,000 in 1986.

Current Research

The USBM maintained nine research centers throughout the Nation, and most conducted research into various aspects of mining and extractive metallurgy that may be directly or indirectly beneficial to the gold mining industry.[12] Because gold mining is pursued in many nations, the results of the ongoing work may, like the USBM's earlier work in heap leaching, ultimately benefit a broad segment of the industry worldwide. In recent years, the USBM's research relating to gold mining has generally focused on advanced mining techniques and the use of cyanide in the recovery process. The USBM addressed several questions regarding the use of cyanide, including such topics as the mass balance of cyanide in the leaching process, the mobility of metals in the heap during heap leaching, the persistence of cyanide in the environment, alternatives to cyanide, and reclamation of mining sites where cyanide had been employed. The USBM also was investigating the leaching of metals from very low-grade ores with the aid of biotechnology. Bioleaching research for precious metals focused on a preleach treatment of precious-metal-bearing sulfide ores.

OUTLOOK

If the final outcomes of the current debate over the proposed revision to the General Mining Law are deemed to be acceptable and affordable by domestic gold producers and encourage continued exploration for new domestic gold deposits, domestic gold reserves production should continue to increase, albeit at a much lower rate than the explosive growth in gold production and reserves seen during the decade of the 1980's. If, on the other hand, the new law places unacceptable burdens on producers and reduces the incentive to explore, production could decline substantially as existing deposits are high graded wherever possible, or reclassified as uneconomic, and both producers and explorationists move to pursue opportunities in more hospitable environments elsewhere. According to data prepared by the Gold Institute, world gold production is projected to increase at a rate of about 1.6% annually through 1997.[13]

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[1] Ounce refers to troy ounce. One kilogram of gold weighs 32.1507 troy ounces.

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[7] Couturier, G. Gold. Advance Copy of Ch. from Canadian Minerals Yearbook—1993. 15 pp.

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[9] Plotnick, M. Made in China. Am. Jewelry Mfr., v. 38, No. 7, July 1993, pp. 32-48. Publ. by The Manufacturing Jewelers and Silversmiths of Am. Inc., Providence, RI 02903.

[10] Work cited in footnote 6.

[11] Nokleberg, W. J., T. K. Bundtzen, and others. Metallogenesis of Mainland Alaska and the Russian Northeast. U.S. Geol. Surv. Open-File Report 93-339, 22 pp., 6 maps. Available from U.S.G.S., Earth Sci. Info. Ctr. and Op. File Report Sales, P.O. Box 25286, Denver, CO 80225-0286. $48.

[12] U.S. Bureau of Mines. Research 1993. BuMines, 1993, 164 pp.

[13] The Gold Institute. World Mine Production of Gold 1993-1997. May 1994, 9 pp.

TABLE 1
SALIENT GOLD STATISTICS

		1989	1990	1991	1992	1993
United States:						
Mine production	kilograms	265,731	294,189	[r]294,062	[r]330,212	331,013
Value in dollars per troy ounce	thousands	$3,268,553	$3,640,820	[r]$3,434,652	[r]$3,662,390	$3,840,876
Percentage derived from:						
Precious-metal ores		W	W	W	W	W
Base metal ores		W	W	W	W	W
Placers		2	1	1	1	1
Refinery production:						
Domestic and foreign ores	kilograms	183,685	225,183	224,675	283,951	243,135
Secondary (old scrap)	do.	[r]51,943	[r]43,980	[r]48,088	53,396	65,964
Imports for consumption:						
Refined	do.	96,967	64,755	147,491	141,251	130,045
Other	do.	55,537	32,764	31,258	33,089	39,260
Exports:						
Refined	do.	123,599	140,923	174,377	256,845	658,120
Other	do.	87,492	155,474	109,750	112,006	143,890
Gold contained in imported coins[1] [2]	do.	13,218	8,429	3,514	NA	NA
Net deliveries from foreign stocks in Federal Reserve Bank	do.	132,231	51,464	61,595	136,389	582,246
Stocks, Dec. 31:						
Industry[3]	do.	30,462	37,065	39,411	36,713	32,728
Futures exchange[4]	do.	69,727	50,881	49,893	46,453	78,514
Volume of U.S. Gold Futures Trading[5]	metric tons	31,065	30,260	21,200	18,669	25,493
Department of the Treasury:[6]						
American Eagle gold coin[7]	kilograms	16,544	17,397	13,713	11,133	21,845
Other Numismatic gold coins	do.	1,349	695	952	965	2,246
Consumption in industry and the arts	do.	115,078	[r]118,216	[r]114,375	[r]110,410	90,411
Price:[8] Average per troy ounce		$382.58	$384.93	$363.29	$344.97	$360.91
Employment[9]		15,100	16,100	15,100	[r]14,800	14,700
World:						
Production, mine	kilograms	[r]2,013,913	[r]2,182,307	[r]2,187,462	[r]2,298,809	2,330,321
Official reserves[10]	metric tons	[r]35,603	[r]35,572	[r]35,501	[r]35,199	34,632

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

[1] Calculated by the Gold Institute from reports by the Bureau of the Census.

[2] Net imports (exports).

[3] Unfabricated refined gold held by refiners, fabricators, dealers, and U.S. Department of Defense.

[4] Commodity Exchange Inc. only. Stocks held by other exchanges estimated to be less than 2% of totals shown.

[5] Exchanges: Commodity Exchanges Inc., and Mid-America Commodity Exchange.

[6] Sales to market fiscal year 1989-1990. Fiscal year begins Oct. 1, of previous year indicated. Gold bullion disbursements to U.S. Mint coin programs fiscal 1991.

[7] Sales program began Oct. 20, 1986.

[8] Engelhard Industries quotation.

[9] Mine Safety and Health Administration.

[10] Held by market economy country central banks and governments and international monetary organizations. Source: International Monetary Fund.

TABLE 2
MINE PRODUCTION OF GOLD IN THE UNITED STATES, BY STATE

(Kilograms)

State	1989	1990	1991	1992	1993
Alaska[1]	5,756	3,232	3,200	5,003	2,777
Arizona	2,768	5,000	6,195	6,656	2,711
California	29,804	29,607	30,404	33,335	35,763
Colorado	3,448	2,357	3,181	3,763	W
Idaho	3,057	W	3,348	[r]4,037	W
Montana[2]	12,434	13,012	13,715	13,994	14,325
Nevada	153,995	179,078	[r]178,488	[r]203,393	210,763
New Mexico	1,076	888	W	W	995
South Carolina	W	W	W	6,747	W
South Dakota	16,123	17,870	16,371	18,681	19,241
Washington	W	9,620	9,954	8,802	7,108
Total[3]	265,731	294,189	[r]294,062	[r]330,212	331,013

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1] These figures, reported to the U.S. Bureau of Mines, probably understate production. Data collected by the State indicate production to have been as follows, in kilograms: 1989—8,852; 1990—7,206; 1991—7,585; 1992—8,163; and 1993—5,946.

[2] In addition to reported data shown in the table, placer production was estimated by the State to have been as follows, in kilograms: 1992—84; and 1993—6.

[3] Includes, for at least some of the years 1989-93, Michigan, Oregon, Utah, and Wisconsin.

TABLE 3
TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of gold
1	Carlin Mines Complex	Eureka, NV	Newmont Gold Co.	Gold ore.
2	Goldstrike	do.	Barrick Goldstrike Mines Inc.	Do.
3	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Corp.	Copper ore.
4	Twin Creeks	Humboldt, NV	Santa Fe Pacific Gold Corp.	Gold ore.
5	Homestake	Lawrence, SD	Homestake Mining Co.	Do.
6	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Do.
7	Smokey Valley Common Operation	Nye, NV	Round Mountain Gold Corp.	Do.
8	Jerritt Canyon (Enfield Bell)	Elko, NV	Independence Mining Co. Inc.	Do.
9	Bullfrog	Nye, NV	LAC Minerals	Do.
10	Mesquite	Imperial, CA	Santa Fe Pacific Gold Corp.	Do.
11	McLaughlin	Napa, CA	Homestake Mining Co.	Do.
12	Getchell	Humboldt, NV	FMG Inc.	Do.
13	Lone Tree	do.	Santa Fe Pacific Gold Corp.	Do.
14	Paradise Peak	Nye, NV	FMC Gold Co.	Do.
15	Castle Mountain	San Bernardino, CA	Viceroy Gold Corp.	Do.
16	Ridgeway	Fairfield, SC	Kennecott Ridgeway Mining Co.	Do.
17	Golden Sunlight	Jefferson, MT	Placer Dome Golden Sunlight Mines Inc.	Do.
18	Mercur	Tooele, UT	Barrick Goldstrike Mines Inc.	Do.
19	Florida Canyon	Lander, NV	Pegasus Gold Inc.	Do.
20	Zortman-Landusky	Phillips, MT	do.	Do.
21	Cannon	Chelan, WA	Asamera Minerals (U.S.) Inc.	Do.
22	Denton-Rawhide	Mineral, NV	Kennecott Rawhide Mining Co.	Do.
23	Wharf	Lawrence, SD	Wharf Resources LTD	Do.
24	Sleeper	Humboldt, NV	Amax Inc.	Do.
25	Barney's Canyon	Salt Lake, UT	Kennecott Corp.	Do.

TABLE 4
GOLD PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (kilograms of gold)	Lode			
		Gold ore		Silver ore	
		Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1989	5,711	169,380,297	236,207	W	W
1990	2,579	199,123,615	271,930	W	W
1991	2,888	[r]217,290,669	[r]269,095	W	W
1992	4,727	[r]238,794,625	[r]300,727	W	W
1993:					
Alaska	W	—	—	—	—
Arizona	—	W	W	—	—
California	W	28,183,004	35,268	—	—
Colorado	—	W	W	—	—
Idaho	—	W	W	—	—
Montana	—	15,372,375	12,138	—	—
Nevada	W	170,590,673	210,557	(2)	W
New Mexico	—	—	—	—	—
South Carolina	—	W	W	—	—
South Dakota	—	4,309,259	19,241	—	—
Utah	—	6,065,791	7,639	—	—
Washington	—	472,759	7,108	—	—
Wisconsin	—	—	—	—	—
Total	3,042	238,720,555	305,185	W	W
Percent of total gold	1	XX	92	XX	W

	Lode				Total	
	Copper ore		Other[1]			
	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold	Metric tons	Kilograms of gold
1989	210,474,747	17,620	W	W	391,059,545	265,731
1990	156,175,612	W	W	W	362,624,535	294,189
1991	196,307,948	W	W	W	[r]422,714,476	[r]294,062
1992	[r]200,441,384	W	W	W	[r]453,159,261	[r]330,212
1993:						
Alaska	—	—	W	W	W	2,777
Arizona	172,356,080	1,830	W	W	172,680,561	2,711
California	—	—	7	W	28,183,011	35,763
Colorado	—	—	W	W	3,628,225	W
Idaho	—	—	W	W	W	W
Montana	W	W	W	W	35,215,778	14,325
Nevada	—	—	(2)	W	170,590,673	210,763
New Mexico	16,948,579	994	4,725	1	16,953,304	995
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	—	4,309,259	19,241
Utah	W	W	—	—	W	W
Washington	—	—	—	—	472,759	7,108
Wisconsin	W	W	—	—	W	W
Total	200,467,384	W	W	W	500,051,235	331,013
Percent of total gold	XX	W	XX	W	XX	100

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

[1] Includes gold-silver, lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

[2] Withheld to avoid disclosing company proprietary data; included in "Gold ore."

TABLE 5
LODE GOLD PRODUCED IN THE UNITED STATES, BY STATE AND METHOD OF RECOVERY

Year and State	Cyanidation		Smelting of concentrates			Smelting of ore		Other processes[1]		Total ore processed[2] (metric tons)	Total gold recovered (kilograms)
	Ore treated (metric tons)	Gold recovered (kilo-grams)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Gold recovered (kilo-grams)	Ore smelted (metric tons)	Gold recovered (kilo-grams)	Ore treated (metric tons)	Gold recovered (kilo-grams)		
1989	172,294,506	228,040	189,266,803	3,827,109	30,283	W	W	W	W	391,059,545	265,731
1990	197,583,498	264,494	163,749,630	3,649,072	25,828	W	W	W	W	362,624,535	294,189
1991	[r]220,059,224	[r]264,154	[r]201,400,053	[r]3,910,870	24,482	W	W	W	W	[r]422,714,476	[r]291,175
1992	[r]245,102,271	[r]298,107	[r]204,789,915	[r]3,997,432	22,806	W	W	W	W	[r]453,159,261	[r]325,485
1993:											
Alaska	—	—	W	W	W	—	—	—	—	W	[3]2,777
Arizona	W	W	172,356,080	2,937,934	1,830	W	W	—	—	172,680,561	2,711
California	28,183,011	35,763	—	—	—	—	—	—	—	28,183,011	[3]35,763
Colorado	3,426,976	3,820	W	W	W	W	W	—	—	3,628,225	W
Idaho	W	W	W	W	W	—	—	—	—	W	W
Montana	15,372,375	12,138	W	W	W	—	—	W	W	35,215,778	14,325
Nevada	170,590,673	210,763	—	—	—	—	—	—	—	170,590,673	[3]210,763
New Mexico	—	—	16,915,415	432,605	961	37,889	34	—	—	16,953,304	995
South Carolina	W	W	—	—	—	—	—	—	h	W	W
South Dakota	4,309,259	19,241	—	—	—	—	—	—	—	4,309,259	19,241
Utah	6,065,791	7,639	W	W	W	—	—	—	—	W	W
Washington	461,122	6,929	11,780	915	179	—	—	—	—	472,759	7,108
Wisconsin	—	—	—	—	—	W	W	—	—	W	W
Total	238,706,742	305,051	260,343,747	4,743,501	20,856	W	W	W	W	500,051,235	327,971

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total," where applicable.

[1] Includes metal recovered by gravity methods.

[2] Includes old tailings and some nongold-bearing ores not separable, in amounts ranging from 0.15% to 0.25% of the totals for the year listed.

[3] Includes some placer production to avoid disclosing company proprietary data.

TABLE 6
GOLD PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

Year	Extraction in vats, tanks, and closed containers		Leaching in open heaps or dumps[2]	
	Ore treated (metric tons)	Gold recovered[3] (kilograms)	Ore treated (metric tons)	Gold recovered[4] (kilograms)
1989	42,464,260	121,716	129,830,246	106,324
1990	47,614,538	135,764	149,968,960	128,730
1991	[r]45,606,862	[r]160,379	[r]174,452,362	[r]103,775
1992	[r]56,099,112	[r]177,658	[r]189,003,159	[r]120,449
1993	54,698,929	176,684	184,007,813	128,367

[r] Revised.

[1] May include small quantities recovered by leaching with noncyanide solutions and by proprietary processes.

[2] May include tailings and waste ore dumps.

[3] May include small quantities recovered by gravity methods.

[4] May include metal recovered by leaching of previously mined ore at some inactive mines.

TABLE 7
U.S. REFINERY PRODUCTION OF GOLD

(Kilograms)

Raw material	1989	1990	1991	1992	1993
Concentrates and ores:					
Domestic and foreign	183,685	225,183	224,675	283,951	243,135
Old scrap	[r]51,943	[r]43,980	[r]48,088	53,396	65,964
New scrap	[r]105,756	[r]100,382	105,086	109,545	84,888
Total	[1]341,383	[r]369,545	[r]377,849	446,892	393,987

[r] Revised.

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

TABLE 8
U.S. CONSUMPTION OF GOLD,[1] BY END-USE SECTOR

(Kilograms)

End use	1989	1990	1991	1992	1993
Jewelry and the arts:					
Karat gold	60,877	[r]69,952	79,875	[r]79,381	60,514
Fine gold for electroplating	1,283	429	373	581	528
Gold-filled and other	7,364	8,132	[r]3,848	3,546	3,532
Total[2]	69,524	[r]78,514	[r]84,096	[r]83,508	64,575
Dental	7,927	8,700	8,485	6,543	6,173
Industrial:					
Karat gold	1,215	1,020	1,068	1,082	1,095
Fine gold for electroplating	20,684	17,251	12,624	10,476	9,094
Gold-filled and other	15,723	12,725	[r]8,102	8,802	9,474
Total[2]	37,621	30,996	[r]21,793	[r]20,360	19,663
Small items for investment[3]	7	7	—	—	—
Grand total[2]	115,078	[r]118,216	[r]114,375	[r]110,410	90,411

[r] Revised.

[1] Gold consumed in fabricated products only; does not include monetary bullion.

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

[3] Fabricated bars, medallions, coins, etc.

TABLE 9
U.S. EXPORTS OF GOLD, BY COUNTRY[1]

Year and country	Ores and concentrates[2]		Waste 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)
1989	16	$165	44,541	$542,150	42,935	$242,690	123,599	$1,490,115	211,091	$2,275,156
1990	328	3,721	66,943	729,150	88,203	413,980	140,923	1,719,470	296,397	2,866,320
1991	10	98	64,204	653,748	45,536	486,266	174,377	2,038,850	284,127	3,178,962
1992	30	221	60,968	548,873	51,008	518,661	256,845	2,877,377	368,851	3,945,133
1993:										
Belgium	54	539	[4]2,300	21,961	—	—	—	—	2,354	22,500
Brazil	—	—	—	—	—	—	499	5,452	499	5,452
Canada	102	925	[4]36,400	342,283	17,498	147,795	26,048	309,672	80,048	800,675
China	—	—	—	—	—	—	1,259	15,388	1,259	15,388
France	—	—	[4]3,600	33,948	17,535	192,611	5,540	65,892	26,675	292,451
Germany	—	—	[4]6	60,405	778	6,949	10,089	117,464	10,873	184,818
Hong Kong	—	—	[4]40	383	—	—	26,464	294,809	26,504	295,192
Israel	—	—	[4](5)	382	80	539	132	1,501	212	2,423
Italy	—	—	[4]1	5,709	192	2,013	177	2,181	370	9,907
Japan	—	—	[4](5)	810	487	3,998	4,581	50,625	5,068	55,434
Korea, Republic of	1	3	—	—	—	—	200	2,080	201	2,084
Mexico	—	—	[4](5)	4	304	1,370	6,939	80,251	7,243	81,626
Singapore	—	—	[4](5)	197	—	—	1,501	16,007	1,501	16,204
Sweden	—	—	[4]9,800	11,381	52	337	—	—	9,852	11,718
Switzerland	—	—	[4]5,100	47,745	25,342	273,514	217,489	2,513,382	247,931	2,834,641
Taiwan	—	—	—	—	3,117	34,130	30,127	340,994	33,245	375,124
Turkey	—	—	—	—	18	189	442	5,174	460	5,363
United Kingdom	51	358	[4]9,600	90,448	2,016	21,711	326,310	3,786,927	337,977	3,899,444
Other	8	55	[4](5)	33	78	350	322	3,519	408	3,952
Total	216	1,880	66,847	615,689	67,497	685,506	658,120	7,611,318	792,680	8,914,396

[1] Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary gold excluded.

[2] Includes gold content of base metal ores, concentrates, and matte destined for refining.

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

[4] Verification of Bureau of the Census export quantities was not possible for some months of 1993. Quantities shown are rounded estimates derived by dividing dollar values, which are believed to be accurate, by an estimated value for waste and scrap of $9,400/kg.

[5] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF GOLD, BY COUNTRY[1]

Year and country	Ores and concentrates[2]		Waste and scrap		Doŕe 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)
1989	2,426	$7,103	39,952	$115,685	13,159	$157,952	96,967	$1,198,734	152,504	$1,479,473
1990	5,346	8,355	23,173	206,975	4,245	50,635	64,755	795,007	97,519	1,060,971
1991	992	10,874	24,668	126,264	5,597	66,735	147,491	1,721,576	178,749	1,925,449
1992	351	3,877	15,649	66,376	17,092	175,542	141,251	1,568,186	174,341	1,813,984
1993:										
Argentina	—	—	136	1,535	—	—	187	2,312	324	3,847
Australia	—	—	(4)	(4)	—	—	457	5,427	457	5,427
Belgium	—	—	13	25	—	—	461	5,512	474	5,537
Bolivia	—	—	150	778	—	—	2,402	25,810	2,551	26,588
Brazil	—	—	23	233	—	—	521	6,254	544	6,489
Canada	—	—	2,569	13,590	11,514	124,717	100,609	1,159,593	114,692	1,297,900
Chile	—	—	159	431	377	4,284	3,779	41,896	4,315	46,611
Costa Rica	—	—	391	2,717	—	—	—	—	391	2,717
Dominican Republic	—	—	8,580	23,934	—	—	—	—	8,580	23,934
Ecuador	—	—	7	6	—	—	2,624	24,262	2,631	24,268
Germany	1	7	1,714	462	3	37	50	644	1,768	1,151
Guyana	—	—	394	2,346	—	—	130	1,369	524	3,716
Malaysia	—	—	2,409	2,681	—	—	—	—	2,409	2,681
Mexico	1,093	12,315	4,372	2,936	119	1,235	573	6,762	6,157	23,248
Panama	—	—	240	1,287	374	2,867	24	254	639	4,408
Peru	1	7	40	294	27	338	2,154	24,525	2,222	25,163
Philippines	(4)	(4)	2,146	312	(4)	(4)	—	—	2,146	312
South Africa, Republic of	—	—	15	109	—	—	5,164	62,897	5,179	63,006
Sweden	—	—	256	28	—	—	—	—	256	28
Switzerland	—	—	2	17	—	—	3,585	40,223	3,587	40,240
Taiwan	—	—	466	2,421	—	—	—	—	466	2,421
Trinidad and Tobago	—	—	510	6,465	—	—	244	2,635	754	9,100
Ukraine	—	—	275	37	—	—	—	—	275	37
United Kingdom	—	—	11	112	4	25	600	7,111	614	7,248
Uruguay	—	—	—	—	—	—	6,255	75,458	6,255	75,458
Other	146	1,202	604	2,604	121	1,401	228	2,490	1,096	7,697
Total[4]	1,240	13,531	25,480	65,360	12,539	134,904	130,045	1,495,434	169,305	1,709,230

[1] Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary gold excluded.
[2] Includes gold content of base metal ores, concentrates, and matte destined for refining.
[3] Data may not add to totals shown because of independent rounding.
[4] Less than a 1/2 unit.

Source: Bureau of the Census.

TABLE 11
GOLD: WORLD MINE PRODUCTION BY COUNTRY[1]

(Kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Argentina	1,150	[r]1,199	[r]1,510	[r][e]1,300	1,350
Armenia	—	—	—	[e]300	500
Australia	203,563	244,137	234,218	[r][e]243,400	247,196
Belize	—	1	[e]5	[e]5	2
Bolivia	3,595	5,198	[r]3,501	4,688	[3]10,403
Botswana[4]	[r]67	[r]46	20	[r]165	[3]192
Brazil[5]	[r]52,527	[r]101,913	[r]89,369	[r]85,862	85,000
Burkina Faso[e]	7,600	[r]7,800	[r]5,600	[r]5,400	5,000
Burundi	18	9	[e]25	[e]32	20
Cameroon	[r]15	[r]10	[r][e]10	[r][e]10	10
Canada	[r]159,527	[r]169,412	176,552	[r]161,402	[3]152,929
Central African Republic	328	241	176	[r]155	150
Chile	22,559	27,503	[r]28,879	[r]33,774	30,300
China[e]	90,000	100,000	120,000	140,000	160,000
Colombia	29,506	29,352	34,844	[r]32,118	[3]27,845
Congo	[r]6	7	12	5	5
Costa Rica[e] [6]	[3]387	460	550	550	600
Cote d'Ivoire	13	20	1,100	[r]1,500	1,500
Dominican Republic	5,238	4,354	3,160	[r]2,375	2,000
Ecuador	10,390	10,710	[r]12,200	[r][e]12,000	11,500
Ethiopia[7]	745	848	3,038	[r]2,224	3,000
Fiji	4,221	[r]4,116	[r]2,713	[r]3,847	[3]3,784
Finland	[r]2,510	2,813	2,200	[r]1,595	1,700
France	3,303	4,236	[r][e]3,060	[r]2,907	2,800
French Guiana	544	870	1,417	[r][e]2,400	3,100
Gabon[8]	81	[e]80	50	[r]70	[3]120
Georgia	—	—	—	[r][e]1,000	800
Germany:					
Eastern states	2,047	1,751	—	—	—
Western states[e]	16	18	—	—	—
Total	2,063	1,769	[e]10	—	—
Ghana	13,358	16,840	[r]26,311	[r]31,032	[3]39,235
Guatemala	48	62	31	[r]32	30
Guinea[9]	2,120	6,340	4,453	2,113	2,100
Guyana[e]	[r]1,300	[r]1,500	[r]1,844	[r]2,475	[3]9,614
Honduras	160	156	[r]180	[r][3]163	175
Hungary[e]	[r]600	[r]600	[r]500	[r]500	500
India[10]	1,827	1,983	1,973	[e]2,000	1,980
Indonesia[11]	6,155	11,158	16,879	37,983	[3]42,097
Iran[e]	400	500	[r]500	[r]500	[3]417
Japan	[r]6,097	7,303	8,299	8,893	9,100
Kazakhstan	—	—	—	[e]24,000	25,000
Kenya	15	25	[e]20	[e]20	20
Korea, North[e]	5,000	5,000	5,000	5,000	5,000
Korea, Republic of[10]	14,270	20,760	20,809	[r]23,263	25,000
Kyrgyzstan	—	—	—	[e]1,000	1,000
Liberia[e] [12]	[3]734	600	600	700	700

See footnotes at end of table.

TABLE 11—Continued
GOLD: WORLD MINE PRODUCTION BY COUNTRY[1]

(Kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Madagascar	45	216	[e]200	[e]200	200
Malaysia	2,884	2,594	2,777	3,513	[3]4,462
Mali[e] [13]	[3]3,000	5,200	4,900	5,700	5,500
Mexico	[r] [e]10,000	[r]9,682	[r]10,142	[r]9,891	[3]9,792
Mongolia[e]	1,200	1,000	800	900	850
Mozambique	—	63	394	[r]296	[3]149
Namibia	336	1,605	1,857	[r]2,025	[3]1,954
New Zealand	4,766	4,626	6,758	[r]10,531	11,000
Nicaragua	1,410	[e]1,200	1,154	[r]1,322	1,800
Panama	—	85	194	250	255
Papua New Guinea	27,538	31,938	60,780	[r]71,190	[3]60,587
Peru	9,898	[r] [e]9,100	[r]9,934	[r]20,505	[3]26,331
Philippines	[r]30,040	24,591	[r]25,916	[r]22,702	[3]15,826
Poland[e]	30,000	30,000	30,000	30,000	30,000
Portugal[e]	[3]295	350	[r]160	[r]89	—
Romania[e]	6,000	[r]3,000	[r]3,000	[r]3,700	3,000
Russia	—	—	—	[e]146,000	149,500
Rwanda	745	[r]2,163	[r] [e]1,000	[r] [e]1,000	1,000
Saudi Arabia	2,900	3,536	[r]4,780	[r]6,150	[3]7,525
Sierra Leone[14]	226	32	26	92	[3]157
Solomon Islands[e]	[3]33	35	30	25	20
South Africa, Republic of	607,460	605,100	[r]601,110	[r]614,071	[3]619,201
Spain	8,566	[r]6,814	[r]7,402	[r]6,582	6,200
Sudan[e]	500	100	50	[r]1,000	1,600
Suriname[e]	[3]31	30	30	[r]300	300
Sweden	5,120	6,326	6,247	[r]6,083	6,500
Taiwan[10]	269	72	—	—	—
Tajikistan	—	—	—	[e]500	400
Tanzania[e]	[r]3,500	[r]3,500	[r]4,200	[r]6,000	6,000
Turkey[e] [15]	1,040	1,010	970	1,120	1,250
U.S.S.R.[16]	304,000	302,000	260,000	—	—
United States	265,731	294,189	[r]294,062	[r]330,212	[3]331,013
Uruguay	—	—	—	—	300
Uzbekistan	—	—	—	[e]80,000	80,000
Venezuela	3,867	7,700	4,215	[r]7,553	[3]8,709
Yugoslavia[17]	3,741	8,190	6,000	[e]5,000	—
Zaire[e]	10,600	9,300	8,800	[r]7,000	6,000

See footnotes at end of table.

TABLE 11—Continued

GOLD: WORLD MINE PRODUCTION BY COUNTRY[1]

(Kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Zambia[18]	129	129	136	[r]271	250
Zimbabwe	16,003	16,900	[r]17,820	[r]18,278	[3]18,916
Total	[r]2,013,913	[r]2,182,307	[r]2,187,462	[r]2,298,809	2,330,321

[e]Estimated. [r]Revised.

[1] Table contains data available through Aug. 9, 1994.

[2] Gold is also produced in Bulgaria, Burma, Cuba, Czech Republic, Norway, Senegal, Serbia and Montenegro, Slovakia, Thailand, and several other countries. However, available data are insufficient to make reliable output estimates.

[3] Reported figure.

[4] Reported as bullion historically including an estimated 2% silver.

[5] Officially reported figures are as follows, in kilograms: Major companies: 1989—22,849; 1990—30,098; 1991—34,053 (revised); 1992—39,044 (revised); and 1993—40,000 (estimated). Garimpos 1989—29,678; 1990—71,815; 1991—55,525; 1992—46,818 (revised); and 1993—45,000 (estimated).

[6] Gold purchases by Banco Central from placer deposits and mines; actual production estimated to be at least twice this amount.

[7] Year ending June 30 of year stated.

[8] Does not include undocumented production from small artisanal production.

[9] Figures include reported SAG mine production of, in kilograms: 1989—1,202; 1990—1,745; 1991—1,453; 1992—1,113; and 1993—500 (estimated). Remainder represents approximate reported sales to Government, of artisanal production. Figures do not include artisanal production smuggled out of the country.

[10] Refinery output.

[11] Excludes production from so-called people's mines, which may be as much as 18,000 kilograms per year, but includes gold recovered as byproduct of copper mining.

[12] These figures are based on gold taxed for export and include gold entering Liberia undocumented from Guinea and Sierra Leone.

[13] Includes estimates (Government estimate 1989) of artisanal production and may include some gold smuggled into Mali. The Kalana Mine accounted for about 13% in 1989; 8% in 1990; about 2% in 1991; less than 1% in 1992; and none in 1993. The Syama Mine began gold production in 1990 and accounted for about 42% of the total output that year, 49% in 1991; 57% in 1992; and 56% in 1993.

[14] Data are based on official exports and do not reflect gold moved through undocumented channels.

[15] Indicates byproduct of base metals.

[16] Dissolved in Dec. 1991.

[17] Dissolved in Apr. 1992; however, information is inadequate to formulate reliable estimates for individual countries.

[18] Year beginning Apr. 1 of year listed.

FIGURE 1

HEAP-LEACH PROCESS COMPONENTS

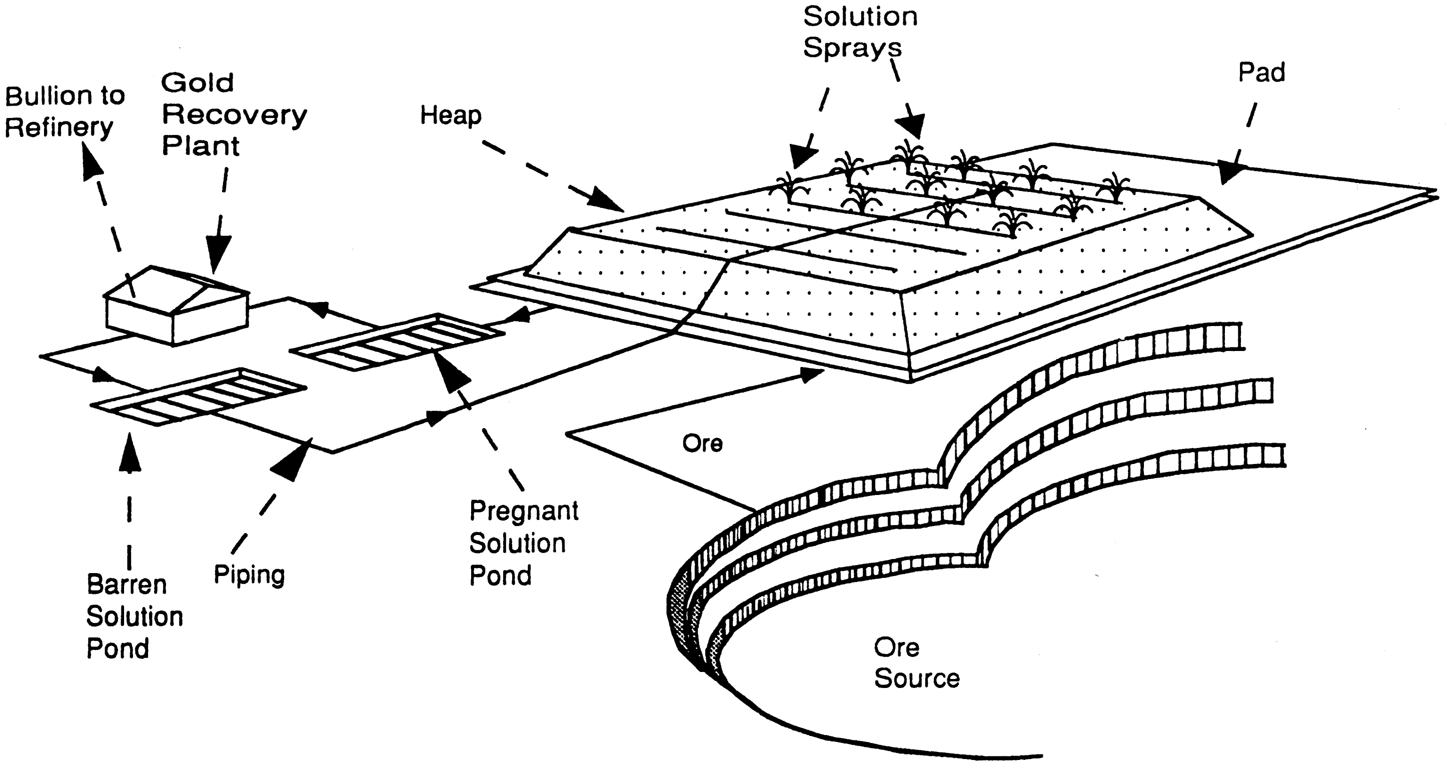
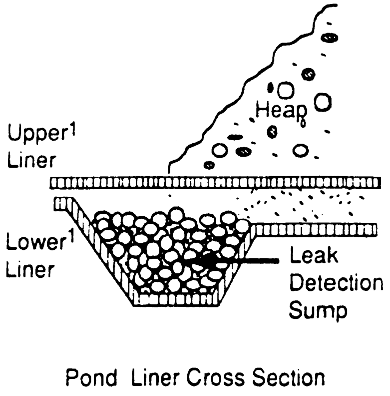


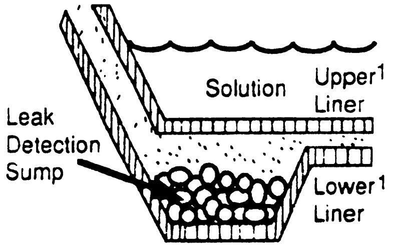
FIGURE 2

HEAP AND POND LINER CROSS SECTIONS

Heap Pond Cross Section



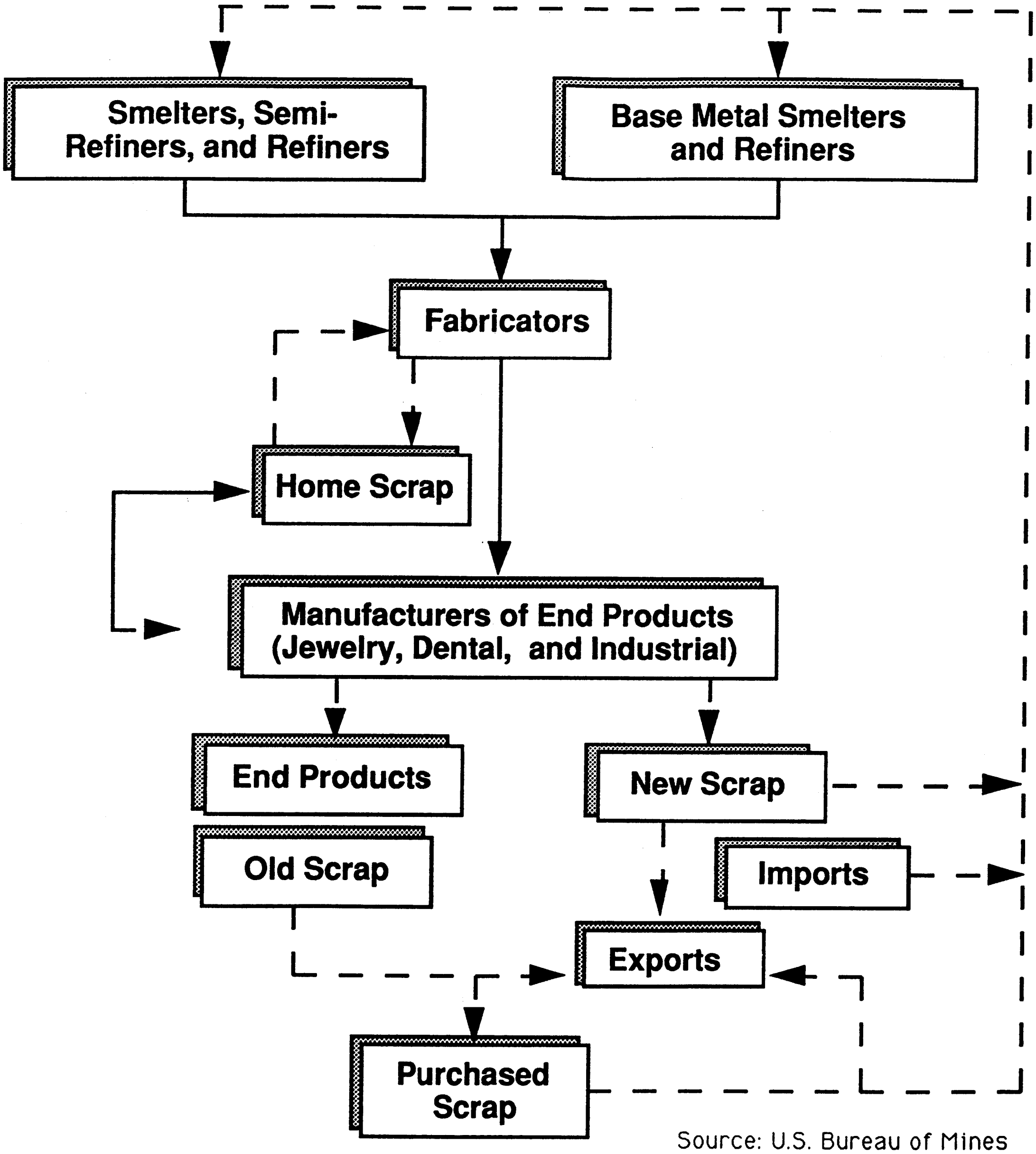
Pond Liner Cross Section



[1] Liners, High density, Polyethylene or polyvinyl chloride 1 mm to 2.5 mm thick

FIGURE 3

SECONDARY GOLD CHART



Source: U.S. Bureau of Mines

GRAPHITE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 27 years of industry, Federal Government, and U.S. Bureau of Mines experience, has been the commodity specialist for graphite since 1980. Domestic survey data were prepared by William Field, statistical assistant; and international data tables were prepared by Amy Durham, international data coordinator.

Amorphous graphite was not mined domestically in 1993. Graphite supplies again exceeded industrial demand. Most prices of the major kinds of graphite dropped somewhat or remained unchanged from those of 1992. Quoted prices mostly reflected the existing oversupply. Production of manufactured graphite and graphite fibers decreased slightly and increased 21%, respectively.

DOMESTIC DATA COVERAGE

Domestic production data for synthetic graphite are developed by the U.S. Bureau of Mines from a voluntary survey of domestic producers. Of the 29 operations polled, 100% responded. This represented 100% of the total production data shown in table 4. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Graphite, a soft crystalline form of carbon, has been called plumbago and black lead. It crystallizes in a lamellar hexagonal system, has a gray to black metallic luster, and is greasy to the feel. It is anisotropic in its physical properties and has a weak plane of cleavage parallel to the lamellae.

The term "amorphous" when applied to graphite is a misnomer. The term "microcrystalline" is more descriptive. The definition of amorphous, as applied to graphite, has been complicated further by longstanding industrial application of the term to very fine particles of crystalline flake graphite that can be sold only for low-value use such as foundry facings. Fine-grained varieties of lump graphite that are easily reduced to fine particle size by grinding are called amorphous lump to distinguish them from the tough, platy and acicular varieties, known as crystalline lump, that can be reduced in particle size only with extreme difficulty.

Crystalline flake graphite is well defined in paragraph 214 of the Tariff Act of 1930 as follows:

"The term crystalline flake means graphite, or plumbago, which occurs disseminated as a relatively thin flake throughout its containing rock, decomposed or not, and which may or has been separated therefrom by ordinary crushing, pulverizing, screening, or mechanical concentration process, such flake being made up of a number of parallel laminae, which may be separated by mechanical means."

Under the foregoing definition, finely divided particles of crystalline flake graphite would be classified as crystalline graphite. The Court of Customs Appeals, however, has held that commercial designations and not scientific terms must govern classification, and when a commercial meaning differs from the technical meaning, the commercial designation must govern. Therefore, quantities of fine crystalline flake graphite are imported under the amorphous classification.

Sri Lankan lump graphite is classified as amorphous or crystalline. Each type is divided into a number of grades, depending on the size (such as lump, ranging from the size of walnuts to that of peas; chip, from that of peas to about that of wheat grains; and dust, finer than 60 mesh), graphitic carbon content, and degree of consolidation.

Amorphous graphite is graded primarily on graphitic carbon content. Commercial ore contains about 75% to 93% carbon, depending on the source.

Crystalline flake graphite from Madagascar is divided into two main grades, "flake" (coarse flake) and "fines" (fine flake). Madagascan crucible flake must have a minimum of 85% graphitic carbon and be essentially all minus 20 plus 80 mesh in particle size. Other crystalline flake graphites are also graded according to graphitic carbon content and particle size.

Natural graphite is marketed in the form of crystalline graphite as flake, lump, chip, and dust and in the form of amorphous graphite in sizes from fine powder to lumps up to the size of walnuts. It is common practice to blend different graphite to obtain a product having certain desired physical and chemical properties. In many instances, the composition of these blends is retained as a trade secret.

Geology-Resources

The three principal types of natural graphite—lump, amorphous, and crystalline flake—are based on physical characteristics that are the result of major differences in geologic origin and occurrence. A variety of silicate minerals are generally associated with graphite in the ore.

Lump graphite occurs as fissure-filled veins. It is typically massive, ranging in particle size from extremely fine grains (amorphous) to coarse, platy intergrowths of fibrous to acicular aggregates (crystalline). The origin of vein-type graphite deposits is believed to be hydrothermal.

Amorphous graphite is formed by metamorphism of coalbeds by nearby intrusives. Its purity depends on the purity of the original coalbeds. Amorphous graphite usually is associated with sandstones, shales, slates, and limestones.

Flake graphite commonly occurs disseminated in regionally metamorphosed sedimentary rocks, such as gneisses, schists, and marbles. It is believed that the graphite was formed under the same conditions that caused the metamorphism of the rocks—from carbon deposited with the sediments.

Although the flake graphite deposits of certain countries conform to this description, most of the commercial deposits that are exploited are the result of weathering of these metamorphic rocks, with the graphite being found in lateritic clays that have accumulated at the surface. Graphite, quartz, and other resistant minerals have been freed by weathering of the feldspars, thus lessening the amount of crushing necessary before beneficiation.

World graphite reserves totaled 21 million metric tons. Detailed breakouts are given in the 1988 Minerals Yearbook chapter. All tonnages are reported in metric tons, unless otherwise noted.

Technology

Mining.—In Sri Lanka, lump graphite is mined underground from narrow, steeply dipping veins. The ore is mined principally by overhand stoping and filling, using temporary stulls when necessary to support the walls. Hand drilling is used in most stoping to achieve selective mining and to avoid unwanted fines and product contamination. Drills are used in developing headings. The ore is hauled by truck to the sorting and classification yard.

Amorphous graphite beds are usually mined underground. However, the beds are much thicker than those of amorphous lump and crystalline lump. The ore is drilled, blasted, hand-loaded into cars, and hauled to the surface by conventional methods.

Flake graphite deposits have been mined by underground and surface methods. Underground deposits are usually unweathered and require drilling and blasting. Most surface mining is confined to the weathered part of the deposit, and normal excavating equipment such as power shovels, bulldozers, and rippers is used with a minimum of drilling and blasting. The ore is usually trucked to the mill.

Milling.—Sri Lankan amorphous lump graphite and crystalline lump graphite are refined by hand cobbing and hand sorting and wiping lumps on wet burlap to remove fines. Light hand sorting and cleaning operations are done by women, while the heavier duties are performed by men.

Most amorphous graphite that requires beneficiation is not worth mining. Preparation for most uses requires grinding only, and coarse impurities are removed by screening or air separation methods.

Flake graphite from disseminated deposits must be concentrated to meet market requirements. Virtually every known concentrating device and combination of separating principles have been tried. The mineral has gained a reputation of being difficult to concentrate, and probably in no other industry has such a large proportion of the mills failed to make commercial recoveries. Graphite actually is one of the easiest minerals to segregate into a rough concentrate, but one of the most difficult to refine.

Because of the premium placed on the mesh size of flake graphite, the problem in milling is one of grinding to free the graphite without reducing the flake size excessively. This is difficult because, during grinding, the graphite flakes are cut by quartz and other angular gangue minerals, thus reducing flake size rapidly. However, if most of the quartz and other angular minerals are removed, subsequent grinding will usually reduce the size of the remaining gangue, with little further reduction in the size of the flake.

Because graphite floats readily and does not require a collector froth, flotation has become the accepted method for beneficiating disseminated ores. The chief problem lies with depressing the gangue minerals. Relatively pure grains of quartz, mica, and other gangue minerals inadvertently become smeared with the soft, fine graphite, making them floatable and resulting in the necessity for repeated cleaning of the concentrates to attain high-grade products.

Substitutes

Some interchange of the various types and grades of natural graphite and between manufactured and natural graphite takes place, but the degree is difficult to determine. Manufactured graphite does not compete with natural graphite in most uses because of its greater cost. Manufactured graphite is not substitutable for natural flake graphite in clay-bonded graphite crucibles, although some crucibles are machined from manufactured graphite for special uses. Calcined coke and other carbons are satisfactory substitutes for graphite for certain foundry core and mold washes and are used when they can compete in terms of price and supply. Other carbons with high purity can be used in batteries.

Economic Factors

The price structure of graphite is quite complex because of the wide variety of products and the lack of standard market quotations. Prices quoted in trade journals are only a range negotiated between buyer and seller and sometimes do not reflect the real market. Quotations are available in Industrial Minerals and the U.S. Bureau of Mines Annual Report. However, average declared import values per ton for amorphous and crystalline graphite have been available for years from U.S. Bureau of the Census data.

The cost for domestically produced graphite from new mines would be much higher than that for graphite from the major foreign sources for the same type and purity. The high cost of production results from high labor costs and the low graphite content of the ore.

Taxes.—Graphite producers are granted a 22% depletion allowance for tax purposes on domestic lump and amorphous and 14% on domestic flake and on foreign operations.

Tariffs.—Duties on graphite items imported from most favored nations (MFN) are minimal. Graphite from a few former Soviet republics (not Ukraine or Russia) and certain other nations are subject to a higher duty.

Operating Factors

Environmental Issues.—Because there was no mining of graphite this year, there were no environment-related issues. Future mining of graphite is highly improbable; there are no domestic reserves and resources are low grade and expensive to recover. Natural graphite is an inert nontoxic substance, and environmental requirements are limited to dust control and certain organic vapors arising from ingredients blended with it to manufacture products.

Postconsumer waste mostly returns to the environment in simple and nonpolluting ways. Graphite products that have contact with molten iron and steel slowly dissolve in it during use. This applies to refractories crucibles, foundry facings, and electrodes, plus a few less important uses, which combine to account for about 75% of total usage. Other important products such as pencils and brake linings slowly dissipate as they are used, almost on an atom-by-atom basis.

Employment.—Production and marketable natural graphite requires little hand labor, except for the graphite mined in Sri Lanka. Even in areas of low-cost labor, mechanical methods are used to mine and concentrate flake graphite.

Because of the very small size of the domestic natural graphite industry, no publishable employment data are available. Because there is only one small mine open intermittently and the product is beneficiated and processed to a minimal extent, employment probably does not exceed 50. Much of the imported graphite requires grinding, perhaps further refining, mixing with other grades to meet consumer specifications, bagging, and shipping. The total number of persons engaged in these operation, including marketing, probably does not exceed 500.

ANNUAL REVIEW

Legislation and Government Programs

No acquisitions of graphite for the strategic and critical materials stockpile occurred in 1993. *(See table 2.)*

Production

United Minerals Co. continued its suspension of production of its amorphous graphitic material from its Montana mine in 1993. Output of manufactured graphite decreased slightly to about 241,000 tons, at 29 plants, with a likelihood of some unreported production for in-house use. Production of all kinds of graphite fiber and cloth increased 13% to 4,080 tons. *(See tables 3 and 4.)*

Consumption and Uses

Reported consumption of natural graphite decreased slightly to about 40,865 tons, according to a survey of more than 230 users. The three major uses of natural graphite were refractories, brake linings, and in packings, which together accounted for 53% of reported consumption. *(See table 5.)*

Nonclay refractories are represented by two important use categories of graphite. Standard refractory products, particularly gunning and ramming mixes, accounted for a sizable part of the demand in the past 5 years, mainly as amorphous graphite. Crucibles, shrouds, nozzles, stopper heads, and retorts, used in hot-metal processing operations such as the continuous casting of steel, use significant amounts of crystalline flake. Coarse flake graphite is preferred for crucibles and refractory associated items, but generally it is mixed with some fine crystalline material of lower value. The newest important refractory use for graphite in steelmaking is in carbon magnesite brick, where large amounts of crystalline flake are now used.

Graphite is used in brake and clutch linings. More graphite is being used as brake and clutch producers change over from asbestos. The graphite lubricates, transfers the heat of friction away from the part, and leads to a lower rate of wear. Graphite is more commonly used in heavier duty nonautomobile lining. Low-quality crystalline flake and amorphous graphite are suitable for foundry facing use. The graphite is mixed with a small amount of clay, suspended in an adhesive material, and applied as a thin coating to mold surfaces to provide for clean and easy mold release of the metal castings.

Graphite is important as a lubricant; when used as a lubricant, it can be a dry powder or mixed with oil or water. It is used with materials that must withstand extreme conditions, such as very high temperatures. Material for this use must be free of abrasive-type impurities.

Graphite is used in packings, which includes expanded graphite and graphite foil. While this category includes uses in ammunition and seed coatings, in addition to packings, most of the tonnage was used to make expanded graphite and graphite foil and final products resulting from them.

Prices

Natural graphite prices are often negotiated between the buyer and seller and are based on purity and other criteria. Therefore, published price quotations such as those in Industrial Minerals are given as a range of prices. Another source of information for graphite prices is the average customs value per ton of the different imported classes. These mainly represent shipments of unprocessed graphite. A third source for natural graphite prices is the amount paid per ton at the point of consumption.

The price for crystalline graphite at the point of consumption—mostly crystalline flake, some crystalline dust, and a little lump graphite—dropped slightly to $1,469 per ton from $1,481. The price for amorphous graphite (including small amounts of amorphous-synthetic graphite mixtures) rose slightly to $683 per ton from $677.

The index of unit value for high-modulus fiber produced in the United States (1973=100) was 42 in 1993, compared with 44 the previous year. *(See table 6.)*

Foreign Trade

Total exports of natural graphite decreased 4%. Exports of graphite electrodes totaled 86,369 tons valued at $178.8 million, of which 49,244 tons ($93.3 million) went to Canada, 3,394 tons ($8.5 million) to Venezuela, 6,613 tons ($10.0 million) to Brazil, 3,469 tons ($11.1 million) to Japan, and the balance to other destinations.

Imports of natural graphite increased 5% from those of 1992. *(See tables 7, 8, and 9.)*

World Review

The world graphite market moved a little closer to balance in supply and demand in 1993. This was observed mostly on the supply side, in the form of drops in production in Madagascar and Romania, or in the form of small increases in production in Canada instead of the large increases that might have been expected. Projects in Namibia and Australia (Munglinup) were dropped. Sales of Malagasy crystalline flake from the U.S. stockpile continued at a moderate rate. Commercial production of crystalline flake graphite from graphite-containing kish waste is not imminent, although progress was made at the kish pilot plant in Chicago. While U.S. apparent consumption of graphite increased moderately, the U.S. price of crystalline flake was unchanged and the price of lump decreased. The market could have been a bit worse, as it was in 1991-92.

Early this year, Industrial Minerals published a major examination of graphite supply-demand. This study delineated the overcapacity and oversupply of the past few years and indicated that any significant improvement would not occur before midyear 1993. It discussed new and proposed projects in detail, such as the coming on-stream of the Uley graphite deposit in Australia at a rate of 5,000 to 10,000 tons of product per year. Demand for ordinary grades of graphite dropped as graphite consumers, particularly the makers of brake linings and expandable graphite, insisted on graphite that is 94% carbon or above. The most damage to demand from the recession occurred in the refractories industry. It concluded that the new projects nearing production face unpleasant prospects.[1]

Brazil.—Nacional de Grafite will bring a new mine and pilot plant on-stream in March 1994, at Salto da Divisa, about 250 kilometers from its major mine at Pedra Azul, and very near the Bahia-Minas Gerais State line. The firm has stated that this crystalline flake graphite deposit is the largest in the world, has more than 100 years of ore supply averaging 5% to 6% graphite at the desired production level, and is capable of producing 40,000 tons per year of 95% graphite product. This production level will hopefully be reached in two years after a $20 million investment. The product is expected to be entirely exported, with the other two mines maintaining their current domestic or export markets. (The Pedra Azul expansion has been suspended.)

Vesuvius Co. has brought a new refractories plant on-stream in Rio de Janeiro among whose products will be some alumina graphite items.

Canada.—Quinto Mining Corp. previously announced the discovery of a large deposit containing graphite, probably amorphous, near Lumby, British Columbia. The graphite would be a byproduct of a sericitic gold ore and is low grade and widely disseminated. Laboratory work has shown it will be difficult to separate the graphite from the mica (sericite) because they are so fine grained. The firm hopes to avoid the problem by selling a mica-graphite final product.

Stratmin Inc. has signed an agreement with St. Genevieve Resources Co. to allow it to use a newly developed method for purifying graphite and use a new method to produce flexible laminated graphite sheets.

China.—According to official trade statistics, China exported a total of 145,000 tons of natural graphite in 1993, 155,000 tons in 1992, 150,000 tons in 1991, and 140,000 tons in 1990. Official statistics indicate that 40,000 tons of natural graphite was added to stocks in 1991. Probably a similar amount was added to stocks in 1992 and a much larger amount in 1990. Domestic consumption of natural graphite is believed to be very large, much larger than Japanese consumption, because of waste during consumption and much shorter product life than is common in industrially advanced countries.

France.—Pechiney signed a letter of intent to merge its synthetic graphite operations in Belgium, France, and Spain into Sigri Great Lakes Carbon Corp. in return for a 10% to 12% stock interest in the new enlarged firm, second largest in the world. Pechiney had only about 4% of the currently oversupplied world market.

Mozambique.—Kenmare Resources PLC completed the financing for its large-flake crystalline flake graphite project at Ancuabe, 100 kilometers from the port of Pemba. The financing is by the Commonwealth Development Corp. and the European Investment Bank. The deposit will be mined by open pit, and the firm stated proven reserves were 1 million tons averaging 11% graphite. Pilot plant testwork has been completed, and the final design specifies a modular flotation plant with a 5,000-ton-per-year capacity for concentrate. The engineering design has been sent out for tender. The plant may be on-stream about yearend.

Sweden.—Norbotten Grus och Grafit AB (NGG) has acquired state-owned graphite claims in the north. The two most promising deposits are at Raitajaervi and Lehtoselkae with ores running 10% to 22% carbon and 19% to 23% carbon, respectively.

Anro Graphite AB expects to have its Kringelgruvan Mine on-stream by early 1995. *(See table 10.)*

Current Research and Technology

The U.S. Bureau of Mines kish process moved closer to implementation. The small pilot plant run by Inland Steel produced about 10 tons of product in 1993 and is expected to produce about 20 tons in 1994. The product almost always has been well received where it has been used, although the price has been 5% to 10% above that for crucible-grade crystalline flake. Some drying equipment still has to be installed in the plant, and other equipment has been modified to make it work better.

Natural fullerenes have been discovered in carbon-containing lightning-seared rocks (fulgurites) from Colorado. The fullerenes are complex configurations of approximately 60 or more carbon atoms, the best known configurations being shaped like a soccer ball. Evidently these fullerenes must have originated under conditions radically different from the natural fullerenes found in coal-like shungite, discovered last year.

The following applications for fullerenes in medicine were discovered this past year: A water-soluble fullerene has been found to block an enzyme the AIDS virus uses to cut up proteins. Fullerenes also can ferry electrons across cell membranes even more efficiently than natural porphyrins can.

Fullerene microtubes now can be filled with lead or other metals to form microscopically thin wires. The fullerene microtubes have natural caps that are destroyed by heating in air, which then allows molten lead to be drawn inside by strong capillary forces. The material inside the microtube may or may not be pure lead.

Other notable applications for fullerenes also were discovered. Coating superconducting metal-containing fullerenes with polystyrene preserved them from decomposition by moisture, which allows them to be used as room-temperature superconductors. Fullerene films will polymerize when exposed to visible or ultraviolet light, the fullerene molecules directly linking together without a bridge.

OUTLOOK

Projected demand for crystalline flake graphite totaled 30,000 tons for 1995 and 35,000 tons for the year 2000. Demand for other graphite, mostly amorphous, totaled 15,000 tons for 1995 and 13,000 tons for the year 2000. This very slow growth rate reflects the maturity of the market, mostly in refractories, and particularly in carbon-magnesite brick. Production capacity is unlikely to increase from the present level while the overcapacity exists.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Graphite. Ch. in Mineral Commodity Summaries, annual.
Graphite. Ch. in Annual Report, annual.
Graphite. Reported annually in Mineral Industry Surveys.

Other Sources

Chemical Week.
European Chemical News.
Industrial Minerals (London).
Materials Engineering.
Wall Street Journal.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS

		1989	1990	1991	1992	1993
United States:						
Production	metric tons	W	—	—	—	—
Apparent consumption[1]	do.	50,867	38,676	14,170	29,527	34,814
Exports	do.	11,452	11,537	19,374	20,217	17,358
Value	thousands	$7,421	$9,481	$11,345	$12,244	$11,149
Imports for consumption	metric tons	62,319	50,213	33,544	49,744	52,172
Value	thousands	$33,707	$35,222	$21,662	$25,538	$29,850
World: Production	metric tons	[r]1,005,417	[r]945,462	[r]771,189	[r]755,905	[e]741,040

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Domestic production plus imports minus exports.

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[1] Harries-Rees, K. Graphite Prices Flaking Away. Industrial Minerals (London), No. 305, Feb. 1993, pp. 27-45.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 1993, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	([1])	15,156
Sri Lanka amorphous lump	5,715	4,934
Crystalline, other than Madagascar and Sri Lanka	([1])	1,754
Nonstockpile-grade, all types	([1])	846

[1] This commodity no longer has a goal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of Dec. 31, 1993.

TABLE 3
PRINCIPAL PRODUCERS OF SYNTHETIC GRAPHITE IN 1993

Company	Plant location	Product[1]
Amoco Performance Products Co.	Greenville, SC	Cloth, high-modulus fibers.
BASF Structural Materials Inc.	Rock Hill, SC	High-modulus fibers.
Carbone of America	St. Marys, PA	Motor brushes; unmachined shapes; other.
Fiber Materials, Inc.	Biddeford, ME	Other.
Fiber Technology Corp.	Provo, UT	
Fortafil Fibers Inc.	Rockwood, TN	High-modulus fibers.
BF Goodrich Co., Engineered Systems Div., Super-Temp Operations	Santa Fe Springs, CA	Other.
Grafil Inc.	Sacramento, CA	High-modulus fibers.
Hercules Inc.	Salt Lake City, UT	Do.
HITCO Materials Group, British Petroleum Co.Ltd.	Gardena, CA	Cloth.
Minerals Technology, Inc.; Specialty Minerals Corp.	Easton, PA	Other.
National Electrical Carbon Co.	Fostoria, OH	Unmachined shapes; high-modulus fibers.
NAC Carbon Products, Inc.	Punxsutawney, PA	Other.
Polycarbon, Inc.	Valencia, CA	Cloth.
Showa Denko Carbon Inc.	Ridgeville, SC	Electrodes; other.
SIGRI Great Lakes Carbon Corp.		
Do.	Hickman, KY	Anodes; crucibles; electrodes; unmachined shapes; other.
Do.	Morganton, NC	Do.
Do.	Niagara Falls, NY	Do.
Do.	Ozark, AR	Do.
Superior Graphite Co.	Russellville, AR	Electrodes.
Do.	Hopkinsville, KY	Other.
Textron Specialty Materials	Lowell, MA	High-modulus fibers.
The Carbide/Graphite Group, Inc.; Graphite Specialties	Niagara Falls, NY	Anodes; crucibles; motor brushes; electrodes; unmachined shapes; refractories; other.
Do.	St. Marys, PA	Do.
The Carborundum Co., Metallics Systems Div.	Sanborn, NY	Unmachined shapes.
UCAR Carbon Company, Inc.	Clarksburg, WV	Anodes; electrodes; unmachined shapes; other.
Do.	Clarksville, TN	Do.
Do.	Columbia, TN	Do.
Zoltek Corp.	St. Charles, MO	High-modulus fibers.

[1] Cloth includes low-modulus fibers; motor brushes include machined shapes; crucibles include vessels.

TABLE 4
U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY END USE

End use	1992 Quantity (metric tons)	1992 Value (thousands)	1993 Quantity (metric tons)	1993 Value (thousands)
Anodes[1]	W	W	W	W
Cloth and fibers (low-modulus)	255	$22,599	37	$4,536
Crucibles and vessels and refractories[1]	W	W	W	W
Electric motor brushes and machined shapes	1,339	16,510	1,147	18,737
Electrodes	161,278	336,155	154,339	368,921
Graphite articles[2]	—	28,364	—	38,663
High-modulus fibers	3,345	145,622	4,045	158,343
Unmachined graphite shapes	3,152	23,752	4,238	27,643
Other	8,771	54,765	8,589	45,479
Total	178,140	627,767	172,395	662,322
Synthetic graphite powder and scrap[3]	69,762	34,808	69,072	36,388
Grand total[4]	247,902	662,575	241,468	698,711

W Withheld to avoid disclosing company proprietary data.

[1] Anodes, crucibles/vessels and refractories end products are included in the "Other" products category.

[2] Includes all items for which quantity data are usually unavailable.

[3] Includes lubricants (alone/in greases), steelmaking carbonraisers, additives in metallurgy, and other powder data.

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

TABLE 5
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Uses	Crystalline Quantity (metric tons)	Crystalline Value (thousands)	Amorphous[1] Quantity (metric tons)	Amorphous[1] Value (thousands)	Total Quantity (metric tons)	Total Value (thousands)
1991	20,482	$31,221	15,951	$11,274	[2]36,434	$42,495
1992:						
Batteries	146	303	—	—	146	303
Brake linings	2,221	3,016	5,145	4,307	7,366	7,323
Carbon products[3]	619	1,912	625	438	1,244	2,350
Crucibles, retorts, stoppers, sleeves and nozzles	W	W	W	W	1,029	1,434
Foundries[4]	864	936	1,888	1,006	2,752	1,942
Lubricant group:						
Lubricants	764	1,197	2,337	1,357	3,101	2,554
Packing; other[5]	3,759	5,402	143	247	3,902	5,649
Pencils	2,670	3,661	261	179	2,931	3,840
Powdered metals	1,739	3,426	225	204	1,964	3,630
Refractories	9,147	12,067	3,812	1,551	12,959	13,618
Rubber	100	235	491	397	591	632
Steelmaking	W	W	W	W	1,466	1,025
Other[6]	1,156	2,256	1,167	1,238	2,323	3,494
Withheld uses	1,083	1,538	1,412	921	—	—
Total	24,268	35,949	17,506	11,845	41,774	47,794
1993:						
Batteries	W	W	W	W	606	1,409
Brake linings	1,666	2,270	5,053	4,214	6,719	6,484
Carbon products[3]	561	1,621	493	331	1,054	1,952

See footnotes at end of table.

TABLE 5—Continued

U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE

Uses	Crystalline Quantity (metric tons)	Crystalline Value (thousands)	Amorphous[1] Quantity (metric tons)	Amorphous[1] Value (thousands)	Total Quantity (metric tons)	Total Value (thousands)
1993—Continued:						
Crucibles, retorts, stoppers, sleeves and nozzles	W	W	W	W	995	$1,020
Foundries[4]	720	$840	2,222	$1,206	2,942	2,046
Lubricant group:						
Lubricants	708	1,231	2,431	1,560	3,139	2,791
Packing; other[5]	4,222	6,045	86	134	4,308	6,179
Pencils	2,563	2,947	236	169	2,799	3,116
Powdered metals	1,996	4,124	372	302	2,368	4,426
Refractories	7,754	8,734	2,732	757	10,486	9,491
Rubber	189	287	424	375	613	662
Steelmaking	W	W	W	W	1,722	1,027
Other[6]	1,460	4,162	1,654	1,466	3,114	5,628
Withheld uses	1,464	1,976	1,859	1,480	—	—
Total	23,303	34,237	17,562	11,994	40,865	46,231

W Withheld to avoid disclosing company proprietary data; included with "Withheld uses" and "Total" where applicable.

[1] Includes mixtures of natural and manufactured graphite.

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

[3] Includes bearings and carbon brushes.

[4] Includes foundries (other) and foundry facings.

[5] Includes packings; ammunition; and seed coating.

[6] Includes paint and polishes; small packages; antiknock and other compounds; soldering/welding; mechanical products; electrical/electronic devices; industrial diamonds; drilling mud; magnetic tape; and other end-use categories.

TABLE 6

REPRESENTATIVE YEAREND GRAPHITE PRICES

(Per metric ton)

	1992	1993
Industrial minerals:[1] [2]		
Crystalline large flake, 85% to 90% carbon	$400- $800	$400- $600
Crystalline medium flake, 85% to 90% carbon	350- 750	300- 500
Crystalline small flake, 80% to 90% carbon	300- 550	250- 500
Amorphous powder, 80% to 85% carbon	220- 440	220- 440
Custom value, at foreign ports:[3]		
Flake	[r]708	710
Lump and chip, Sri Lankan	1,073	789
Amorphous, Mexican	125	127

[r] Revised.

[1] Prices are normally c.i.f. (cost, insurance, and freight) main European port.

[2] Source: Industrial Minerals, No. 303, Dec. 1992, p. 66, and No. 315, Dec 1993, p. 54.

[3] Source: Department of Commerce, Bureau of the Census.

TABLE 7

U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE,[1] BY COUNTRY

Country	Natural[2]		Artificial[3]		Total[4]	
	Quantity (metric tons)	Value[5]	Quantity (metric tons)	Value[5]	Quantity (metric tons)	Value[5]
1992:						
Canada	5,180	$3,389,714	14,833	$6,370,111	20,013	$9,759,825
France	29	94,717	1,051	1,688,774	1,080	1,783,491
Germany	71	188,884	721	646,165	792	835,049
Japan	260	432,090	4,539	10,167,361	4,799	10,599,451
Korea, Republic of	71	43,918	1,656	1,850,319	1,727	1,894,237
Mexico	9,430	3,643,596	1,279	726,634	10,709	4,370,230
Netherlands	118	42,040	3,381	1,688,756	3,499	1,730,796
Venezuela	659	951,675	671	472,197	1,330	1,423,872
Other	4,399	3,457,008	6,356	9,078,595	10,756	12,535,603
Total	20,217	12,243,642	34,487	32,688,912	54,705	44,932,554
1993:						
Canada	3,884	2,514,791	13,846	5,944,390	17,730	8,459,181
France	107	43,978	714	1,916,551	820	1,960,529
Germany	34	14,639	436	429,824	471	444,463
Japan	275	428,692	3,260	6,236,315	3,534	6,665,007
Korea, Republic of	38	41,922	4,498	2,838,470	4,536	2,880,392
Mexico	7,448	2,764,781	742	488,361	8,190	3,253,142
Netherlands	1	3,325	1,393	1,127,825	1,394	1,131,150
Venezuela	388	628,067	687	559,334	1,074	1,187,401
Other	5,183	4,708,917	9,463	11,310,237	14,646	16,019,154
Total[4]	17,358	11,149,112	35,039	30,851,307	52,397	42,000,419

[1] Numerous countries for which data were reported have been combined within the "Other" category under the "Country" list.

[2] Amorphous, crystalline flake, lump or chip, and natural, not elsewhere classified. The applicable "Harmonized Tariff Schedule" (HTS) nomenclature title and code(s) are: "Natural graphite in powder or in flakes"/"Other"; HTS Nos. 2504.10/.90.0000.

[3] Includes data from the applicable "Harmonized Tarif Schedule" (HTS) nomenclatures: "Artificial graphite" and "Colloidal or semi-colloidal graphite;" their respective HTS code Nos. are: 3801.10/.20.0000.

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

[5] Values are free alongside ship (f.a.s.).

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY

Country	Crystalline flake[1]		Lump or chippy dust		Other natural crude and refined[1]		Amorphous		Total[2]	
	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
1991	12,301	$11,936	434	$626	9,229	$7,699	11,580	$1,401	33,544	$21,662
1992:										
Austria	—	—	—	—	—	—	20	10	20	10
Brazil	[r]810	[r]1,249	—	—	[r]810	[r]1,260	—	—	1,620	2,509
Canada	7,470	4,856	—	—	9,130	5,400	—	—	16,600	10,256
China	[r]3,380	[r]1,643	—	—	[r]3,416	[r]2,029	1,663	436	8,459	4,108
France	41	74	—	—	109	462	—	—	150	537
Germany	51	149	—	—	13	101	—	—	64	250
India	178	88	—	—	160	173	—	—	338	261
Japan	(4)	(4)	—		[r]3,190	[r]1,413	—	—	3,190	1,413
Macau	—	—	—	—	—	—	40	30	40	30
Madagascar	2,011	1,730	—	—	1,341	1,003	—	—	3,352	2,733
Mexico	—	—	—	—	387	259	13,970	1,752	14,357	2,011
Russia	—	—	—	—	15	35	—	—	15	35
Sri Lanka	—	—	492	528	—	—	—	—	492	528
United Kingdom	46	73	—	—	4	9	—	—	49	82
Zimbabwe	[r]497	[r]380	—	—	[r]497	[r]380	—	—	994	760
Other[5]	1	11	—	—	3	4	—	—	4	15
Total	[r]14,485	[r]10,253	492	528	[r]19,075	[r]12,528	15,693	2,228	49,744	25,538
1993:										
Austria	—	—	—	—	—	—	20	10	20	10
Brazil	328	453	—	—	2,952	4,079	—	—	3,280	4,532
Canada	8,050	4,689	—	—	9,838	5,730	—	—	17,888	10,419
China	2,818	1,246	—	—	6,485	2,892	91	14	9,394	4,152
France	76	182		—	57	435	—	—	133	617
Germany	136	1,743	—	—	21	114	—	—	157	1,857
Hong Kong	—	—	—	—	—	—	385	61	385	61
India	21	10	—	—	199	279	—	—	220	288
Japan	—	—	—	—	333	1,663	—	—	333	1,663
Madagascar	2,011	1,419	—	—	1,341	946	—	—	3,352	2,365
Mexico	—	—	—	—	387	162	13,681	1,732	14,068	1,894
Namibia	16	9	—	—	—	—	—	—	16	9
Norway	56	23	—	—	—	—	—	—	56	23
South Africa, Republic of	74	111	—	—	—	—	—	—	74	111
Sri Lanka	—	—	712	562	—	—	—	—	712	562
Switzerland	(6)	7	—	—	10	117	—	—	11	124
Ukraine	—	—	—	—	16	60	—	—	16	60
United Kingdom	101	123	—	—	20	10	—	—	121	134
Zimbabwe	521	255	—	—	1,217	596	—	—	1,738	851
Other[5]	198	104	—	—	(6)	14	—	—	198	118
Total[2]	14,406	10,374	712	562	22,875	17,097	14,177	1,817	52,172	29,850

[r] Revised.

[1] The information framework from which data for this material were derived originated from Harmonized Tariff Schedule (HTS) base data.

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

[3] Customs values.

[4] Revised to zero.

[5] Includes Armenia, Australia (1993), Belgium, Finland (1992), Italy, and Poland (1993).

[6] Less than 1/2 unit.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF GRAPHITE ELECTRODES,[1] BY COUNTRY

Country	Quantity[2] (metric tons)	Value[3] (thousands)
1992:		
Canada	1,417	$1,696
Germany	3,884	7,280
India	1,358	2,299
Italy	4,466	7,425
Japan	5,678	9,940
Mexico	8,218	11,075
Spain	878	1,579
Other	1,489	2,446
Total	27,388	43,740
1993:		
Canada	5,407	8,318
Germany	2,175	5,894
India	1,983	3,571
Italy	5,729	9,009
Japan	6,374	12,237
Mexico	10,511	15,414
Spain	539	1,123
Other	1,271	2,212
Total	33,989	57,778

[1] The applicable "Harmonized Tariff Schedule" (HTS) code and nomenclature title are: (HTS 8545.11.0000); "Electric Furnace Electrodes."

[2] For both 1992 and 1993 data for countries reflecting less than 500 metric tons each for yearly imports have been combined under the "Other" category in the "Country" list.

[3] Customs values.

Source: Bureau of the Census.

TABLE 10
GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Argentina[e]	[2]100	100	100	90	100
Austria	15,307	[r]22,705	[r]19,750	[r]19,547	19,500
Brazil (marketable)[3]	31,650	28,890	26,965	[r]29,414	29,000
Burma[4]	—	45	[r]36	—	—
Canada (exports of natural graphite)	6,000	10,200	6,200	17,400	18,800
China[e]	[r]490,000	[r]455,000	[r]289,000	[r]300,000	310,000
Czech Republic[5]	—	—	—	—	20,000
Czechoslovakia[6]	[r]66,000	[r]39,000	[r]47,000	[r] [e]20,000	—
Germany	[r] [e]15,800	[r]19,314	[r]15,807	[r]11,963	10,000
India (run-of-mine)[7]	58,000	61,000	69,922	[e]70,000	64,000
Korea, North[e]	35,000	35,000	35,000	38,000	38,000
Korea, Republic of:					
Amorphous	100,282	98,987	75,239	[e]75,000	72,000
Crystalline flake	1,186	703	1,552	[r]8,412	8,000
Madagascar	15,863	18,036	14,079	[r]8,910	8,000
Mexico:					
Amorphous	38,304	22,553	35,315	[r]47,053	49,440
Crystalline flake	1,942	2,365	1,943	[r]985	1,000
Namibia[e]	—	—	200	200	200
Norway	1,800	[e]5,000	6,930	[r] [e]5,000	5,000
Romania	10,000	[r] [e]6,000	[r] [e]6,000	2,300	2,000
Russia	—	—	—	[e]15,000	10,000
Sri Lanka	4,163	5,469	6,381	[r]3,307	4,000
Turkey (run-of-mine)[8]	11,873	18,712	25,867	[r]20,978	20,000
Ukraine	—	—	—	[e]50,000	40,000
U.S.S.R.[e] [9]	84,000	80,000	75,000	—	—
United States	W	—	—	—	—
Zimbabwe	18,147	16,383	12,903	[r]12,346	12,000
Total	[r]1,005,417	[r]945,462	[r]771,189	[r]755,905	741,040

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

[1] Table includes data available through May 31, 1994.

[2] Reported figure.

[3] Does not include the following quantities sold directly without beneficiation, in metric tons: 1989—13,005 (revised); 1990—8,400 (revised); 1991—7,298 (revised); 1992—8,957 (revised); and 1993—9,000 (estimated).

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

[5] Formerly part of Czechoslovakia.

[6] Dissolved Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from what is now the Czech Republic.

[7] Indian marketable production is 10% to 20% of mine production.

[8] Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.

[9] Dissolved in Dec. 1991.

GYPSUM

By Lawrence L. Davis

Mr. Davis, a physical scientist with 38 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for gypsum since 1985. Domestic survey data were prepared by Virginia Harper, statistical assistant; and international data tables were prepared by Jeremy Tidwell, Section of International Data.

Public Law 100-418 requires U.S. Government agencies to implement the use of metric units in their business activities. The U.S. Bureau of Mines (USBM), to be in compliance with the law, has developed a schedule for making an orderly transition from English to metric units when reporting gypsum statistics in the Annual Report.

For the 1993 Annual Report, all weight data will be reported in metric units. Additional lines in appropriate tables will show total weights in English units. All other data will continue to be in English units.

For the 1994 Annual Report, weight data will be reported in metric units only. All other data; e.g., wallboard area; will continue to be reported in English units.

For the 1995 Annual Report, all data will be reported in metric units.

Demand for gypsum products increased in 1993, a result of increased construction activity, especially in new housing starts that increased 7% to 1.3 million units. The quantity of crude gypsum mined, calcined gypsum produced, and wallboard products shipped was greater than that in 1992.

Sales of gypsum products increased 9% to 24 million metric tons, and value increased 32% to $1.8 billion. Increased demand caused higher prices for gypsum products. Imports for consumption of crude gypsum increased 3% to about 7.4 million tons. Total value of gypsum product exports decreased 20% to $78 million.

DOMESTIC DATA COVERAGE

Domestic production data for gypsum are developed by the USBM from a survey of U.S. gypsum operations. Of the 117 operations to which the annual survey request was sent, 100 responded, representing 85% of the total crude gypsum production shown in tables 1 and 2. Nonrespondents were estimated from monthly and quarterly canvasses or from previous years' data. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Gypsum has a composition of 79% calcium sulfate and 21% water, $CaSO_4 \cdot 2H_2O$, and is used as a commercial and generic term for all calcium sulfate materials. The well-formed transparent crystalline variety is called selenite. The massive variety is called alabaster and can be easily carved. The fibrous, silky variety is called satin spar. Gypsite is a mixture of clay and gypsum crystals.

Anhydrite is calcium sulfate, $CaSO_4$, with no water of crystallization. It is a naturally occurring mineral commonly associated with gypsum. When gypsum is calcined at high temperatures, it is converted to anhydrite.

Commercially calcined gypsum, $CaSO_4 \cdot 1/2H_2O$, is a manufactured hemihydrate product produced by partial calcination of gypsum. It is produced by heating gypsum at temperatures to 350° F. The hemihydrate product, commonly called plaster of paris, is called stucco by the wallboard manufacturers. When water is added to form a paste, the calcined material reabsorbs water and it quickly sets and hardens to form gypsum again.

Byproduct gypsum is a chemical product of manufacturing processes such as phosphoric acid, hydrofluoric acid, citric acid, and titanium dioxide from ilmenite, consisting essentially of $CaSO_4 \cdot 2H_2O$. The sludge produced from scrubbers in the desulfurization of stack gas in thermal powerplants is also byproduct gypsum.

Keene's cement is anhydrous gypsum plaster with certain accelerator additives. It is produced by special high-temperature calcining. All of these minerals and materials, including the articles molded from the plaster, are commonly called gypsum or plaster.

Industry Structure

The domestic gypsum industry is large and is dominated by a few large vertically integrated companies that mine and calcine gypsum and manufacture plaster and wallboard products. These companies also sell crude gypsum for use in cement and agriculture. The large wallboard producers, through foreign subsidiaries, produce most of the crude gypsum that is imported to feed coastal wallboard plants. Plants on the east coast import mostly from Canada's Maritime Provinces, while plants on the west coast import gypsum from Mexico. Crude gypsum from Spain, the other major source of U.S. imports, is used mainly by cement plants.

Gypsum production is worldwide, with at least 80 countries known to produce. Because of its wide distribution and plentiful supply, most of the world's production is consumed domestically.

Exceptions include Canada and Mexico, which export significant portions of their production to the United States; Thailand and Australia, which export to much of the Southeast Asia market; and Spain, which exports to the United States, Scandinavia, and other countries. In the United States and other industrialized nations, the major use of gypsum is in the manufacture of gypsum wallboard products. Most crude gypsum is mined in rural areas and shipped to urban areas for manufacture into wallboard and ultimate consumption. In developing countries, most gypsum is consumed by local cement plants.

Geology-Resources

Gypsum deposits may be found in any geologic era, but they are most common in the Permian. They are commonly found in association with the source rocks for petroleum. Most massive gypsum and anhydrite deposits occur as large, lenticular, stratified bodies that were formed by evaporation of seawater in basins that have one or more restricted openings to the sea. The basins range in diameter from a few miles to many hundreds of miles.

Classic evaporite formation involves the deposition of anhydrite, with later hydration of the anhydrite by meteoric waters to gypsum at depths ranging from zero to 1,000 feet. The depth of hydration is generally related to topography, structure, and climate because these factors affect the depth of ground water and surface water penetration.

Technology

Gypsum deposits are explored to determine their physical and chemical properties and to determine a minable thickness and the ratio of gypsum to anhydrite. The depth of hydration is important in mining because the presence of only a few percent anhydrite is sufficient to render gypsum unusable for making plaster. Adequate samples may be obtained from outcrops or drill cores.

Deposits near the surface are developed by stripping the overburden, developing either single- or multiple-bench open pits, and constructing access and transportation routes. Underground ore bodies are developed by sinking shafts or driving adits, with mining development and production by the room-and-pillar system.

Most domestic gypsum is produced from surface mines using standard open pit mining methods. In a typical domestic mine, the gypsum is drilled and blasted as needed, usually every week or two. Broken gypsum rock, loaded with hydraulic shovel or front-end loader, is hauled to the primary crusher by a fleet of three or four 35-ton haultrucks. All material removed from the mines is crude gypsum. All waste is left in the mine.

The processing of crude gypsum depends on the end use. Gypsum for use in cement is crushed to minus 1 1/2 inch plus 3/8 inch. For agricultural or filler use, the gypsum is pulverized to 100 mesh or finer.

To produce plaster and wallboard products, minus-100-mesh gypsum is heated in batch kettles to remove three-quarters of the water of crystallization, converting gypsum, $CaSO_4 \bullet 2H_2O$, to the hemihydrate product, $CaSO_4 \bullet 1/2H_2O$. A few rotary kilns also are used, in which case a coarse feed with fines removed is calcined. During the commercial calcining process, gypsum is heated to 250° F for about 2 hours, then the temperature rapidly rises to 300° to 350° F, at which time the calcine, called stucco, is dumped into a hot pit. The calcine is then mixed with various additives, including a retarder or accelerator, and manufactured into prefabricated wallboard products and other plaster and cement products.

Plaster is generally reground calcine, modified with retarders or accelerators and containing various binders such as hair, sisal, fiberglass, aggregates, or colored pigments. Retarders, usually glue, starch, or slaughterhouse byproducts, can increase the setting time to as much as 6 hours. Accelerators, such as metal salts, set plaster, or anhydrite, can reduce the setting time to less than 5 minutes. The plaster is packed in bags and sold under various trade names.

Prefabricated products include lath, veneer base, sheathing, and wallboard. These board products are manufactured by continuous methods on automatic machines that can be adjusted to any of the standard products. A slurry of wet plaster with additives and an accelerator is spread between two moving sheets of paper. Moving through the shaping rolls, the edges are molded and sealed. The green board is run out on a traveling belt until the plaster has set. The board is then cut with a revolving knife into appropriate lengths and slowly passed through a drying kiln.

ANNUAL REVIEW

Production

The United States remained the world's leading producer of gypsum, accounting for 15% of the total world output. Crude gypsum was mined by 31 companies at 58 mines in 19 States. Production increased 7%. Leading producing States, in descending order, were Oklahoma, Iowa, Texas, Michigan, Nevada, California, and Indiana. These seven States produced more than 1 million tons each and together accounted for 76% of total domestic production.

Leading companies were USG Corp., 11 mines; National Gypsum Co., 7 mines; Georgia-Pacific Corp., 7 mines; Harrison Gypsum Inc., 2 mines; and Temple-Inland Forest Products Corp., 1 mine. These 5 companies, operating 28 mines, produced 67% of the total crude gypsum.

Leading individual mines, in descending order of production, were USG's Plaster City Mine, Imperial County, CA; USG's Sweetwater Mine, Nolan County, TX; USG's Sperry Mine, Des Moines County, IA; USG's Shoals Mine, Martin County, IN; Temple-Inland's Fletcher Mine, Comanche County, OK; National's Tawas Mine, Iosco County, MI; USG's Alabaster Mine, Iosco County, MI; Briar's Briar Mine, Howard County, AR; Harrison's Cement Mine, Caddo County, OK; and

National's Sun City Mine, Barber County, KS. These 10 mines accounted for 40% of the national total. Average output for the 58 active mines increased 7% to 273,000 tons.

Gypsum was calcined by 13 companies at 70 plants in 28 States, principally for the manufacture of gypsum wallboard and plaster. Calcined output increased slightly in tonnage and 9% in value. Leading States, in descending order, were California, Iowa, Texas, Florida, Nevada, and New York. These 6 States, with 27 plants, accounted for 48% of the national output.

Leading companies were USG, 20 plants; National Gypsum, 18 plants; Georgia-Pacific, 10 plants; Domtar, 7 plants; and Celotex, 4 plants. These 5 companies, operating 59 plants, accounted for 83% of the national output.

Leading individual plants were, in descending order of production, USG's Jacksonville plant, Duval County, FL; USG's Plaster City plant, Imperial County, CA; USG's Sweetwater plant, Nolan County, TX; USG's Sperry plant, Des Moines County, IA; USG's Shoals plant, Martin County, IN; USG's Baltimore plant, Baltimore County, MD; National's Tampa plant, Hillsborough County, FL; USG's Stony Point plant, Rockland County, NY; Temple-Inlands Fletcher plant, Comanche County, OK; and Centex's Bernalillo plant, Sandoval County, NM. These 10 plants counted for 29% of the national production. Average calcine production for the 70 U.S. plants was 218,000 tons, slightly more than that in 1992.

A total of 846,000 tons of byproduct gypsum, valued at $3.4 million, was used, principally in agriculture but some for gypsum wallboard manufacturing. Approximately 89% was of nonphosphogypsum origin compared with 90% in 1992.

According to the Gypsum Association, yearend gypsum wallboard plant capacity for producing 1/2-inch regular wallboard increased slightly to 24.64 billion square feet per year. Total wallboard shipments were 21.4 billion square feet, 87% of capacity. Domtar's plants at Florence, CO, and at Sweetwater, TX, remained closed throughout the year. *(See tables 2 and 3 and figure 1.)*

Consumption and Uses

Apparent consumption, defined as production plus net imports plus industry stock changes, of crude gypsum, including byproduct gypsum, increased 8% to 24 million tons. Net imports provided 31% of the crude gypsum consumed. Apparent consumption of calcined gypsum increased slightly to 15.1 million tons.

Yearend stocks of crude gypsum at mines and calcining plants were 2.3 million tons. Of this, 40% was at calcining plants in coastal States.

Of the total gypsum products sold or used, about 23% was uncalcined. Uncalcined gypsum, crushed and screened to specifications, is marketed for use in portland cement manufacture, agriculture, and fillers. The cement industry uses gypsum to retard the setting time of concrete.

Finely ground gypsum rock is used in agriculture to neutralize alkaline and saline soils, improve the permeability of argillaceous materials, and provide sulfur and catalytic support for maximum fertilizer utilization and leguminous productivity. Small amounts of very pure gypsum are used as fillers and in glassmaking, papermaking, and pharmaceutical applications. In 1993, 59% of the uncalcined gypsum was used in portland cement and the remainder was used mainly for agricultural purposes.

Of the total calcined gypsum products, most went into prefabricated products. A small percentage was used in industrial and building plasters. Of the prefabricated products, based on surface square feet, 65% was regular wallboard; 23% was fire-resistant type X wallboard; 5% 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, 81% was 1/2-inch and 11% was 5/8-inch.

In descending order, the leading sales regions for prefabricated products were the South Atlantic, East North Central, Pacific, and West South Central. Together these regions accounted for 62% of the total. *(See tables 4 and 5 and figure 2.)*

Markets and Prices

On an average value-per-ton basis, f.o.b. mine or plant, crude gypsum decreased slightly to $6.74, calcined gypsum increased 8% to $17.88, and byproduct gypsum decreased 39% to $4.03. Prefabricated products were valued at $89.75 per ton, plasters at $130.22 per ton, and uncalcined products at $12.99 per ton.

Quoted prices for gypsum wallboard products were published monthly in Engineering News Record. Spot prices in December, based on truck lots delivered to the job, showed a wide range. Regular 1/2-inch wallboard prices ranged from $93 per thousand square feet at Cincinnati to $170 at New York. The average price in December for 20 cities was $130 per thousand square feet, with some minor discounts for prompt payment. This represented a 5% increase compared with that of December 1992.[1]

With increased demand for gypsum products and improving prices, the industry reported improved earnings. National Gypsum emerged from chapter 11 bankruptcy protection in July. The company also received a $75 million credit line from General Electric.[2] Later in the year, National sold a 20% interest to Lafarge Copee.[3] USG went into chapter 11 bankruptcy in March and emerged in May.[4]

Foreign Trade

Imports for consumption of crude gypsum increased 3% to 7.4 million tons. Net imports represented 31% of apparent consumption. Crude gypsum from Canada and Mexico was used mainly to feed wallboard plants in coastal cities. Imports from Spain, the other major source of imported gypsum, were used mostly for portland cement manufacture. Gypsum wallboard imports, principally from Canada, increased 102% to 268 million square feet. *(See tables 6 and 7.)*

World Review

Estimated world production of crude gypsum increased slightly to 103 million tons. Total world production figures are probably low because, in some countries, significant production was consumed captively and not reported. Also, production from small deposits in developing countries was intermittent and often unreported. The United States remained the world's largest producer of crude gypsum with 15% of the world total. *(See table 8.)*

Canada.—The gypsum wallboard plant in McAdam, New Brunswick, formerly owned by Eastern Gypsum Inc. and closed since 1991, was reopened under new ownership by Nova Gypsum Co.

The Gypsum Association in the United States, of which all Canadian wallboard producers were members, reported that yearend capacity for 1/2-inch regular wallboard in Canada was 3.48 billion square feet, slightly more than the 1992 yearend capacity.

Germany.—The Fraunhofer Institute of Structural Physics developed a gypsum foam using flue gas desulfurization gypsum. The foam, made by mixing gypsum, water, and an isocyanate prepolymer, was reported to provide very good sound insulation.[5]

Oman.—Large deposits of gypsum were found in Shuwaymiyah. The reserves, estimated to be more than 100 million tons, are the largest in Oman.[6]

Taiwan.—Universal Cement Corp. purchased property in Taoyuan, where it plans to build a new wallboard plant. The plant, the company's second, was scheduled to be completed in 1995.[7]

United Kingdom.—British Gypsum Ltd. took delivery of byproduct gypsum from the newly commissioned flue gas desulfurization units at National Power's Drax powerplant in North Yorkshire. The first shipment of synthetic gypsum from the Ratcliffe-on-Soar powerplant were expected to begin in 1994.[8]

Lafarge Plasterboard Ltd. awarded a contract for the design and construction of a specialty plaster production plant. The facility will be built at Lafarge's plasterboard plant at Portbury, near Bristol.[9]

OUTLOOK

More than 90% of the gypsum consumed annually in the United States is used in construction, mainly in gypsum wallboard products, building plasters, and the manufacture of portland cement. The decline in construction activity that depressed demand for gypsum products over the past several years appears to have ended. Gypsum product demand recovered in 1992 and 1993, although not to the record highs of 1989. A slow but steady recovery is expected to continue over the next few years.

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[1] Engineering News Record. Dec. 20, 1993, p. 61.

[2] The Wall Street Journal. July 12, 1993, p. 4.

[3] Rock Products. V. 92, No. 12, Dec. 1993, p. 9.

[4] Saporito, B. USG—The Benefits of Bankruptcy. Fortune, July 12, 1993, p. 98.

[5] Chemical Engineering. V. 100, No. 8, Aug. 1993, p. 19.

[6] U.S. Embassy, Muscat, Oman. State Dep. Telegram 01041, Mar. 1993, p. 1.

[7] Rock Products. V. 96, No. 3, Mar. 1993, p. 75.

[8] British Geological Survey. United Kingdom Minerals Yearbook 1993, p. 3-2.

[9] Industrial Minerals (London). No. 312, Sept. 1993, p. 84.

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TABLE 1

SALIENT GYPSUM STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Active mines and plants[1]	112	106	112	109	112
Crude:					
Mined	15,988	14,883	14,021	14,759	15,812
Value	$128,448	$99,567	$94,199	$100,583	$106,539
Imports for consumption	8,440	7,916	6,925	7,180	7,393
Byproduct gypsum sales	658	667	618	630	846
Calcined:					
Produced	16,232	15,924	13,933	15,068	15,226
Value	$285,659	$278,607	$240,663	$249,846	$272,222
Products sold (value)	[2]$1,926,676	[2]$1,712,848	[2]$1,348,714	[2]$1,348,648	$1,780,711
Exports (value)	$60,311	$84,452	$85,613	$96,983	$77,629
Imports for consumption (value)	$111,012	$110,205	$88,141	$96,036	$110,998
World: Production	[r]104,216	[r]104,271	[r]100,141	[r]101,671	[e]103,203

[e] Estimated. [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.

TABLE 2

CRUDE GYPSUM MINED IN THE UNITED STATES, BY STATE

State	1992			1993		
	Active mines	Quantity (thousand metric tons)	Value (thousands)	Active mines	Quantity (thousand metric tons)	Value (thousands)
Arizona and New Mexico	6	696	$5,606	6	791	$6,210
Arkansas, Kansas, Louisiana	5	1,317	10,261	5	1,429	11,077
California, Nevada, Utah	13	2,658	12,903	12	2,901	15,702
Colorado, South Dakota, Wyoming	5	664	4,909	6	707	5,008
Indiana, New York, Ohio, Virginia	5	1,843	16,553	5	1,902	16,510
Iowa	6	1,989	11,626	6	1,988	12,280
Michigan	5	1,606	13,889	5	1,687	14,230
Oklahoma	8	2,361	14,915	8	2,651	15,434
Texas	5	1,624	9,920	5	1,756	10,088
Total[1]	58	14,759	100,583	58	15,812	106,539
Total thousand short tons	XX	16,269	XX	XX	17,430	XX

XX Not applicable.

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

TABLE 3

CALCINED GYPSUM PRODUCED IN THE UNITED STATES, BY STATE

State	1992 Active plants	1992 Quantity (thousand metric tons)	1992 Value (thousands)	1993 Active plants	1993 Quantity (thousand metric tons)	1993 Value (thousands)
Arizona, Colorado, New Mexico, Utah	5	738	$5,895	5	836	$6,842
Arkansas, Louisiana, Oklahoma	7	1,617	24,802	7	1,315	21,246
California	6	1,514	25,366	6	1,520	27,004
Delaware, Maryland, North Carolina, Virginia	6	1,462	31,427	6	1,479	32,162
Florida	3	1,111	10,818	3	1,146	25,688
Georgia	3	582	9,737	3	506	8,584
Illinois, Indiana, Kansas	6	1,256	20,762	6	1,308	21,854
Iowa	5	1,361	20,529	5	1,349	20,255
Massachusetts, New Hampshire, New Jersey	5	919	19,064	5	914	19,919
Michigan	4	570	11,997	4	586	12,326
Nevada	4	977	12,539	4	1,025	15,260
New York	4	919	20,435	4	1,008	22,372
Ohio	3	337	6,791	3	375	7,779
Texas	5	1,127	16,185	5	1,206	18,721
Washington and Wyoming	4	580	13,498	4	654	12,210
Total[1]	70	15,068	249,846	70	15,226	272,222
Total thousand short tons	XX	16,610	XX	XX	16,784	XX

XX Not applicable.

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

TABLE 4

GYPSUM PRODUCTS (MADE FROM DOMESTIC, IMPORTED, AND BYPRODUCT GYPSUM) SOLD OR USED IN THE UNITED STATES, BY USE

(Thousands metric tons and thousand dollars)

Use	1992 Quantity	1992 Value	1993 Quantity	1993 Value
Uncalcined:				
Portland cement	3,022	35,049	3,290	37,719
Agriculture and miscellaneous[1]	2,663	29,681	2,273	34,540
Total[2]	5,685	64,731	5,563	72,260
Total thousand short tons	6,267	XX	6,132	XX
Calcined:				
Plasters	W	W	703	94,868
Prefabricated products[3]	16,629	1,283,917	17,979	1,613,583
Total calcined[4]	16,629	1,283,917	18,682	1,708,451
Total calcined[4] thousand short tons	18,330	XX	20,593	XX
Grand total[2] [4]	22,314	1,348,648	24,245	1,780,711
Grand total[4] thousand short tons	24,597	XX	26,726	XX

W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[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 do not include "Plasters" in 1992.

TABLE 5
PREFABRICATED GYPSUM PRODUCTS SOLD OR USED IN THE UNITED STATES

Product	1992			1993		
	Thousand square feet	Thousand metric tons[1]	Value (thousands)	Thousand square feet	Thousand metric tons[1]	Value (thousands)
Lath:						
3/8 inch	10,400	7	$1,841	8,867	6	$1,606
1/2 inch	300	(2)	45	193	(2)	30
Other	—	—	—	5,867	5	407
Total[4]	10,700	7	1,886	14,927	11	2,044
Total thousand short tons	XX	8	XX	XX	12	XX
Veneer base	397,350	376	30,185	405,815	369	31,929
Sheathing	182,822	162	21,541	218,901	194	24,731
Regular gypsumboard:						
3/8 inch	609,364	468	45,176	778,869	604	62,153
1/2 inch	10,024,439	8,157	533,923	11,180,478	8,986	770,285
5/8 inch	1,273,671	1,221	55,432	1,567,859	1,360	68,185
1 inch	158,482	152	21,847	172,342	165	32,225
Other[3]	142,242	137	16,151	124,062	98	16,611
Total[4]	12,208,198	10,136	672,529	13,823,610	11,213	949,460
Total thousand short tons	XX	11,173	XX	XX	12,360	XX
Type X gypsumboard	4,899,560	4,773	392,447	4,960,743	4,700	381,882
Predecorated wallboard	98,580	85	28,252	90,468	81	27,064
5/16-inch mobile home board	790,567	527	65,250	1,161,521	780	103,847
Water-/moisture-resistant board	566,033	504	63,595	610,398	528	71,261
Other	54,362	55	8,233	117,347	104	21,366
Grand total[4]	19,208,172	16,629	1,283,917	21,403,730	17,979	1,613,583
Grand total thousand short tons	XX	18,330	XX	XX	19,819	XX

XX Not applicable.

[1] Includes weight of paper, metal, or other materials.

[2] Less than 1/2 unit.

[3] Includes 1/4, 7/16, and 3/4-inch gypsumboard.

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

TABLE 6
IMPORTS FOR CONSUMPTION OF CRUDE GYPSUM, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Australia	20	189	30	239
Bahamas, The	—	—	69	429
Canada[1]	5,034	38,913	5,209	44,564
China	29	437	2	227
Dominican Republic	(2)	10	(2)	11
France	(2)	66	(2)	8
Germany	—	—	(2)	3
Jamaica	49	376	76	584
Japan	(2)	3	(2)	9
Mexico	1,747	9,659	1,667	9,264
Netherlands	(2)	4	—	—
Spain	300	3,213	339	2,809
Taiwan	(2)	2	—	—
United Kingdom	1	101	1	76
Total[3]	7,180	52,972	7,393	58,221
Total thousand short tons	7,915	XX	8,149	XX

XX Not applicable.

[1] Includes anhydrite.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 7
SUMMATION OF U.S. GYPSUM AND GYPSUM PRODUCTS TRADE DATA

(Thousand metric tons and thousands dollars)

Year	Crude[1]		Plasters[2]		Boards[3]		Other[4]	Total[5]
	Quantity	Value	Quantity	Value	Quantity	Value	Value	Value
Exports:								
1989	98	2,286	96	15,914	88	25,140	16,972	60,311
1990	117	5,056	85	18,381	63	30,959	30,056	84,452
1991	67	3,720	87	19,872	95	36,943	25,077	85,613
1992	98	3,946	137	22,303	137	39,177	31,557	96,983
1993	69	3,640	156	21,173	91	24,618	28,198	77,629
Imports for consumption:								
1989	8,440	59,107	3	270	322	29,355	22,280	111,012
1990	7,916	61,009	1	236	247	22,786	26,174	110,205
1991	6,925	52,070	10	258	80	7,842	27,971	88,141
1992	7,180	52,972	6	660	96	8,803	33,600	96,036
1993	7,393	58,221	23	1,665	171	16,241	34,870	110,998

[1] Import and export data are for "Gypsum; anhydrite," Harmonized Tariff Schedule 2520.10.0000.

[2] Import and export data are for "Plasters," Harmonized Tariff Schedule 2520.20.0000.

[3] Import and export data are for "Boards, sheets, panels, tiles and similar articles, not ornamented: Faced or reinforced with paper or paperboard only," Harmonized Tariff Schedule 6809.11.0000.

[4] Import and export data are for "Boards, sheets, panels, tiles, and similar articles, not ornamented: other," "Harmonized Tariff Schedule 6809.19.000," and "Other articles," Harmonized Tariff Schedule 6809.90.0000.

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

Source: Bureau of the Census.

TABLE 8
GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Afghanistan[e]	3	3	3	3	3
Algeria[e]	275	250	152	150	150
Angola[e]	57	57	57	57	50
Argentina	402	[r]616	[r]78	[r]567	570
Australia[e]	[r]1,800	[r]1,800	2,000	2,000	2,000
Austria[2]	806	[r]633	655	[r]792	800
Bolivia[e]	(3)	(3)	[r]4	[r]6	(3)
Azerbaijan[4]	—	—	—	[e]100	75
Bhutan[e]	22	22	22	20	20
Bosnia and Herzegovina	—	—	—	[r] [e]50	30
Brazil[2]	861	824	967	[r] [e]970	970
Bulgaria[2]	[r]538	494	[r]63	[r] [e]65	70
Burma[5]	32	33	[r]34	[e]36	35
Canada[2]	[r]9,179	[r]8,790	6,830	[r]7,566	[6]8,097
Chile	277	254	336	[r]424	400
China[e]	[r]9,020	[r]10,180	[r]10,500	[r]11,000	10,600
Colombia	553	[r]608	639	[r]671	640
Croatia	—	—	—	[r] [e]50	50
Cuba[e]	[r]130	[r]130	[r]130	[r]125	125
Cyprus	[e]34	37	[e]37	[r]35	[6]90
Czech Republic[7]	—	—	—	—	650
Czechoslovakia[8]	796	714	[e]624	600	—
Dominican Republic	171	78	118	[r]83	85
Ecuador	[r]11	[r]24	24	[e]24	24
Egypt[2]	1,309	1,279	1,239	[r] [e]1,200	1,200
El Salvador[e]	5	5	[r]5	[r]5	5
Ethiopia[e] [2] [9] [10]	2	2	2	[r] [e]3	25
France[2]	5,684	5,796	[r] [e]5,600	[r]5,160	5,000
Germany (marketable):[2]					
Eastern states	2,678	2,300	—	—	—
Western states	2,201	2,172	—	—	—
Total	4,879	4,472	[e]4,211	[r]4,353	4,300
Greece[2]	541	450	[r] [e]450	[e]400	400
Guatemala	57	66	52	[r]68	60
Honduras[e]	[r]25	[r]25	27	26	26
Hungary[e] [2]	113	112	[r]110	[r]110	110
India	[r]1,564	[r]1,661	1,553	[e]1,550	1,900
Indonesia	(3)	(3)	404	[e]400	400
Iran[11]	7,858	7,724	8,050	[r]8,716	8,600
Iraq[e] [12] [13]	[r]450	380	190	380	400
Ireland	[r]300	394	[r] [e]400	[r] [e]350	350
Israel[e]	31	38	[6]26	26	26
Italy	[r]1,231	[r]1,262	[r] [e]1,285	[r] [e]1,300	1,200
Jamaica	78	82	136	[r]145	144

See footnotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Japan[e]	[r]6,300	[r]6,400	[r]5,400	[r]5,400	5,500
Jordan	132	93	55	[r]83	83
Kenya[e] [2]	[6]36	36	36	36	36
Laos	104	53	77	[r]80	[6]80
Latvia[4]	—	—	—	[e]350	300
Lebanon[e]	2	2	2	2	2
Libya[e]	180	180	180	180	180
Luxembourg[e] [2]	(3)	(3)	(3)	(3)	(3)
Macedonia	—	—	—	[r] [e]30	30
Mali[e]	1	1	1	1	1
Mauritania	6	8	3	3	3
Mexico[2]	5,390	5,434	[r]4,774	[r]5,158	[6]5,828
Moldova[4]	—	—	—	[e]300	250
Mongolia[e]	30	30	25	25	25
Morocco[e]	[r]450	[r]450	[r]450	[r]450	450
Namibia	—	—	—	(3)	(3)
Nicaragua[2]	12	13	16	[r]9	[6]11
Niger[e]	3	1	[6]1	[6]2	2
Pakistan	467	478	522	[r]462	540
Paraguay[e]	[6]5	5	5	5	5
Peru[e]	160	150	[r]160	[r]35	35
Philippines[2]	[e]117	[e]117	[r]28	[r]25	25
Poland[2]	[r]1,416	[r]916	[r]788	[r]843	800
Portugal[e] [2]	300	300	300	[r]417	459
Romania[e]	1,400	800	[r]800	[r]800	800
Russia[4]	—	—	—	[e]1,800	1,500
Saudi Arabia[e]	375	375	375	375	375
Serbia and Montenegro	—	—	—	[r]48	45
Sierra Leone[e]	4	4	4	4	4
Slovakia[2] [7]	—	—	—	—	75
Slovenia	—	—	—	[r] [e]10	10
Somalia[e]	4	3	1	2	2
South Africa, Republic of	407	391	420	334	250
Spain[2]	[e]5,500	[r]7,808	[r]8,054	[r]7,750	7,500
Sudan[e] [2]	[6]10	5	7	10	10
Switzerland[e]	[r]230	[r]230	[r]230	[r]200	200
Syria	180	175	175	[r]234	235
Taiwan	4	2	4	[r]2	[6]3
Tajikistan[4]	—	—	—	[e]500	400
Tanzania[2]	6	36	35	[e]35	35
Thailand	5,477	5,753	7,196	[r]7,111	7,000
Tunisia[e]	100	100	100	100	100
Turkey	214	[r]172	[r]307	[r]278	280
Turkmenistan[4]	—	—	—	[e]300	200

See foonotes at end of table.

TABLE 8—Continued

GYPSUM: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country		1989	1990	1991	1992	1993[e]
U.S.S.R.[14]		4,900	4,500	[e]4,000	[r]—	—
United Arab Emirates[e]		87	89	95	95	95
United Kingdom[e][2]		[r]4,000	[r]4,000	[r]3,500	[r]3,000	3,500
United States[15]		15,988	14,883	14,021	14,759	[6]15,812
Uruguay[e]		[r]145	145	145	145	145
Venezuela		332	201	244	[r]175	180
Vietnam[e]		25	25	30	30	30
Yemen		63	66	[r]100	[r]80	80
Yugoslavia[16]		546	535	[e]450	—	—
Zambia[e][12][13]		15	14	14	[r]13	13
Total[17]	thousand metric tons	[r]104,216	[r]104,271	[r]100,141	[r]101,671	103,203
Total	thousand short tons	[r]114,879	[r]114,939	[r]110,386	[r]112,073	113,761

[e]Estimated. [r]Revised.

[1]Table includes data available through Aug. 3, 1994.

[2]Includes anhydrite.

[3]Less than 1/2 unit.

[4]Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5]Data are for years beginning Apr. 1 of that stated.

[6]Reported figure.

[7]Formerly part of Czechoslovakia; data were not reported separately until 1993.

[8]Dissolved Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from the Czech Republic and Slovakia.

[9]Data are for years ending July 7 of that stated. Reported in cubic meters and estimated at mean weight of 1.8 tons per cubic meter.

[10]Probably does not include production for cement manufacture (normally 3% to 5% of finished cement, equivalent of an additional 12,000 to 15,000 metric tons per year).

[11]Data are for years beginning Mar. 21 of that stated.

[12]For cement production only. Information is insufficient to formulate reliable estimates for output for other uses (plaster, mortar, etc.).

[13]Data are for years beginning on Mar. 1 of that stated.

[14]Dissolved in Dec. 1991.

[15]Excludes byproduct gypsum.

[16]Dissolved in Apr. 1992.

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

FIGURE 1
SUPPLY OF CRUDE GYPSUM IN THE UNITED STATES

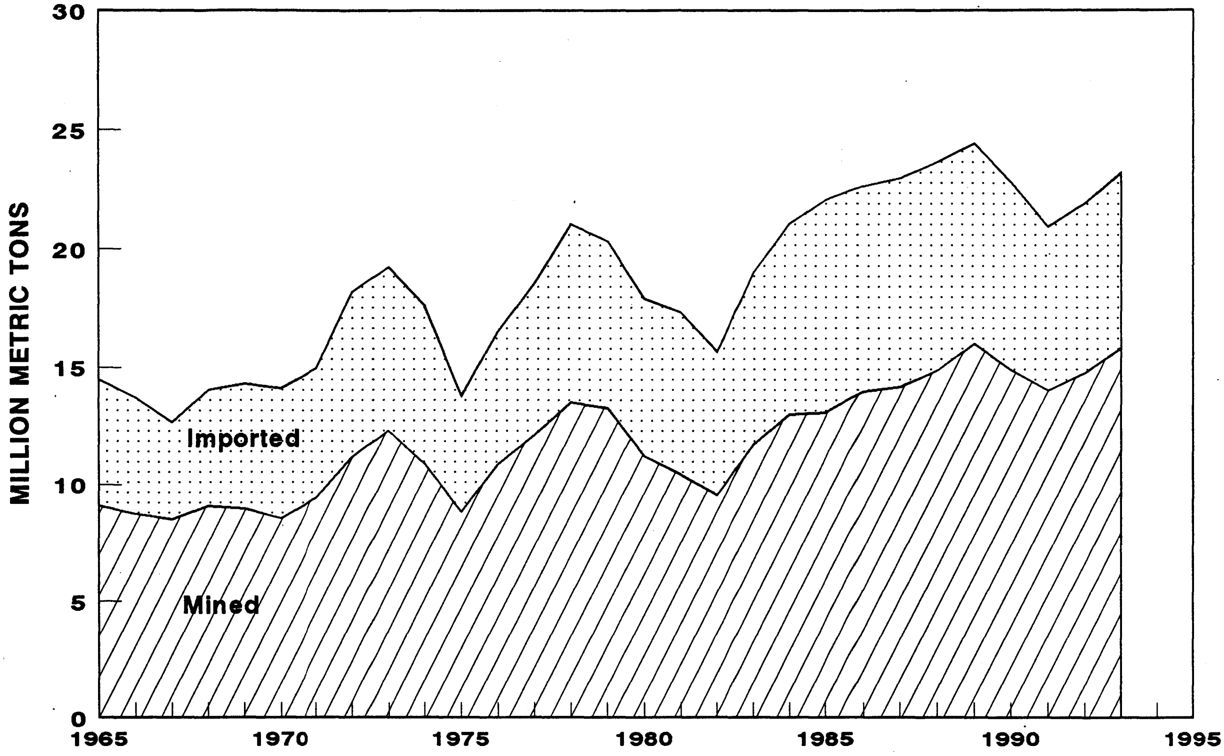
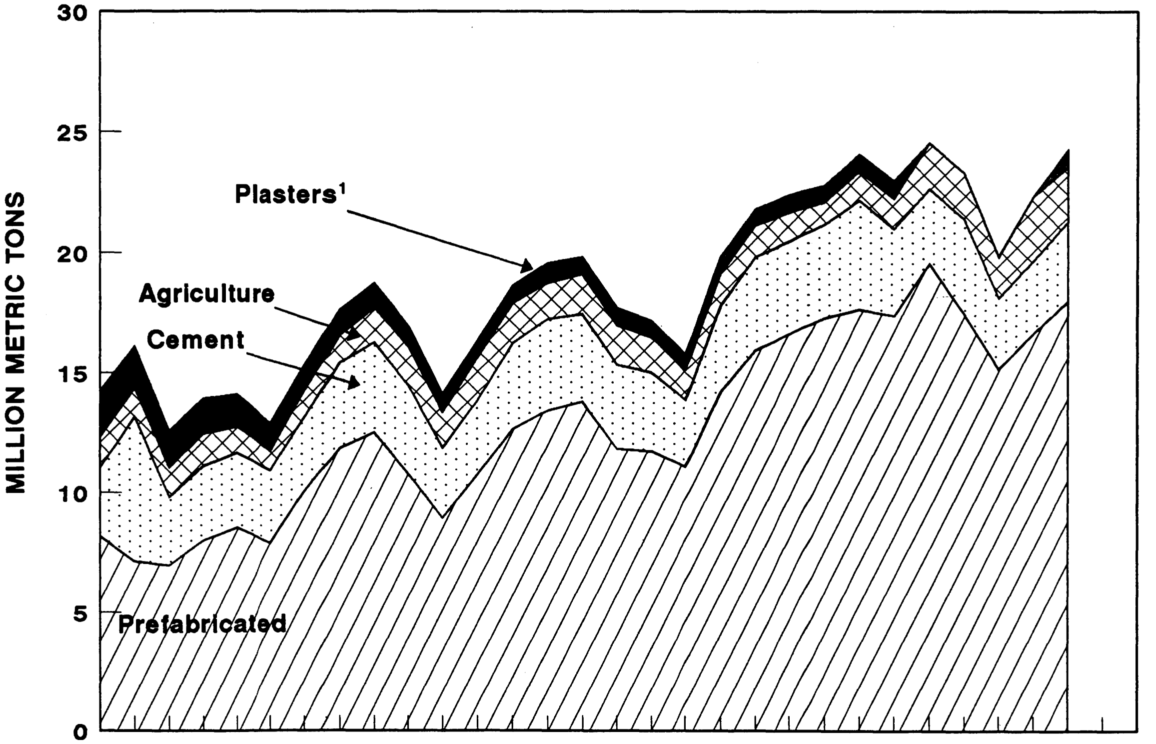


FIGURE 2
SALES OF GYPUSM PRODUCTS, BY USE



[1]Plaster data withheld from 1989 through 1992.

HELIUM

By William D. Leachman

Mr. Leachman, a chemical engineer with 40 years of U.S. Bureau of Mines experience, has been the commodity specialist for helium since 1983. He also prepared the domestic survey and international data tables.

Grade-A helium (99.995% or better) sales volume in the United States by private industry and the U.S. Bureau of Mines (USBM) was 67.6 million cubic meters [2,437 million cubic feet (MMcf)] in 1993.[1] Grade-A helium exports by private producers were 28.0 million cubic meters (1,008 MMcf), for total sales of 95.6 million cubic meters (3,445 MMcf) of U.S. helium. The USBM price for Grade-A helium, f.o.b. plant, was $1.983 per cubic meter [$55 per thousand cubic feet (Mcf)] and bulk liquid helium was $2.379 per cubic meter ($66 per Mcf) on January 1, 1993, with additional costs for container services and rent. On October 1, 1993, the bulk liquid helium price was raised to $2.524 per cubic meter ($70 per Mcf). Private industry also increased its helium prices last year, but they are lower than the USBM's.

DOMESTIC DATA COVERAGE

Domestic production data for helium are developed by the USBM 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 USBM operations represent 100% of the total helium sales and recovery shown in table 2.

BACKGROUND

The USBM 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 USBM for assistance because of its natural gas expertise. In 1925, the Government's Helium Program was officially placed under USBM control by Congress (Helium Act of 1925). In 1929, the USBM Amarillo, TX, large-scale helium extraction and purification facility was built and began operation. During World War II, demand increased significantly, and four more small Government helium plants were built.

New technology increased helium demand in the 1950's and led to the construction of the Keyes, OK, plant in 1959. Dwindling Hugoton-Panhandle Field natural gas supplies aroused concerns that no economic source of helium would exist by the turn of the century.

In 1960, Congress replaced the 1925 act with new legislation (Helium Act Amendments of 1960). The purposes of the act were to provide for conservation of helium for essential Government activities and to supply the current and foreseeable future helium needs of Federal agencies. The act directed the Secretary of the Interior to purchase and store helium for future Government use and to operate and maintain helium production and purification plants and related helium storage, transmission, and shipping facilities.

Purchases for helium conservation were made under 22-year contracts with private natural gas companies, which added crude helium extraction capabilities to their existing gas processing facilities. Four companies built five crude helium plants. The USBM constructed a high-pressure pipeline to transport the helium from Bushton, KS, and intermediate points to the USBM-owned Cliffside Field near Amarillo, TX, for storage.

Helium needs of Federal agencies, particularly the U.S. Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE), have been met, and there is enough helium in storage to meet their foreseeable needs. The present Federal helium demand is supplied solely by the USBM's Exell Helium Plant, 56 kilometers (35 miles) north of Amarillo.

In the mid-1970's, the USBM began accepting privately owned crude helium for storage in Cliffside under long-term contracts. Private industry currently has a 9-month supply of helium in Government storage, assuming all private market requirements would be supplied from storage.

Geology-Resources

Domestic measured and indicated helium resources as of January 1, 1993, the latest figures available, are estimated to be 13 billion cubic meters [467 billion cubic feet (Bcf)]. The resources include measured reserves and indicated resources estimated at 6.9 billion cubic meters (248 Bcf) and 0.9 billion cubic meters (33 Bcf), respectively, in natural gas with a minimum helium content of 0.3%. A slight increase in the measured reserves of helium is reported due to ongoing evaluations of the Nation's depleting helium resources. The measured reserves included 1 billion cubic meters (35 Bcf) stored by the USBM in the helium conservation storage system. Measured helium resources in natural gas with a helium content of less than 0.3% are estimated to be 1.2 billion cubic meters (44 Bcf). Indicated helium resources in natural gas with a helium content of less than 0.3% are estimated to be 4 billion cubic meters (143 Bcf). Approximately 4.5 billion cubic meters (163 Bcf) or 91% of the domestic helium resources under Federal ownership are in the Riley Ridge area and the Church Buttes Field in Wyoming and in the Cliffside Field in Texas.

Most of the domestic helium resources are in the midcontinent and Rocky Mountain regions of the United States. The measured helium reserves are in approximately 98 gasfields in 11 States. About 83% of these reserves is contained in the Hugoton Field in Kansas, Oklahoma, and Texas; the Keyes Field in Oklahoma; the Panhandle and Cliffside Fields in Texas; and the Riley Ridge area in Wyoming. The USBM analyzed a total of 220 natural gas samples from 19 States and 2 foreign countries during 1993 in conjunction with its program to survey and identify possible new sources of helium.

Technology

Technology that uses liquid helium to produce superconducting temperatures continues to be developed and utilized. Liquid helium continues to be used at Fermi National Accelerator Laboratory for Tevatron/Tevatron 1, which was the world's first superconducting particle accelerator. The liquid helium-cooled superconducting magnets used in this accelerator provide an intense and extremely steady magnetic field using only a fraction of the energy required by conventional electromagnets. The Tevatron is presently the second most energetic particle accelerator in the world (1.6 trillion electron volts). In 1993, the Superconducting Supercollider (SSC) project, which would have used liquid helium-cooled superconducting magnets, was terminated by Congress.

Argonne National Laboratory is developing a marine magnetohydrodynamic (MHD) propulsion system for military and commercial use. This system has no moving parts, but uses magnetic fields and electricity to pump water through a tube. This method of propulsion was illustrated in the film "Hunt for Red October." Researchers at Argonne used the world's largest liquid-helium-cooled superconducting dipole magnet to study this propulsion system. Development of this technology could lead to a new generation of water transportation vessels that would travel more quickly, quietly, and efficiently than present ships.

Liquid helium use in magnetic resonance imaging (MRI) continues to increase as the medical profession accepts and develops new uses for this equipment. MRI equipment is providing accurate diagnoses of medical problems where exploratory surgery was previously required. Another medical application being developed uses MRI to determine through blood analysis if a patient has any form of cancer. Most researchers seem to think it will be at least 4 to 8 years before uses of the new high-temperature (about -184 °C or -300 °F) superconducting materials affect liquid helium demand.

Lifting gas applications are increasing. The U.S. Navy and U.S. Air Force are investigating the use of airships to provide early warning systems to detect low-flying cruise missiles. The Drug Enforcement Administration has installed six tethered radar blimps along the southern border of the United States to detect drug smugglers. In addition, NASA is now using helium-filled balloons to sample the atmosphere in Antarctica to determine what is depleting the ozone layer that protects the Earth from harmful ultraviolet radiation. A helium-filled balloon also will lift the solar observatory to the edge of space from Antarctica to study sunspots. The project originally was planned to be launched from the space shuttle, but about $400 million will be saved by using helium to lift the 2-ton observatory. A stealth blimp is being tested by the Army's Intelligence and Electronic Warfare Center in New Jersey. In the commercial market, several companies in addition to Goodyear are now using "blimps" for advertising.

The development of Strategic Defense Initiative (SDI) weapons such as the antisatellite (ASAT) rocket, chemical laser, and rail gun has slowed with the decline of the "cold war." The ASAT rocket uses liquid helium-cooled infrared sensors for target location and guidance. Gaseous helium is used in the lasing gas mixture of the chemical laser, and liquid helium is used to cool the tracking telescope used to locate the target and aim the laser beam. High-pressure gaseous helium provides the initial push that inserts the projectile into the bore of the rail gun at a velocity of about 1,770 kilometers per hour (1,100 miles per hour). Electromagnetic energy applied along the bore accelerates the projectile to a final velocity of about 14,500 kilometers per hour (9,000 miles per hour). Superconducting magnetic energy storage (SMES) also is being investigated to provide power for DOD laser systems and electric power peak shaving in commercial applications. SMES allows the accumulation and storage of electrical energy over the long term (hours) when excess capacity is available and discharges it in minutes or as needed to provide for peak demands. Some small commercial units are already in service.

Other evolving technologies that require the unique properties of helium are (1) metastable helium for energy storage, which involves raising helium electrons to an excited energy state and then stabilizing the atom there; (2) fiber-optic production, where an ultrapure inert atmosphere is required; (3) helium-filled plastic pillows, where helium's low density is required to simulate a precursor wave from a nuclear blast; (4) helium ion tumor treatment, where large inert particles are required; (5) liquid helium-cooled superconducting microswitches, called Josephson junctions, which are much faster than conventional semiconductors and use less power; (6) "Aneutronic" nuclear fusion, where nuclear energy is produced by fusion of deuterium and helium-3, results in few or no neutrons; (7) helium-hydrogen breathing mixtures that enable deep-sea divers to reach depths below 580 meters (1,700 feet); and (8) an 11% oxygen-in-helium mixture is being used at NASA's Ames Research Center in its combustion-driven Shock Tunnel Facility. This facility is similar to a wind tunnel but provides much higher pressures and velocities needed to test space plane models at Mach 16.

ANNUAL REVIEW

Legislation and Government Programs

The Federal Helium Program is designed to provide all Federal agencies with their current and foreseeable future helium needs to carry out other Government programs authorized and funded by Congress. The USBM's major helium customers are DOD, NASA, and DOE.

In the Vice President's National Performance Review, it was determined that the Federal Government needed to reexamine its role in the Federal Helium Program. The report states that the program can be run more efficiently, reducing outlays by Federal helium customers and increasing revenue. Suggestions were made to cancel the helium debt, reduce the selling price for USBM helium, discontinue nonrevenue-producing functions, increase efficiencies of helium operations, and begin sales of crude helium as market conditions permit. The USBM is implementing these suggestions into the operation of the Helium Program.

Production

In 1993, 16 privately owned domestic helium plants were operated by 12 companies. Eleven of the privately owned plants and the USBM plant extracted helium from natural gas. All extraction plants except one use cryogenic extraction processes. The volume of helium recovered from natural gas increased 8%, while sales only increased about 1% in 1993. A shortage of private helium production was prevented by purifying crude helium that had been stored in the USBM's Cliffside Field. All natural gas processed for helium recovery came from gasfields in Colorado, Kansas, Oklahoma, Texas, and Wyoming. Seven private plants and the USBM's plant purified helium this year. Pressure-swing adsorption is used for helium purification at all seven of the private helium plants and at the USBM's plant. The USBM also uses cryogenic purification for backup. The USBM and six private plants that produce Grade-A helium also liquefy helium. The plant operators and locations are Air Products and Chemicals Inc., Hansford County, TX, and Liberal, KS; Exxon Co., U.S.A., Shute Creek, WY; Kansas Refined Helium Co., Otis, KS; and Praxair, Inc., Bushton and Ulysses, KS. Nitrotec's helium plant near Burlington, CO, produces Grade-A helium but does not liquefy it. *(See tables 1, 2, and 3, and figures 1 and 2.)*

Consumption and Uses

The major domestic end uses of helium were cryogenics, welding, and pressurizing and purging. Minor uses included synthetic breathing mixtures, chromatography, leak detection, lifting gas, heat transfer, and controlled atmospheres. *(See figure 3.)* The Pacific and Gulf Coast States were the principal areas of helium consumption.

USBM's sales to Federal agencies and their contractors totaled 7.933 million cubic meters (286 MMcf) in 1993, a decrease of about 8% when compared with last year's sales. This decrease was due largely to slowdowns in DOD programs as the cold war eased and budget restraints imposed on NASA and DOE by Congress.

The Federal agencies purchase their major helium requirements from the USBM. Direct helium purchases by DOD, NASA, DOE, and the National Weather Service constituted most of the USBM's Grade-A helium sales. Most remaining helium sales to Federal agencies were made through USBM contract distributors, who purchased equivalent volumes of USBM helium under contracts described in the Code of Federal Regulations (30 CFR 602). Some of the contract distributors also have General Services Administration helium supply contracts. These contracts make relatively small volumes of helium readily available to Federal installations at lower freight charges by using the contractors' existing distribution systems.

Stocks

The volume of helium stored in the USBM helium conservation storage system, including the conservation pipeline network and Cliffside Field, totaled 0.95 billion cubic meters (34.3 Bcf) at yearend. The storage system contains crude helium purchased under contract by the USBM from 1962 to 1973 and privately owned helium stored under contract. Excess private helium is extracted from natural gas supplying fuel markets in the winter and stored by the USBM under contract. This privately owned crude helium is returned to the owners as needed for purification to supply private demand. During 1993, 29.6 million cubic meters (1,069 MMcf) of private helium was delivered to the USBM's helium conservation storage system and 17 million cubic meters (613 MMcf) was withdrawn for a net increase of 12.6 million cubic meters (456 MMcf) of private helium in storage. *(See table 4.)*

Transportation

All Grade-A gaseous helium sold by the USBM was shipped in cylinders, modules (large gas cylinders), special railway tankcars, or highway tube semitrailers. Small gas cylinders are filled at the Amarillo plant, and railway tankcars are filled at the Exell plant. Other shipping containers for gaseous helium can be filled at either plant. The USBM's liquid helium was shipped in dewars and semitrailers from the Exell plant. Private producers and/or distributors shipped helium predominantly as a liquid in semitrailers. These semitrailers delivered the liquid helium to distribution centers where some of it was gasified and compressed into trailers and small cylinders for delivery to the end user. The remaining liquid helium was sold as bulk liquid or repackaged in dewars of various sizes for delivery.

Prices

The USBM price for Grade-A helium, f.o.b. plant, was $1.983 per cubic meter ($55 per Mcf) and bulk liquid helium was

$2.379 per cubic meter ($66 per Mcf) on January 1, 1993, with additional costs for container services and rent. On November 1, 1993, the bulk liquid helium price was raised to $2.524 per cubic meter ($70 per Mcf). Private industry also increased its helium prices last year, but lagged behind the USBM's price.

Foreign Trade

Exports of Grade-A helium, all by private industry, decreased by 9% in 1993 to 28 million cubic meters (1,008 MMcf). *(See table 3.)* About 45% of the exported helium was shipped to Europe. Belgium-Luxembourg, France, and the United Kingdom, collectively, received about 88% of the European exports. About 36% of the U.S. helium exports went to Asia, with Japan receiving about 84%. Other exports were as follows: about 8% to North America; about 4% to Australia-New Zealand, 3% to the Middle East; 2% to South America; 1% to Central America; and less than 1% each to Africa and the Caribbean. The shipments of large volumes of helium to Western Europe were attributed to helium uses in cryogenic research and superconducting applications. Significant volumes also were used in breathing mixtures for diving, welding, and as a lifting gas. Although no helium was imported by the United States in 1993, import tariffs on helium remained at the 3.7% rate for most favored nations established on January 1, 1987. The non-most-favored-nation tariff also remained unchanged at 25%. No changes in import tariffs are scheduled at this time.

World Review

World production of helium, excluding the United States, was estimated to be 11 billion cubic meters (400 MMcf), most of which was extracted in Poland and Russia. The remainder was produced in small plants in China and India. *(See table 5.)*

OUTLOOK

Until recently, all superconductors required liquid helium (-269°C or -452°F) to reach superconducting temperatures. Current research on superconductors has resulted in the discovery of superconducting materials that operate above liquid nitrogen temperatures (-196° C or -320°F). These new superconductors have physical limitations, such as brittleness and poor current-carrying capacities, which have precluded their use in most superconducting applications. As these physical problems are solved, the new materials will replace liquid helium-cooled superconductors.

Since 1989, the market for U.S.-produced helium has grown at an average annual rate of 4.6%. Private industry's market has been growing at 5.7% per year, while the Federal market has dropped 18% since 1989. In 1993, private industry supplied about 88% of the domestic demand while the USBM supplied the remaining 12%. Private industry supplies all of the U.S. helium exports. The foreign market decreased this year, accounting for only 29.3% of U.S. helium sales, but it has grown at an average rate of almost 6% per year since 1989.

The outlook for helium is slowing in the Federal sector with cutbacks and elimination of programs that use large volumes of helium. High-temperature superconductors are beginning to be used in commercial applications, but an adverse impact is not expected in the near future.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Helium. Ch. in Commodity Annual Report, annual.
Helium. Ch. in Minerals Commodity Summary, annual.
Information Circular 9129, Analyses of Natural Gases, 1917-85, by B. J. Moore and S. Sigler.
Information Circular 9301, Analyses of Natural Gases, 1986-90, by J. E. Hamak and S. Sigler.
Information Circular 9318, Analyses of Natural Gases, 1991, by J. E. Hamak and B. D. Gage.
Information Circular 9356, Analyses of Natural Gases, 1992, by J. E. Hamak and S. Sigler.
Information Circular 9342, Helium Resources of the United States, 1991, by J. E. Hamak and B. D. Gage.

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[1] All metric helium volumes herein reported are at 101.325 kilopascals absolute (14.696 psia) and 15 °C (59 °F). Helium volumes, reported in parentheses following metric units, are measured in cubic feet at 14.7 psia and 70 °F. One thousand cubic feet (1 Mcf) at 14.7 psia and 70 °F = 27.737 cubic meters at 101.325 kilopascals absolute and 15 °C. One cubic meter at 101.325 kilopascals and 15 °C = 36.053 ft^3 at 14.7 psia and 70 °F.

TABLE 1
OWNERSHIP AND LOCATION OF HELIUM EXTRACTION PLANTS IN THE UNITED STATES IN 1993

Category and owner or operator	Location	Product purity
Government-owned:		
U.S. Bureau of Mines	Masterson, TX	Grade-A helium[1]
Private industry:		
Air Products Helium, Inc.	Hansford County, TX	Do.
Do.	Liberal, KS	Do.
Enron Helium Co.	Bushton, KS	Crude helium
Exxon Co., U.S.A.	Shute Creek WY	Grade-A helium[1]
Kansas Refined Helium Co.	Otis, KS	Do.
KN Energy, Inc.	Scott City, KS	Crude helium[2]
National Helium Corp.	Liberal, KS	Crude helium
Maxus Energy Corp.	Sunray, TX	Do.
Mesa, Inc.	Fain, TX	Do.
Do.	Satanta, KS	Do.
Nitrotec	Burlington, CO	Grade-A helium
Trident NGL, Inc.	Ulysses, KS	Crude helium
Phillips Petroleum Co.	Dumas, TX	Do.
Do.	Hansford County, TX	Do.
Praxair, Inc.	Bushton, KS	Grade-A helium[1]
Do.	Elkhart, KS	Deactivated
Do.	Ulysses, KS	Grade-A helium[1]

[1] Including liquefaction.

[2] Output is piped to Ulysses, KS, for purification.

TABLE 2
HELIUM RECOVERY IN THE UNITED STATES[1]

(Thousand cubic meters)

	1989	1990	1991	1992	1993
Crude helium:					
U.S. Bureau of Mines total storage	(10,471)	(12,837)	(9,551)	(9,359)	(8,849)
Private industry:					
Stored by U.S. Bureau of Mines	15,176	14,064	26,580	25,319	29,641
Withdrawn	(18,120)	(21,265)	(18,105)	(17,874)	(16,378)
Total private industry storage	(2,943)	(7,201)	8,475	7,445	13,263
Total crude helium	(13,414)	(20,038)	(1,076)	(1,914)	4,414
Stored private crude helium withdrawn from storage and purified by the U.S. Bureau of Mines for redelivery to industry	(152)	(178)	(613)	(510)	(638)
Grade-A helium:					
U.S. Bureau of Mines sold	9,712	11,170	9,399	8,630	7,933
Private industry sold	70,153	73,665	78,702	85,762	87,625
Total sold	79,865	84,835	88,101	94,392	95,558
Total stored	(13,566)	(20,216)	(1,689)	(2,424)	3,776
Grand total recovery	66,299	64,619	86,412	91,968	99,334

[1] Negative numbers are enclosed in parenthesis ( ) to denote net withdrawal from the USBM's underground storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.

TABLE 3
TOTAL SALES OF GRADE-A HELIUM PRODUCED IN THE UNITED STATES

(Million cubic meters)

Year	Volume		
	Domestic sales	Exports[1]	Total sales
1989	57.8	22.1	79.9
1990	60.1	24.7	84.8
1991	61.0	27.1	88.1
1992	63.7	30.7	94.4
1993	67.6	28.0	95.6

[1] Source: Bureau of the Census.

TABLE 4
SUMMARY OF U.S. BUREAU OF MINES HELIUM CONSERVATION STORAGE SYSTEM OPERATIONS [1]

(Thousand cubic meters)

	1991	1992	1993
Helium in conservation storage system at beginning of period:			
Stored under U.S. Bureau of Mines conservation program	912,999	903,448	894,089
Stored for private producers under contract	41,300	49,161	56,096
Total	954,299	952,609	950,185
Input to system:			
Net deliveries from U.S. Bureau of Mines plants[2]	(9,551)	(9,359)	(8,849)
Stored for private producers under contract	26,580	25,319	29,641
Total	17,029	15,960	20,792
Redelivery of helium stored for private producers under contract[2]	(18,718)	(18,384)	(17,016)
Net addition to system[2]	(1,689)	(2,424)	3,776
Helium in conservation storage system at end of period:			
Stored under U.S. Bureau of Mines conservation program	903,448	894,089	885,240
Stored for private producers under contract	49,161	56,096	68,721
Total	952,609	950,185	953,961

[1] Crude helium is injected into or withdrawn from the USBM's underground storage facility, a partially depleted natural gas reservoir in Cliffside Field near Amarillo, TX.

[2] Numbers in parentheses indicate net withdrawal from storage.

TABLE 5
WORLD GRADE-A HELIUM PRODUCTION CAPACITY, DECEMBER 31, 1993

(Million cubic meters)

	Capacity
United States	[1]111
Rest of world[e]	11
Total[e]	122

[e] Estimated.

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

FIGURE 1
HELIUM RECOVERY IN THE UNITED STATES

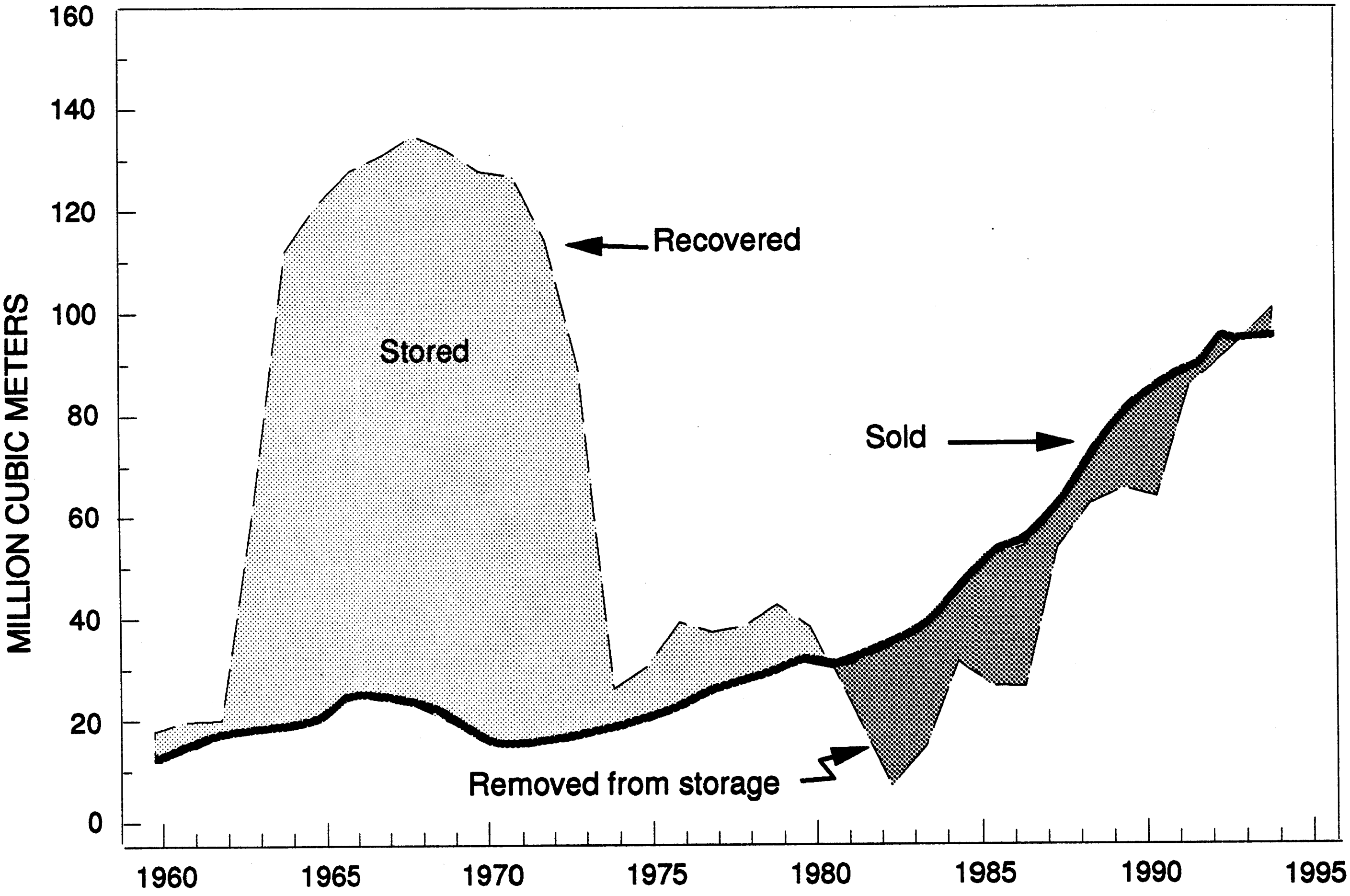


FIGURE 2
MAJOR U.S. HELIUM-BEARING NATURAL GAS FIELDS

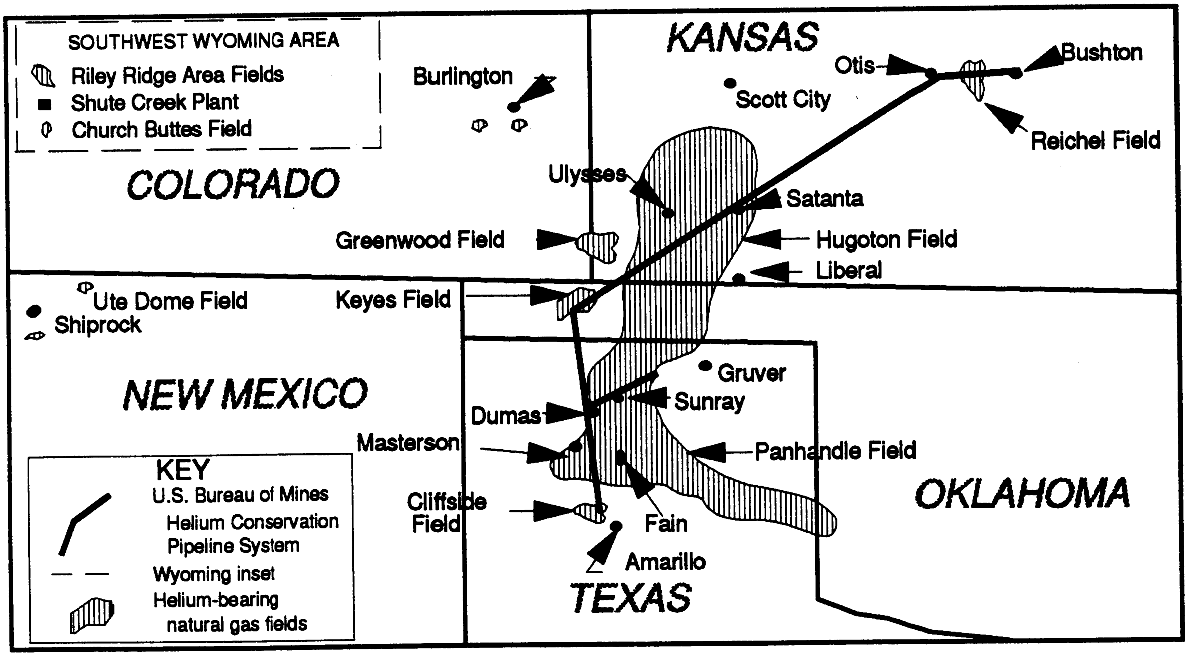
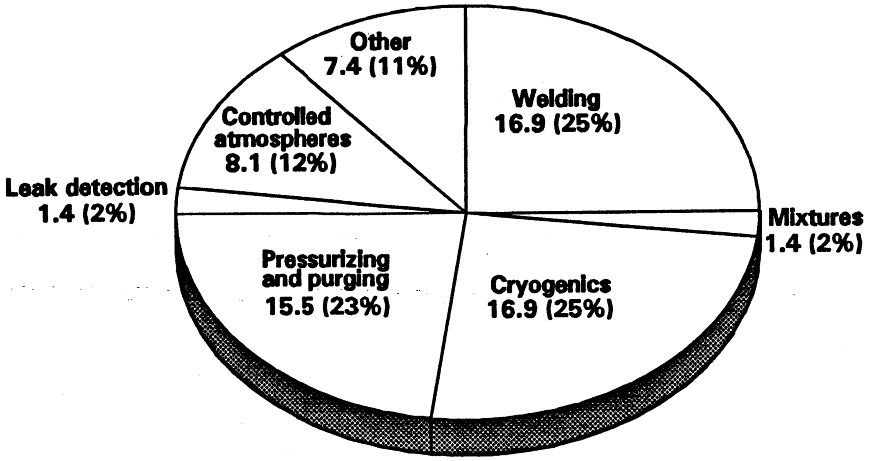


FIGURE 3

ESTIMATED HELIUM CONSUMPTION, BY END USE, IN THE UNITED STATES IN 1993

(Million cubic meters)



Estimated total helium used
(67.6 million cubic meters)

IODINE

By Phyllis A. Lyday

Mrs. Lyday, a physical scientist with the U.S. Bureau of Mines, has been the commodity specialist for iodine for 15 years. Domestic survey data were prepared by Gail Mason, statistical assistant; and international data tables were prepared by Amy Durham, international data coordinator.

Three producers of crude iodine supplied approximately 55% of domestic demand; the remainder was imported. Because some exports and imports are in product categories rather than crude products, net imports are not clearly developed. The major world producer, Japan, produced iodine from brines associated with gas production. The second largest producer, Chile, produced iodine as a coproduct of sodium nitrate.

DOMESTIC DATA COVERAGE

Domestic production data for iodine are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. operations. Of the four operations to which a survey request was sent, four responded, representing an estimated 100% of the total production shown in tables 1 and 6. *(See tables 1 and 6.)*

BACKGROUND

Definitions, Grades, and Specifications

Commercial crude iodine normally has a minimum purity of 99.5%. Resublimed iodine is usually 99.9% pure. Most iodine is converted for industrial use to potassium iodide, sodium iodide, and other inorganic compounds, as well as numerous organic compounds.

Geology-Resources

Iodine occurs in rocks and soils, surface and underground brines, and caliche ores. Michigan brines contain about 30 parts per million (ppm) of iodine in the Sylvania Formation of Devonian age. California brines contain 30 to 70 ppm of iodine in brines associated with oilfields in the middle Miocene age, Monterey Formation, and the lower Pliocene age Repetto Formation. Louisiana brines contain about 35 ppm of iodine. In Oklahoma, iodine concentrations associated with oil and gas range between 150 and 1,200 ppm. In Woodward County, OK, iodine occurs in the Morrowan Formation of Pennsylvania age. The iodine concentration averages about 300 to 350 milligrams per liter; 22 barrels of brines are required for each kilogram of iodine.

Extensive iodine-bearing nitrate ores occur in caliche deposits in a belt several hundred kilometers long in the Atacama Desert of northern Chile. The ore layers are 1 to 3 meters thick, usually flat or gently dipping and near the surface. Evaporate minerals such as lautarite (CaI_2O_6) and dietzeite ($2CaO{\cdot}I_2O_5{\cdot}CrO_3$) occur as cementing material in unconsolidated surface material or as veins and impregnations in bedrock.

Japanese brines contain 50 to 135 ppm of iodine in the Kiwada, Otadai, and Umegase Formations of the Kazusa Group of Pliocene age. The major iodine-producing area was the southern Kanto Gasfield, which extends over Chiba, Tokyo, and Kanagawa Prefectures. Iodine was produced in the Niigata and Nakojo Gasfields in Niigata Prefecture, on the Sea of Japan side of central Japan, and the Sadowara Gasfield in Miyazaki Prefecture, southern Kyushu.

In Indonesia, iodine occurs with trace amounts of bromine in brines associated with oil. The most important iodine-producing area is the Gujangon anticline of sandstone and diatomaceous marls of the Upper Pliocene, Kailiberg Formation.

On Okinawa, iodine occurs in concentrations of about 85 ppm in the Tomigusuku Formation of the Shimajiri Group of late Miocene-early Pleistocene age.

Technology

Processing.—In Japan and the United States, iodine is removed from brines by processes that separate the brines from any associated hydrocarbons. In the blowing-out process, brine is acidified and iodine is liberated by reducing the pH to about 3. A countercurrent stream of air transports the liberated iodine to a second tower where the iodine is absorbed by a solution of hydriodic acid. The iodine settles, is filtered, and is melted under concentrated acid. Brine stripped of iodine is treated and then injected into its subsurface formation of origin.

In the absorption process, brine is passed through an absorber, and the waste brine is neutralized and sent to a disposal well. The absorbent laden with iodine is treated with an alkaline solution to regenerate the absorbent and eludes iodine as sodium iodide. Iodide is precipitated under acid.

Japanese plants also use an ion-exchange resin. Upon saturation, the iodine is eluted using a caustic solution that regenerates the resin. Iodine is then processed with a sodium chloride solution and melted under acid.

Chilean caliche deposits are mined by open pit methods. The ore is leached with an alkaline solution to dissolve the iodine as sodium iodate, which is converted to sodium iodide. Iodine is precipitated by reacting with additional alkaline solution. The precipitated iodine is filtered in bag filters, and the iodine free-leach solution is returned to the nitrate-leaching cycle.

Recycling.—The removal of ionic silver from photographic processing solutions, such as developer, fixer, bleach fixers, and wash waters, can be accomplished with halogens such as iodine and an adsorbent. Photographic silver is commonly recovered by electrolytic methods if the concentration is greater than 500 ppm. Adsorbents such as natural and synthetic zeolites, activated alumina, activated silica, Fuller's earth, and ion exchange resins are used to recover low concentrations of silver from a stream.

Economic Factors

Prices.—Changes in the official price of crude iodine have in the past been initiated during shortages. Because iodine cannot be substituted readily in radiopaque media, animal feeds, catalysts, and stabilizers shortages tend to cause the accumulation of inventories to ensure an adequate supply. An adequate supply tends to lower and stabilize the price.

Costs.—One typical iodine brine well costs about $2 million to complete and is between 1,800 and 3,000 meters deep. Electrical costs for maintaining the pumps to bring the brine to the surface, for air-blowing the iodine, and for injecting the brine are major components of maintenance costs. Capital costs have been estimated at $20 per pound of annual iodine production. These costs include high-quality stainless steels because iodine is highly corrosive. In addition, the brine must be leased from private landowners over large acreage for many years. The principal material cost is for chlorine because 1 pound is required for every 1.4 to 1.8 pounds of iodine produced.

Tariffs.—Crude and resublimed iodine enters the United States duty free. Calcium and cuprous iodine has a 25% ad valorem duty for non-most-favored-nation (MFN) status. Potassium iodide has duties of 2.8% ad valorem for MFN status and 7.5% ad valorem for non-MFN status.

Depletion Provisions.—The domestic and foreign depletion allowances for mined iodine are 14% of gross income, and they may not exceed 50% of net income without the depletion deduction. The domestic and foreign depletion allowances for minerals from brine wells are 5%. The domestic and foreign depletion allowances for solid minerals are 14%.

Operating Factors

Environmental Requirements.—The injection 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 injection wells for iodine in Oklahoma were drilled for the injection of waste associated with brine production or oil and gas effluent. Woodward Iodine Corp. operated 22 production wells and injected the waste brine through 10 injections wells. Brine-production and injections wells are 2,130 to 2,290 meters deep. IoChem Corp. had nine production wells and four injection wells. North American Brine Resources operated iodine production facilities at the site of two injection wells for waste brines associated with oil production.[1]

Toxicity.—Iodine is absorbed by the body and concentrated in the thyroid. Iodine is essential to higher animals and humans. A normal person requires about 75 milligrams of iodine per year, which is usually consumed as iodized salt that contains one part sodium or potassium iodide to 100,000 parts of sodium chloride. Iodine deficiency is a major cause of goiter.

The maximum safe concentration of iodine for short-term air environment exposure of up to 1 hour is 1.0 ppm. Exposure of the lungs and eyes can be irritating at concentrations of 0.1 ppm and should be avoided. Greater exposure can cause severe irritations to the eyes and the respiratory tract and may lead to pulmonary edema.

In 1979 and 1986, nuclear accidents caused the release of radioactive iodine, I^{131}, into the atmosphere. A dosage of potassium iodide (KI) administered before or shortly after exposure to radioactive iodine can block the intake of radiation to the thyroid. The dosage must be repeated if exposure continues. Replenishing the thyroid with KI prevents the thyroid from using radioactive I^{131} for normal metabolic needs.

During the 1940's and 1950's, civilians living near the Hanford nuclear weapons plant in Washington were deliberately exposed to high levels of radiation in the form of radioactive iodine. The iodine was deposited on grass that was eaten by cows and conveyed to humans through milk. More than 800,000 people in a 194,000-square-kilometer area of eastern Washington and parts of Idaho and Oregon and some children may have been exposed to as much as 870 rads and adults may have absorbed 350 rads to their thyroid. Federal guidelines call for evacuation if the dose to the thyroid reaches between 5 and 25 rads.[2]

The Joint Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Expert Committee on Food Additives and No. 832 in the WHO Technical Report Series released its 40th report. The report is an evaluation of certain veterinary drug residues in food. Closantel, an anthelmintic containing 38% iodine by weight, was one of five anthelmintics examined for acceptable daily intakes and maximum residue limits in food-producing animals. The report identifies deficiencies in the available data and specifies the further information required for reevaluation.[3]

ANNUAL REVIEW

Legislation and Government Programs

The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), proposed in the Federal Register June 12, 1992, to amend its existing air contaminant standards that set permissible exposure limits (PEL's) for the maritime, construction, and agriculture industry sectors. Only employees of farms with more than 10 employees are covered under OSHA standards. Included in the proposed PEL's are iodoform and methyl iodide.

The EPA announced that the use of Iprodione will not be used in processed foods. EPA announced that the pesticide posed only a negligible risk to public health, but was seeking to comply with a 1992 Federal court decision. The action, announced jointly with the Food and Drug Administration and the U.S. Department of Agriculture, was expected to increase the need for a workable alternative to the "Delaney clause" risk standard. The clause required the Federal Government to ban from processed foods any substance found to cause cancer in animals. Although there is a need for a standard for assessing potential harm to human health, there is little consensus on a proposal to replace the clause.[4]

Strategic Considerations

The National Defense Stockpile contained 2,631,292 kilograms of crude iodine. The stockpile goal for iodine was reduced to zero with the passage of Public Law 102-484 on October 23, 1992. A meeting for prospective offers was held on June 3 at the Defense National Stockpile Center in Arlington, VA. On May 12, a draft Invitation for Bids for Iodine was circulated. The Defense Logistics Agency (DLA) of the U.S. Department of Defense sold 45 kilograms (kg) of excess iodine valued at $275 ($2.75 per pound) during fiscal year 1993.

Production

IoChem began production in 1987, 1.2 kilometers east of Vici, Dewey County, OK, by the blowing-out process. The majority of production was shipped to Schering AG, Germany, under a long-term contract. IoChem was reported to have nine production wells and four injection wells with a total production capacity of 1,400 kg per year.

North American began operating a miniplant at Dover in Kingfisher County, OK, in 1983. Two plants are at an oilfield injection disposal site that obtains brines from about 50 wells in the Oswego Formation. Iodine concentrations ranged up to 1,200 ppm. The company closed a plant in 1992 that began operating in 1991 because of the low-market prices for iodine.

Woodward Iodine began production in 1977 and was purchased by Asahi Glass Co. of Japan in 1984. Woodward operated a plant in Woodward County that produced iodine from 22 brine production wells using the blowing-out process and injected waste through 10 injection wells.

Consumption and Uses

Iodine was used primarily in animal feed supplements, catalysts, inks and colorants, pharmaceutical, photographic equipment, sanitary and industrial disinfectants, stabilizers, and radiopaque medium. Other smaller uses included production of batteries, high-purity metals, motor fuels, iodized salt, and lubricants.

Iodine deficiency is the largest preventable cause of mental impairment in the world. Disorders stemming from a lack of iodine range from simple goiter to the severe cluster of mental and physical handicaps known as cretinism. In between are mental retardation, learning disabilities, apathy and lack of motivation in adults, and increased rates of stillbirths and miscarriages. By simply adding iodine to salt the deficiency disorders could be eradicated within a few years.[5]

Excessive levels of iodine, which may cause thyroid cancer, were found in cat foods by scientists at the University of Missouri. Iodine is an essential nutrient in the diet, so high doses were thought to be healthy.[6]

The lithium-iodine battery was the first commercially successful lithium battery and is unusual because of its in situ growth of electrolytes. Superior charge transfer is achieved using an iodine compound with powdered iodine. Layers of lithium iodide act as both electrolyte and separator and are self-sealing in the event of a crack. Thus, the batteries are intrinsically reliable and withstand abuse.

Producers sold iodophors for medical, veterinary, and food-processing applications. The two main classes of iodophors are povidone iodine, manufactured from polyvinylpyrrolidone and utilized in human skin disinfectants, and the nonionic detergent-iodine combinations, utilizing primarily nonoxynol and the poloxamers. Iodophors are highly self-stable, substantially free of the corrosive effects of noncomplexed-iodine concentrations, and relatively nonirritating to human skin. One of the world's largest producers of nonionic detergent iodines is West Agro, Inc.[7]

Tall oil was produced using iodine as a stabilizer by Arizona Chemical Co., a division of International Paper Co., Hercules, Inc., and Westvaco, Inc. Modest reductions in supply were attributed to the limited availability of wood rosin. Tall oil fatty acid inventories declined during 1993 in the United States and Europe.[8]

Eastman Chemical Co. was spun off from the Eastman Kodak Co. Eastman became one of Tennessee's leading employers and joined the ranks of a public company headquartered in Kingsport, TN. The company manufactures chemicals, fibers, and plastics.[9] Acetic anhydride manufactured uses methyl iodide as a catalyst to produce acetic acid.[10]

Kodak planned to concentrate on photography and imaging and its health sciences division. Kodak manufactures its own film and paper supports, as well as photographic-grade gelatin and processing chemicals and equipment. In the photographic business, a thin gelatin of imaging layers containing light-sensitive silver halide crystals or auxiliary layers help to regulate the photographic or physical performance.

A regenerable biocide delivery unit is an extension of technology developed by Umpqua Research Co. for the space shuttle program in the late 1970's and currently used on the shuttle to purify drinking water. Water is passed through an anion exchange bed that has been treated with iodine. An improvement in the unit regenerates the resin bed in situ using small amounts of elemental iodine. The improved unit has been licensed for water purification of between 9 to 68 liters (2 to 15 gallons) per minute of water for community applications.[11] *(See table 2.)*

Prices

The average declared c.i.f. value for imported crude iodine was $7.90 per kg ($3.58 per pound). The average declared c.i.f. value for imported crude iodine from Japan averaged $7.82 per kg ($3.55 per pound). The average declared c.i.f. value for iodine imported from Chile was $8.01 per kg ($3.63 per pound). The average producer price was $7.98 per kilogram ($3.62 per pound). Quoted yearend U.S. prices for iodine and its primary compounds are shown in table 3. *(See table 3.)*

Foreign Trade

The U.S. Government adopted the Harmonized Commodity Description and Coding System (Harmonized System) as the basis for its export and import tariff and statistical classification systems. The system is intended for multinational use as a basis for classifying commodities in international trade for tariff, statistical, and transportation purposes. The Harmonized System, as proposed, includes resublimed and crude iodine under the same code, and the duty rate is free. Values that differ significantly could be a result of items being placed in the wrong category. *(See tables 4 and 5.)*

World Review

Canada.—In 1976, research was begun to selectively leach amorphous manganese dioxide from the coatings on mineral grains to enhance geochemical anomaly in soils. In recent soil analysis studies on iodine, an anomaly with a contrast of 100-times-background was found at the Sleeper and Rabbit Creek gold mines in Nevada. Trace elements released by oxidation of sulfide-mineral deposits in the bedrock migrate up through overburden by ground water flow, capillary action, or diffusion of volatile compounds. The iodine anomaly was found at a point where the Rabbit Creek deposit was buried by 183 meters (600 feet) of basin fill.[12]

Chile.—Sociedad Química y Minera de Chile (SQM, formerly known as SOQUIMICH) was the largest producer of iodine in Chile. SQM planned to expand potash with a $57.5 million share offer in the United States. On July 8, 1993, SQM issued a prospectus that advertised American Depositary Shares, backed by Series B shares in the company. The money would enable SQM to embark on a $229.7 million expenditure between 1993 and 1997 that includes $7 million to extract nitrates and iodine from fines at the Pedro de Valdivia ore crushing facility. A supplemental amount of $7 million during 1994 and 1995 was to be spent on the construction of a new iodine facility at Lagunas, northern Chile.[13]

Cominac S.A., a subsidiary of Inversiones Errazuriz S.A. Enterprises, began production at two of three reserve areas of the Pozo Almonte Project. The site is in a valley where the natural gravity flow is utilized to collect the iodine-rich solutions. A third reserve area was undergoing a third step in a civil process to determine ownership. The two areas under development are not involved in the civil processing and are under development by a subsidiary company, Compania de Salitre y Yodo de Chile (Cosayach). Cosayach has a plant to recover 600 tons of iodine per year by heap leaching. Plans to expand capacity were being developed.

ACF Minera Ltda. is a Chilean company with a 50% joint venture with DSM N.V. of the Netherlands. The company maintains three production facilities that have a nameplate capacity of 1,200 tons that are in the first region of Chile at La Granja, Lagunas, and Iris. The facilities are about 161 kilometers (100 miles) southeast of the port city of Iquique. The production capacity was reported to be 810 tons of 99.5% to 100.5% iodine, with mineral reserves of 48,000 tons of iodine in situ. The company also owns mineral rights at other locations in the first and second regions of Chile.

Mineral Yolanda, Yumbres, Chile, planned to produce 1.7 million tons per year of nitrate ore that includes iodine with a $78 million investment. The project is wholly owned by Kap Resources Ltd., Vancouver, Canada. The mineral salts or caliche will be leached with seawater to dissolve the salts. The solution will be processed to extract the iodine. The remaining solution will be evaporated in solar ponds to concentrate the nitrate salts.[14]

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.—Japan was the world's leading producer of iodine in 1993. Six companies operated 17 plants with a total production capacity of 9 million kg per year. Plans were announced to close two small plants by midyear 1994. Production of iodine was from underground brines associated with natural gas.

Russia.—Authorities in the Tyumen region will hold open bidding to extract iodine from a deposit near the city of Tobolsk. The Tyumen region was reported to contain one-half of Russia's known iodine reserves. The iodine deposit was discovered in the 1960's but remained unexploited because of the region's oil boom. Preliminary studies indicate that the deposit could produce from 1,000 to 2,000 tons of iodine annually. Russia consumes 1,600 tons of iodine per year and imports 85% of that amount.[15] *(See table 6.)*

Switzerland.—The Nuclear Medicine division of Mallinckrodt Medical Inc. acquired Oryx Pharmaceutica AG, Zurich, Switzerland. Oryx, which sells more than one-half of the radiopharmaceuticals in Switzerland, had distributed nuclear medicine products manufactured by Mallinckrodt since the 1970's.[16]

Current Research

Trifluoromethyl iodide (CF_3I), an FIC, can replace the common CFC's used in household refrigerants. An FIC is a molecule that contains fluorine, iodine, and carbon and in some cases hydrogen. FIC's have advantages as CFC replacements because they are about the same cost as the replacements now used, HFC-134a, have low toxicity, and do not damage the ozone layer. FIC's break down rapidly on exposure to sunlight; therefore, they have an ozone depletion potential of about zero. FIC's are nonflammable and noncorrosive. FIC's will have higher refrigeration capacities and energy efficiencies will be essentially unchanged. The U.S. Air Force began testing the toxicity of CF_3I as a potential substitute for Halon 1301.[17] Scientists at E.I. du Pont de Nemours & Co. Inc. have produced nonprotonated material by heating C_{60} and excessive trifluoromethyl iodide. The compounds are more volatile but display surface properties of perfluoroalkylated materials, such as Teflon.[18]

Pennsylvania State University studied new methods of producing acetic acid from methane using rhodium trichloride as a catalyst. The yield of acetic acid was increased by adding a source of iodine ions. The new process is similar to the Monsanto process used commercially for carbonylation of methanol to acetic acid using a rhodium-base catalyst. In the new method the methane is hydrolyzed to acetic acid. This reduces the steps from three to one, thereby making the process more economical.[19]

Chemists at the University of Salford and the ICI Runcorn Technical Center prepared thermoplastic hydrogels from linear copolymers of vinyl pyrrolidone and methyl methacrylate. The hydrogels demonstrated favorable properties such as film-forming capacity, melt processability, fluid retention, and biocompatability.[20]

OUTLOOK

Iodine production capacity in the United States and Chile has doubled during the past decade, ensuring an adequate world supply. Uses for iodine in specialty chemicals have remained stable. Recent developments in digital images using computers can produce electronic prints and overhead transparencies without using processing. Using a digital camera or scanning the film and converting to digital, the images are produced and stored on hard drives, disks, tape, or optical storage.

The trend to digital imaging is used for recording most sporting events, game shows, and some situation comedies for broadcasts. However, 75% to 85% of all televised shows seen during prime time are recorded on 35-millimeter (mm) motion picture film and then transferred to videotape or laser disc for display. Furthermore, just about all feature films for movie theater presentation are shot and printed on film. The main reason is the image quality. A frame of 35-mm color negative film contains about 6.6 million pixels or about 15 times that of the best current high-definition television system and 4 times that of the digital systems now in development. Most popular home video rentals have been box office movie hits. Future use of iodine in films and processing could be limited to specialty imaging in the next decade.[21]

New uses of IFC's as halogen replacements could cause an increased demand for iodine. More tests need to be completed on the IFC's before they are acceptable, but preliminary tests are promising.

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TABLE 1
SALIENT IODINE STATISTICS

(Thousand kilograms and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Production	1,508	1,973	1,999	1,995	1,935
Imports for consumption[1]	3,326	3,168	3,555	3,745	3,615
Exports[1]	NA	2,100	1,317	1,807	1,219
Consumption:[2]					
Apparent	4,834	3,041	4,327	3,933	4,331
Reported	2,900	3,100	3,200	3,400	3,547
Price, average c.i.f. value, dollars per kilogram	$19.50	$13.78	$10.16	$9.03	$7.98
World: Production	[r]16,259	[r]17,113	[r]17,448	[r]16,581	[e]16,625

[e]Estimated. [r]Revised. NA Not available.

[1]Bureau of the Census.

[2]Calculated by production plus imports minus exports.

TABLE 2
U.S. CONSUMPTION OF CRUDE IODINE, BY PRODUCT

Product	1992		1993	
	Number of plants	Consumption (thousand kilograms)	Number of plants	Consumption (thousand kilograms)
Reported consumption:				
Resublimed iodine	9	148	8	170
Hydriodic acid	3	107	3	289
Calcium iodate	(1)	(1)	(1)	(1)
Calcium iodide	3	125	3	121
Cuprous iodide	3	62	3	81
Potassium iodide	4	530	5	650
Potassium iodate	3	40	3	49
Sodium iodide	6	94	4	62
Other inorganic compounds	14	1,219	9	525
Ethylenediamine dihydroiodide	4	559	3	654
Povidone iodine	—	—	3	361
Other organic compounds	8	516	7	585
Total	[2]27	3,400	[2]27	3,547
Apparent consumption	XX	4,000	XX	4,400

XX Not applicable.

[1]Included with calcium iodide.

[2]Nonadditive total because some plants produce more than one product.

TABLE 3
YEAREND 1993 PUBLISHED PRICES OF ELEMENTAL IODINE AND SELECTED COMPOUNDS

	Dollars per kilogram[1]	Dollars per pound[1]
Calcium iodate, FCC drums, f.o.b. works	16.42	7.45
Calcium iodide, 50-kilogram drums, f.o.b. works	23.65-25.65	11.62-12.07
Iodine, crude, drums	10.00-11.00	4.75- 5.21
Potassium iodide, U.S.P., drums, 5,000-pound lots, delivered	26.48	12.01
Iodine, U.S.P.	17.00	7.70
Sodium iodide, U.S.P., crystals, 5,000-pound lots, drums, freight equalized	36.38	16.50

[1] Conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiations and/or somewhat different price quotations.

Source: Chemical Marketing Reporter. V. 245, No. 1, Jan. 3, 1994, pp. 31-37.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1992		1993	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude:				
Chile	1,963	16,723	1,621	12,977
Japan	1,689	16,188	1,880	14,696
Total	3,652	32,911	3,501	27,673
Iodide, potassium:				
Canada	15	166	17	184
Chile	6	58	14	123
India	40	389	49	452
Japan	—	—	34	238
Other[2]	30	279	—	—
Total[3]	93	891	114	997
Grand total	3,745	33,802	3,615	28,670

[1] Declared c.i.f. valuation.
[2] Includes Germany, Mexico, Sweden, Switzerland, and the United Kingdom.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 5
U.S. EXPORTS OF CRUDE IODINE, BY TYPE AND COUNTRY

(Thousand kilograms and thousand dollars)

Country	1992		1993	
	Quantity	Value[1]	Quantity	Value[1]
Iodine, crude/resublimed:				
Belgium	13	52	—	—
Canada	94	966	28	312
Germany	567	4,925	573	5,078
Hong Kong	15	175	—	—
Japan	428	4,664	—	—
Mexico	350	2,819	380	2,865
Philippines	—	—	16	33
Taiwan	59	106	—	—
United Kingdom	67	889	—	—
Other[2]	32	543	19	269
Total	1,625	15,139	1,016	8,557
Iodide, potassium:				
Canada	76	67	23	360
China	18	58	148	479
Colombia	36	42	—	—
Germany	—	—	5	50
Mexico	1	2	—	—
Spain	11	55	—	—
Sweden	18	20	—	—
Turkey	—	—	14	186
Other[3]	24	159	13	103
Total[4]	182	402	203	1,178
Grand total	1,807	15,541	1,219	9,735

[1] Declared f.a.s. valuation.

[2] Includes Australia, The Bahamas, Ecuador (1992), El Salvador (1992), France (1992), Ghana, Indonesia (1992), Ireland (1992), Italy, the Republic of Korea (1992), Kuwait (1992), New Zealand (1992), Panama (1992), Peru, the Philippines (1992), Spain (1992), Turkey (1992), and the United Arab Emirates (1992).

[3] Includes Belgium (1992), Brazil (1992), Chile, Finland (1992), Hong Kong, Ireland (1992), the Republic of Korea, Mexico (1992), Norway (1992), Saudi Arabia, the Republic of South Africa (1992), and Thailand (1992).

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

Source: Bureau of the Census.

TABLE 6

CRUDE IODINE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand kilograms)

Country	1989	1990	1991	1992	1993[e]
Azerbaijan[2]	—	—	—	[e]600	600
Chile	[r]4,645	[r]5,099	[r]5,621	[r]5,887	5,550
China[e]	500	500	500	500	500
Indonesia	14	60	36	[e]35	40
Japan	7,592	7,581	[r]7,492	[r]6,764	7,200
Russia[2]	—	—	—	[e]200	200
Turkmenistan[2]	—	—	—	[e]600	600
U.S.S.R.[e, 3]	2,000	1,900	1,800	—	—
United States	1,508	1,973	1,999	1,995	[4]1,935
Total	[r]16,259	[r]17,113	[r]17,448	[r]16,581	16,625

[e] Estimated. [r] Revised.

[1] Table includes data available through June 24, 1994.

[2] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3] Dissolved in Dec. 1991.

[4] Reported figure.

IRON ORE

By William S. Kirk

Mr. Kirk became the commodity specialist for iron ore in 1992 and was previously responsible for cobalt, depleted uranium, hafnium, nickel, radium, thorium, and zirconium. The domestic survey data were compiled by Debra A. Nolan, statistical assistant, Branch of Data Collection and Coordination. The world production table was prepared by Amy D. Durham and Ronald H. Hatch, International Data Section.

Iron ore is essential to the economy and national security of the United States. As the basic raw material from which iron and steel is made, its supply is critical to any industrial country. Scrap is used as a supplement in steelmaking, but is limited as a major feed material because there is a limited quantity of high-quality scrap.

Nineteen-ninety-three was a year of recovery for the domestic iron ore industry as consumption rose by 2.3%. Production and shipments also rose slightly from 1992 levels. The increases were attributed to a 6.9% increase in raw steel production.

Production in the United States posted a moderate gain, while production in China rose by 19%. Australia and Brazil continued to be the leading exporters of iron ore with a combined total of close to 60% of the world total.

DOMESTIC DATA COVERAGE

U.S. production data for iron ore are developed by the U.S. Bureau of Mines (USBM) from two separate, voluntary surveys of domestic operations. The annual "Iron Ore" survey (1066-A) provides the basic data used in this report. Of 39 addressees to whom the 1066-A form was sent, 31 responded, representing 100% of total production shown in tables 1 through 4. In past years, production for nonrespondents to the annual survey was estimated from monthly surveys (1066-M), from railroad reports, or from reported production levels in prior years. This information may be supplemented by employment data, mine inspection reports, and information from consumers.

Data on consumption and stocks of iron ore and agglomerates at iron and steel plants were provided by the American Iron Ore Association (AIOA). AIOA also provided data on ore shipments from loading docks on the upper Great Lakes as well as receipts at transfer docks and furnace yards nationwide. The dock and steel plant data were compiled jointly by AIOA and the American Iron and Steel Institute (AISI). Data on consumption of iron ore for nonsteel end uses were compiled from information gathered from other USBM surveys.

BACKGROUND

Economic Factors

The United States has exhausted the reserves of high-grade direct-shipping ore it once had in Michigan and Minnesota. Almost all of the ore being mined now is low-grade taconite, which requires costly beneficiation and pelletizing. Moreover, the taconite mining and pelletizing complexes are deep in the interior of the country, far from any saltwater harbor. Because of the advantages of Great Lakes shipping, U.S. pellets are currently competitive at Gary, Cleveland, and Detroit. However, high rail costs put U.S. pellets at a disadvantage in the mid-Atlantic States and Alabama. Imported ores and agglomerates from Brazil, Canada, and Venezuela constitute the bulk of the iron units consumed at these coastal steelworks.

The St. Lawrence Seaway is a mixed blessing for the mining industry, being a bottleneck for ore carriers as well as an inexpensive means of transport in the Great Lakes region. The eight locks in the Welland Canal and the seven locks in the St. Lawrence River are all similar in size and have a gate-to-gate length of 262 meters (m). The relatively short length of each lock prevents oceangoing ore carriers longer than 222 m from entering the Great Lakes. At the same time, domestic "1,000 footers" cannot leave the Lakes. Foreign ore bound for Indiana or Ohio either has to be offloaded onto smaller vessels in the gulf of the St. Lawrence or transferred to rail cars at Baltimore or Philadelphia. In some cases, ore is barged from the Port of New Orleans up the Mississippi River to steelworks in the Ohio River Valley and western Pennsylvania. The high rail costs that keep domestic ores from going to the coastal steelworks also keep foreign ores out of the inland steelmaking regions.

Operating Factors

Statistics on employment and productivity in the U.S. iron ore industry in 1993, shown in table 2, were derived from quarterly employment data supplied by the Mine Safety and Health Administration (MSHA) and from production data derived from USBM surveys. Both sets of data were obtained from producers' reports.

The statistics include production workers employed at mines, concentrators, and pelletizing plants and in repair and maintenance shops, but do not include 844 persons engaged in management, research, or office work at mines and plants. Employees engaged in ore preparation, such as sintering, at blast furnace sites are not included.

Because employment data reported to MSHA are primarily for safety analysis, hours spent by salaried employees in mines or plants may be included by operators in the total number of hours worked at individual mines or plants. This has resulted in understatement of calculated productivity by 10% to 25% for some operations, but its affect on others is not known. If company reporting practice is consistent, however, comparison of productivity from one year to the next should be reasonably valid.

ANNUAL REVIEW

Legislation and Government Programs

Voluntary Restraint Agreements (VRA's) on steel imports expired on March 31, 1992. Under the VRA's, steel-producing nations had agreed to limit steel exports to the United States in return for withdrawal of charges by U.S steel companies that the imports were a cause of injury to the U.S. steel industry. In June 1992, U.S. steelmakers filed new complaints with the International Trade Commission (ITC) against 21 nations, alleging injury to the U.S. industry as a result of illegal subsidies and sales at less than face value. The ITC issued an initial decision affirming the claims of injury against a number of these nations. Effective December 7, 1992, importers were required to provide funds or bonds to cover countervailing duties, pending a final decision in 1993.

The ITC announced its final determination on the question of injury on July 27, 1993. The result was mixed for the U.S. steel industry. The Commission found that the U.S. industry was being harmed by virtue of imports of plate products from Belgium, Brazil, Canada, Finland, Germany, Mexico, Poland, Romania, Spain, Sweden, and the United Kingdom, and corrosion-resistant (galvanized) product from Australia, Canada, France, Germany, Japan, and the Republic of Korea. In the case of cold-rolled steel products, injury to the U.S. industry was found only as a result of imports from Germany, the Netherlands, and the Republic of Korea; imports from 10 other countries that had been determined to be either illegally subsidizing or unfairly pricing their products were determined to be causing no injury to U.S. industry. For a more extensive treatment of this subject, refer to the Iron and Steel chapter.

Production

There was movement among domestic producers toward installing direct-reduced iron (DRI) capacity. Cyprus Northshore Mining Co., Silver Bay, MN, made a significant move toward that goal, when the Minnesota Pollution Control Agency board voted 8 to 0 to accept a recommendation that the project did not need a time-consuming environmental impact study before a construction permit was approved. Cleveland-Cliffs Inc. (CCI) was considering the idled Republic Mine near Palmer, MI, as a site for the construction of a DRI plant.

Strikes closed four mines in Minnesota and Michigan during the year. Hibbing Taconite Co. and National Steel Pellet Co. on the Mesabi iron range of Minnesota and the Empire Iron Mining Partnership and the Tilden Mine on the Marquette iron range of Michigan were closed on August 1 after their contracts expired on the 31st of July. Although the contract between Eveleth Mines and the United Steelworkers also expired on July 31, production continued through yearend. Labor agreements were reached with employees at Hibbing, Empire, and Tilden, while National was still idle at yearend.

In 1993, iron ore was produced by 16 companies operating 17 mines, 12 concentration plants, and 10 pelletizing plants. The mines included 16 open pits and 1 underground operation. Virtually all ore was concentrated before shipment, and 97.9% was pelletized.

Combined United States and Canadian production represented only about 11% of the world output of usable ore in 1993. At least 57 other countries mined crude ore during the year. The leading producer was Brazil, which accounted for 20.7% of world output in terms of metal content, followed by Australia and China, each with 15.5%. Trends in world mine production since 1989 are shown on a country basis in table 19.

Domestic iron ore production, at 55.7 million metric tons (Mmt), was little changed from that of the previous year. Productivity for usable ore in the Lake Superior District rose slightly. Iron ore was produced by 16 open pit mines and 1 underground mine. Eleven mines produced ore for the iron and steel industry, while the remainder shipped ore mainly to cement plants. Installed domestic production capacity for usable ore on December 31, 1993, was estimated at 82 million metric tons per year (Mmt/yr), of which 81 Mmt was pellets. Total output of usable ore was equivalent to about 68% of installed production capacity. An average of 3.3 tons of crude ore was mined in 1993 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 54.5 Mmt, 98% of usable ore output. The average iron content of usable ore produced was 63.1%. Shipments from U.S. loading docks on the upper Great Lakes totaled 59.5 Mmt in 1993 compared with 58.3 Mmt in 1992.

Michigan.—Michigan accounted for 23% of the national output of usable ore in 1993. One hundred percent of the State's production consisted of pellets produced at the Empire and Tilden Mines near Ishpeming in Marquette County. Both mining ventures are managed by CCI's Cleveland-Cliffs Iron subsidiary. Empire shipped 6.7 Mmt of pellets produced from magnetite concentrate. Tilden shipped 1.5 Mmt of magnetite pellets and 4 Mmt of hematite pellets, for a total of 5.1 Mmt. Production of usable ore was down 8.4% from the 1992 figure of 13.9 Mmt. Production of pellets totaled 12.8 Mmt, of which 7.3 Mmt was made at Tilden.

Minnesota.—Minnesota produced 75.5% of the national output of usable ore in 1993. All of the State's production came from open pit mines on the Mesabi Range. Production of pellets totaled 41.7 Mmt, equivalent to 86.4% of installed production capacity of the State's seven taconite plants.

Inland Steel Mining Co., Virginia, MN, closed its Minorca Pit in September after its reserves were depleted. Inland had produced 120 Mmt of ore from the pit since it opened in 1976. The company continued to mine the Laurentian Pit.

Eveleth Mines reopened its pellet plant on March 9. Mining had resumed about 2 weeks earlier. The facility closed in November 1992 after Armco Steel Co. LP, part owner of the mine, determined that the mine's costs were too high. LTV Steel Co. closed its Northwest Ore division as of August 1, after close to 100 years of natural ore production on the Mesabi range. Natural ore, as opposed to taconite, is a friable, medium- to high-grade ore needing minimal beneficiation.

Missouri.—The Pea Ridge Iron Ore Co. produced iron oxide powder at its mining complex near Sullivan, MO. The company has the only active underground iron mine in the country. In January 1991, the company ceased pellet production and began concentrating on specialty iron oxide products, which had formerly been coproducts.

Utah.—Geneva Steel of Utah operated two open pit mines.

Consumption and Uses

Although crude steel production rose 6.9% and net shipments of semifinished steel rose by 8.3% in 1993 and capability utilization rose from 82.2% in 1992 to 89.1%, these increases were not matched by increases in iron ore consumption. Iron ore consumption rose by only 2.3% and pig iron production, an excellent indicator of iron ore consumption, increased by 2.6%.

This apparent paradox can be explained by examining the source of some of the shipments of steel and how most of the steel was made. As to the source, imports of semifinished steel rose markedly. For the 5 years prior to 1993 these imports ranged from 2 to 2.6 Mmt and averaged 2.2 Mmt. Imports in 1993 were 4.5 Mmt. Net imports of semifinished steel in 1993 were up 130.8%. To meet the higher demand, integrated producers sharply increased imports of semifinished steel.

In 1993, 83.9% of steel produced in the United States was continuous cast compared with 78.9% in 1992. Continuous casting reduces consumption of iron ore because it results in the generation of less home scrap. Basic oxygen furnaces, used by all integrated producers, can use no more than about 28% scrap. Because producers have less home scrap to remelt, they can use more purchased scrap. Thus, they obtain additional iron units from scrap rather than ore.

Another factor affecting the consumption of iron ore is that electric arc furnaces, used in steelmaking primarily by minimills, do not use iron ore. Electric arc furnace steelmaking accounted for 39.4% of total steelmaking in 1993. This was the largest ever share for electric arc furnace steelmaking for the United States.

Consumption of iron ore for ironmaking and steelmaking totaled 71.5 Mmt. Monthly consumption of pellets, direct-shipping ore, and merchant sinter by the industry averaged 5.82 Mmt compared with 5.71 Mmt in 1992. Reported consumption of iron ore for manufacture of cement, heavy-medium materials, animal feed, ballast, ferrites, pigments, and other nonsteel products was 1.1 Mmt.

U.S. production of hot metal and pig iron totaled 48.2 Mmt, a 1.6% increase from that of 1992. During 1993, the number of blast furnaces in operation ranged from 40 to 42.

Consumption of iron ore and all types of agglomerates reported to the AISI by integrated producers of iron and steel totaled 75.2 Mmt. This included 60.8 Mmt of pellets; 12.5 Mmt of sinter, briquettes, etc.; and 2 Mmt of natural coarse ore. Of the primary ore consumed, 79% was of domestic origin, 9% came from Canada, and 12% came from other countries. Other materials consumed in sintering plants included mill scale, flue dust, limestone and dolomite, slag and slag scrap, and coke breeze. Other iron-bearing materials charged to blast furnaces included steel furnace slag, mill scale, and slag scrap.

The U.S. steel industry accounted for 98.4% of domestic iron ore consumption in 1993.

Stocks

Stocks declined by 6.6% to 21.5 Mmt as the result of strikes at four iron ore production plants.

Transportation

After years of debate, representatives of the U.S. Army Corps of Engineers, the Michigan Department of Natural Resources, the U.S. Coast Guard, and the U.S. Fish and Wildlife Service signed a memorandum of agreement that set the navigation season for the Soo Locks at March 25-January 15.

The Mackinaw, the largest icebreaker on the Great Lakes, received a reprieve. During the year, the U.S. Coast Guard convinced Congress that it was time to decommission the ship. The severe winter of 1993-94 prompted the Lake Carriers' Association and other groups to lobby for retaining the ship. Congress agreed to fund the Mackinaw through fiscal year 1995.

Prices

As in 1992, iron ore producers were forced to accept price reductions. The 2 consecutive years of price reductions offset 3 consecutive years (1989-91) of gains.

Most iron ore prices are negotiated between buyer and seller. About 80% of domestic ore is produced by captive mines (mines producing for company smelters) and therefore does not reach the open market. The average f.o.b. mine value of usable ore shipped in 1993 was $29.21 per ton, 6.3% higher than that of 1992. This average value was based primarily on producers' statements and should approximate the average commercial selling price less the cost of mine-to-market transportation.

Foreign Trade

U.S. exports of iron ore were less than 1% higher than those of 1992. Virtually all exports consisted of pellets and concentrates shipped via the Great Lakes to Canadian steel companies that are partners in U.S. taconite projects in Michigan and Minnesota. U.S. imports of iron ore rose 12.7% to 14.1 Mmt.

Net imports averaged 11.5 Mmt from 1989 through 1992; 1993 net imports were 9 Mmt, equivalent to 14.3% of U.S. ore consumption, down from 15.3% in 1992. Canada's share of net imports was 53% and Brazil's was 20%.

World Review

At least 59 countries mined iron ore during the year, producing a total of 988.8 Mmt. China was the largest producer, with an output of 234.7 Mmt.

For the third consecutive year, Australia was the leading exporter of iron ore, shipping 116.4 Mmt to world markets, followed closely by Brazil, which exported 111.9 Mmt. Together, the two countries accounted for 57.7% of export in 1993. The next largest exporter was India, at 8%. Total exports were 395.7 Mmt, up from 367.3 Mmt in 1992. Australia's principal customer, Japan, accounted for about one-half of its exports. Brazil's primary customers were the European Community (EC) and Japan.

Integrated iron ore operations have become extremely complex and are so large as to resemble medium-sized towns in some cases. The production capacity of an operation of this magnitude is determined by equipment limitations at several stages of recovery. To simplify analysis and make comparisons of individual mines easier, data were collected that represent the rated or design capacity at three key points in the recovery process: crusher-screen output, concentrator output, and pelletizing furnace output. These three points were chosen because they serve to readily separate the mining, beneficiating, and agglomerating stages of the operation. At the first two points, the iron ore is already in a marketable form and can be diverted for sale or tolling if bottlenecks occur either downstream at the operation or upstream at competitors' facilities.

Changes in the economics of the process also could make diversion feasible. Table 21 shows world pelletizing capability at the close of 1993. The data represent the rated capacities of 82 plants in 26 countries. A significant part of the data was published by the Trust Fund Project on Iron Ore Information in 1993. The table excludes plants that have not produced since 1982. Four of these idled plants are identified in the table footnotes because they could be reactivated in some realistic scenarios. Table 21 also excludes sintering plants.

Australia.—The country continued to be the world's leading exporter of ore in 1993. BHP Iron Ore Ltd. developed the Yarrie Mine in Western Australia. The first full trainload of ore left the mine on December 1. The new operation was to replace the Goldsworthy Mine. Reserves at the deposit were estimated at 35 Mmt. The production rate was 5 Mmt/yr. Construction involved the extension of rail and power lines from Shay Gap and installation of a crushing plant, stockpiling and train loading facilities, an accommodation village, offices, and workshops.

BHP also increased the production capacity at its Yandi Mine in Western Australia to meet increased future demand. Opened in 1992, the Yandi began producing at a rate of 10 Mmt/yr.

Robe River Mining Co. completed the development of its Mesa J deposit, which was begun in 1992.

Brazil.—Cia. Vale do Rio Doce expanded its Ponta de Madeira port at Sao Luis by adding a second loading pier. This increased the loading capacity at the port from 35 to 50 Mmt/yr.

China.—Anshan Iron & Steel Corp. began expanding the Qidashan iron mine and beneficiation plant. Construction was to be completed by July 1, 1995. The expansion was expected to double the facility's iron ore capacity to 16 Mmt/yr.

India.—A pelletizing plant was being built for a subsidiary of Essar Gujarat, which produced 60% of India's DRI from its new hot-briqueted iron (HBI) plant. The plant, being built in Visakhapatnam, on the east coast, was to have a production capacity of 3 Mmt/yr. Of that, 2.2 Mmt/yr was to be shipped to the State of Gujarat on the west coast to feed Essar's three 440,000-metric-ton-per-year (mt/yr) DRI modules. Ispat was building a 1-Mmt/yr DRI plant at Alibagh near Bombay.

Essar Gujarat signed a memorandum of understanding with Met-Chem, of Canada, to develop a new iron mine in the Bailadilla mining district of eastern India. The deposit would be leased from the National Mineral Development Corp. (NMDC), which operated export mines in the district. The mine was to be open pit and have a primary crushing/screening plant for sized lump ore. Production was expected to be 6 Mmt/yr of run-of-mine ore, yielding 2.4 to 3 Mmt/yr of lump ore and about 2.7 Mmt/yr of fines.

Japan.—On March 19, the Kamaishi iron mine closed, bringing to an end 150 years of operations. The mine, in Iwate, in northeastern Honshu, was the last operational Japanese iron mine. Discovered in 1727, the deposit played a major role in the development of Japan's modern steelmaking industry in the 1850's. At its peak in 1934, annual production was 1.4 Mmt and once employed more than 3,000 people. The mine closed because it could not compete with cheaper, higher grade imported ore.

Libya.—Libyan Iron and Steel Co. (LISCO) was planning to add a third Midrex DRI module to its Misurata steel complex. The module was to be situated adjacent to the existing two-module Midrex DRI plant, which completed its second full year of operation in 1992. The new module, which was scheduled to begin operation in 1996, would increase total DRI capacity to 1.75 Mmt/yr.

Peru.—Production at the Marcona Mine, which was sold to Capital Steel (Shougang) Corp., China, rose from 3 Mmt in 1992 to 5.5 Mmt in 1993.

Technology

Joint-venture partners, CRA, Ltd. Australia, and Midrex Direct Reduction Corp., U.S.A., dedicated their HIsmelt Research and Development Facility (HDRF) in November. The $140 million project, in Kwinana, 40 kilometers (25 miles) south of Perth, Western Australia, embarked on a year long study to determine the technical and economic parameters for the scale-up and commercialization of the HIsmelt Direct Iron Ore Smelting Process. If the process could be successfully commercialized, it would serve as an alternative to the traditional blast furnace route and would compete against the Corex process owned by Vöest-Alpine Industrieanlagenbau AG of Austria. Like the Corex process, it would eliminate the need for coke ovens, blast furnaces, and sinter plants, thereby bypassing many of the environmental problems associated with cokemaking and sintering. It also used relatively cheap energy coal rather than higher quality coking coal.

The heart of the new complex was a prototype smelt reduction vessel (SRV), which had a production capacity of 0.1 Mmt/yr. The capacity of a commercial-sized plant was considered to be 0.5 to 1 Mmt/yr. The process was a single-stage process that involved the direct smelting of iron ore in a closed molten bath reactor. Coal was injected into the iron bath to maximize recovery of the carbon and to generate bath turbulence. The ore was preheated and prereduced in a circulating fluidized bed prior to injection into the horizontal SRV. Hot air was supplied to the top of the SRV to postcombust the generated CO. The hot metal and slag tapped from the SRV were transported to the pig caster and the slag pens.

The USBM published a report (RI 9473) entitled "Use of Oxygen Enriched Gas for the Oxidation of Acid and Fluxed Taconite Pellets." The USBM, in cooperation with CCI (Hibbing, MN), investigated ways of enhancing the quality (compressive strength and reducibility) of domestic acid and fluxed magnetic pellets by modifying the oxygen content during the preheat and induration periods of the firing operation.

OUTLOOK

At present consumption rates, known world iron reserves are sufficient to meet cumulative world demand well beyond the 21st century.

The domestic iron ore industry is totally dependent on the steel industry for sales. This dependence is not expected to change in the near future. Because of this relationship, the reader is referred to the outlook section in the "Iron and Steel" chapter. Only 8% of the iron ore produced from 1989 through 1993 was exported, with virtually all of it being pellets going to steelworks in Ontario. It is difficult for the United States to compete in the world iron ore market because of the country's declining ore grades, the inland location of its mines, and high labor and fuel costs.

For the near term, growth of the U.S. iron ore industry is tied to the growth of the integrated steelworks along the Great Lakes. The U.S. steel industry is concentrating on making high-value, quality steels, not increasing output. Domestic blast furnace production in the year 2000 is expected to be no more than 50 Mmt. The U.S. iron ore industry has no choice but to focus on making higher quality agglomerates, such as fluxed pellets, that meet much tighter chemical and physical specifications than have been required in the past. The hope for the domestic iron ore industry is that one or more of the new direct processes, COREX, DIOS, AISI, HIsmelt, carbide, etc., will prove to be economic for lake producers.

Electric arc furnaces currently account for more than one-third of total crude steel production. Because of advances in steelmaking, steel products now require lower residual alloy content than can be readily achieved with scrap. This indicates a role for imported DRI in the coastal regions of the United States. The growth of gas-based DRI production capacity outside North America has been spectacular in recent years. Although a large part of this growth has occurred in Venezuela, the bulk of the construction has been spread evenly through a variety of countries that have surplus natural gas. It is too early to tell whether coal-based DRI production will be economically feasible in the United States. No matter how spectacular DRI growth is over the next decade, it will not be able to replace more than a fraction of the world's blast furnace production because of technological restrictions. The blast furnace is expected to remain the mainstay of the iron and steel industries in most developed countries over the next 25 years.

In contrast to the United States, demand for iron ore in the Pacific Rim is expected to increase, particularly in China. Steelworks in the EC have become more competitive in recent years and should benefit from the growth in steel consumption that is forecasted to occur in Western Europe after the single market takes effect and internal trade barriers are removed.

The increase in consumption in Asia is expected to benefit Australia, primarily. Australia and Brazil are the two leading exporters of iron ore; each accounts for about 30% of the world total, while the next closest exporter accounts for less than 10% of the world total. Of the two, Australia seems to be better placed to take advantage of growth of iron ore consumption in Asia because of Australia's proximity and the consequent lower freight rates.

There is a large potential market for

steel used as framing in the construction industry. There were 1.3 million homes started in the United States in 1993. According to the AISI, 15,000 of the houses were steel framed, up from 500 in 1992. The AISI predicts that 75,000 will be built in 1994. If that growth rate continues, it could have a positive effect on iron ore consumption.

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TABLE 1
SALIENT IRON ORE STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Iron ore (usable,[1] less than 5% manganese):					
Production	59,032	56,408	56,761	55,593	55,661
Shipments	58,299	57,010	56,775	55,569	56,251
Value	$1,939,873	$1,740,925	$1,674,100	$1,732,416	$1,642,841
Average value at mines, dollars per ton	33.27	30.54	29.49	31.18	29.21
Exports	5,365	3,199	4,045	5,055	5,061
Value	$192,796	$124,076	$156,242	$186,864	$166,904
Imports for consumption	19,596	18,054	13,335	12,504	14,097
Value	$522,262	$559,525	$436,777	$395,791	$420,799
Consumption (iron ore and agglomerates)	80,447	76,855	66,366	75,067	76,793
Stocks, Dec. 31:					
At mines, plants and loading docks[2]	[r]4,575	[r]4,795	[r]4,853	[r]3,783	2,504
At receiving docks[3]	15,730	[r]15,911	[r]17,612	[r]16,093	16,548
At consuming plants	2,171	[r]2,273	[r]2,981	[r]2,981	2,288
Total	[r]22,476	[r]22,979	[r]25,446	[r]22,857	21,340
World: Production	[r]1,013,383	[r]984,048	[r]955,552	[r]963,159	[e]988,797

[e]Estimated. [r]Revised.
[1]Direct-shipping ore, concentrates, agglomerates, and byproduct ore.
[2]Excludes byproduct ore.
[3]Transfer and/or receiving docks of Lower Lake ports.

TABLE 2
EMPLOYMENT AT IRON ORE MINES AND BENEFICIATING PLANTS, QUANTITY AND TENOR OF ORE PRODUCED, AND AVERAGE OUTPUT PER WORKER-HOUR IN THE UNITED STATES IN 1993, BY DISTRICT AND STATE

District and State	Average number of employees	Worker-hours (thousands)	Production (thousand metric tons)				Average per worker-hour (metric tons)		
			Crude ore	Usable ore	Iron contained (in usable ore)	Iron content, natural (percent)	Crude ore	Usable ore	Iron contained
Lake Superior:									
Michigan	2,067	3,878	38,810	12,780	8,659	62.3	10.01	3.30	2.23
Minnesota	5,055	10,401	141,453	42,033	26,264	63.5	13.60	4.04	2.53
Total or average[1]	7,122	14,279	180,263	54,814	34,923	63.2	12.62	3.84	2.45
Other States[2]	92	196	643	848	322	59.1	3.27	4.32	1.64
Grand total or average[1]	7,214	14,475	180,906	55,661	35,245	63.1	12.50	3.85	2.43

[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 1993, BY DISTRICT, STATE, AND MINING METHOD

(Thousand metric tons unless otherwise specified and exclusive of ore containing 5% or more manganese)

District and State	Number of mines	Open pit	Underground	Total quantity
Lake Superior:				
Michigan	2	38,810	—	38,810
Minnesota	9	141,453	—	141,453
Total	11	180,263	—	180,263
Other States:				
Missouri	1	—	414	414
Other[2]	4	229	—	229
Total	5	229	414	643
Grand total	16	180,492	414	180,906

[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 1993, BY DISTRICT, STATE, AND TYPE OF PRODUCT

(Thousand metric tons and exclusive of ore containing 5% or more manganese)

District and State	Direct-shipping ore	Concentrates	Agglomerates[1]	Total quantity[2]
Lake Superior:				
Michigan	—	—	12,780	12,780
Minnesota	—	322	41,711	42,033
Total[2]	—	322	54,492	54,814
Other States:				
Missouri	—	287	8	295
Other[3]	553	1	—	553
Total	553	288	8	848
Grand total[2]	553	610	54,499	55,661

[1] Data may include pellet chips and screenings.

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

[3] Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 5

SHIPMENTS OF USABLE IRON ORE[1] FROM MINES IN THE UNITED STATES IN 1993

(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[2]		
Lake Superior:						
Michigan	—	—	12,940	12,940	62.3	W
Minnesota	—	353	42,105	42,459	63.5	$1,126,576
Total reportable or average[2]	—	353	55,046	55,399	63.2	1,126,576
Other States:						
Missouri	—	287	—	287	70.5	W
Other[3]	542	23	—	564	53.3	5,954
Total reportable or average[2] [3]	542	310	—	852	59.1	5,954
Total withheld	—	—	—	—	—	510,311
Grand total or average	542	663	55,046	56,251	63.1	1,642,841

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

[1] Includes byproduct ore.

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

[3] Includes California, Montana, New Mexico, South Dakota, Texas, and Utah.

TABLE 6

CONSUMPTION OF IRON ORE[1] AT U.S. IRON AND STEEL PLANTS

(Thousand metric tons)

Year	Iron ore originating areas					Total[2]
	U.S. ores		Canadian ores		Foreign ores	
	Great Lakes	Other U.S.	Great Lakes	Other Canada		
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	56,169
1987	44,004	710	—	8,686	7,651	61,051
1988	51,048	1,242	—	9,453	10,122	71,865
1989	51,845	1,710	—	7,473	12,034	73,062
1990	54,340	1,516	—	8,257	9,571	73,685
1991	47,945	659	—	7,229	7,828	63,661
1992	53,786	482	—	6,861	7,425	68,555
1993	54,889	515		6,182	8,306	69,892

[1] Excludes dust, mill scale, and other revert iron-bearing materials added to sinter.
[2] Data may not add to totals shown because of independent rounding.

Source: American Iron Ore Association.

TABLE 7

CONSUMPTION OF IRON ORE AND AGGLOMERATES AT U.S. IRON AND STEEL PLANTS, BY TYPE OF PRODUCT

(Thousand metric tons)

Type of product	1989	1990	1991	1992	1993
Blast furnaces:					
Direct-shipping ore	3,211	2,479	1,918	2,035	1,963
Pellets	61,659	60,512	52,534	60,138	60,730
Sinter[1]	13,664	12,226	10,561	11,438	12,451
Total[2]	78,533	75,217	65,013	73,611	75,144
Steelmaking furnaces:					
Direct-shipping ore	142	53	33	20	11
Pellets	76	50	40	61	61
Sinter[1]	—	13	5	10	4
Total[2]	219	115	78	91	76
Grand total[2]	78,752	75,333	65,091	73,702	75,220

[1] Includes briquettes, nodules, and other.
[2] Data may not add to totals shown because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 8
U.S. CONSUMPTION OF IRON ORE AND AGGLOMERATES, BY END USE

(Thousand metric tons and exclusive of ore containing 5% or more manganese)

Year	Blast furnaces	Steel furnaces	Sintering plants[1]	Miscellaneous[2]	Subtotal integrated iron and steel plants[3] [4]	Direct-reduced iron for steelmaking[5]	Nonsteel end uses[6]	Total[4]
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	[r]71,865	443	1,293	[r]73,601
1989	65,597	336	7,118	10	73,062	487	1,208	74,757
1990	67,551	89	5,809	235	73,685	583	940	75,208
1991	57,380	53	6,212	16	63,661	584	691	64,936
1992	62,382	54	6,108	10	[r]68,555	389	976	[r]69,914
1993	63,936	76	5,792	86	69,892	441	1,132	71,465

[r] Revised.

[1] Excludes dust, mill scale, and other revert iron-bearing materials.

[2] Sold to nonreporting companies or used for purposes not listed.

[3] Source: American Iron Ore Association.

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

[5] U.S. Bureau of Mines estimates based on production reports compiled by Midrex Corp.

[6] Includes iron ore consumed in production of cement and iron ore shipped for use in manufacturing paint, ferrites, heavy media cattle feed, refractory and weighing materials, and for use in lead smelting. Data from U.S. Bureau of Mines surveys.

TABLE 9
GREAT LAKES FREIGHT RATES FOR IRON ORE, 1990-93

Origin	Destination	Dollars per long ton[1]	
		Class X	Other
Head of the Lakes	Lower lake ports	6.00	6.50
Marquette	do.	—	5.40
Escanaba	Lake Erie ports	4.50	4.88
Do.	Lower Lake Michigan ports	3.60	3.90

[1] Excludes winter surcharges for shipments after Dec. 15 and before Apr. 15.

Sources: Cleveland-Cliffs Inc., Interlake Steamship Co., and Skillings' Mining Review.

TABLE 10

UNITED STATES AND CANADIAN IRON ORE SHIPMENTS ON THE GREAT LAKES

(Thousand metric tons)

Loading district	1989	1990	1991	1992	1993
Lake Superior	45,296	46,661	44,734	45,897	46,830
Lake Michigan	5,742	4,987	5,218	6,133	6,283
Eastern Canada	9,480	10,836	8,375	8,853	9,714
Total[1]	60,518	62,484	[2]58,326	60,883	62,827
U.S. flag fleet shipments[3]	51,799	54,055	49,794	51,359	52,352
Percent carried by U.S. fleet	86	87	85	84	83

[1] Includes transshipments.

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

[3] Includes mill scale, scarfer ore, and slag, in addition to iron ore.

Source: Lake Carriers' Association, 1993 Annual Report.

TABLE 11

U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY OF DESTINATION

(Thousand metric tons and thousand dollars)

	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Canada	5,359	192,334	3,193	123,601	4,032	154,934	[r]5,043	185,972	5,043	165,489
India	1	59	1	57	(1)	12	(1)	12	(1)	5
Mexico	(1)	15	1	103	2	75	(1)	46	3	228
Netherlands	—	—	(1)	6	—	—	—	—	—	—
Venezuela	(1)	44	—	—	(1)	15	2	46	(1)	8
Other	4	345	4	308	12	1,205	11	785	15	1,174
Total[2]	5,365	192,796	3,199	124,076	4,045	156,242	5,055	186,864	5,061	166,904

[r] Revised.

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 12
U.S. EXPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1991			1992			1993		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)
Concentrates	13	733	55.07	15	488	31.60	8	300	38.50
Coarse ores	(2)	6	32.26	3	98	29.87	1	53	36.11
Fine ores	10	771	78.65	7	203	27.30	7	284	43.53
Pellets	4,017	154,361	38.43	4,653	170,193	36.58	5,031	165,076	32.81
Briquettes	1	44	68.43	1	64	64.43	—	—	—
Other agglomerates	4	283	73.43	375	15,768	42.05	13	1,092	82.24
Roasted pyrites	(2)	45	99.96	1	50	94.48	1	99	90.55
Total[3]	4,045	156,242	38.62	5,055	186,864	36.97	5,061	166,904	32.98

[1] Unit values shown are calculated from unrounded data.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Australia	394	5,211	14	584	—	—	163	3,453	254	3,552
Brazil	5,169	90,885	4,276	90,443	2,481	55,188	2,442	52,962	2,872	63,008
Canada	8,538	292,866	9,344	339,622	7,299	266,496	6,834	242,877	7,442	243,373
Chile	61	1,200	138	2,905	103	2,154	107	2,158	68	1,243
India	59	1,037	—	—	(1)	2	—	—	—	—
Liberia	200	2,950	—	—	—	—	—	—	—	—
Mauritania	594	10,130	666	14,142	459	10,057	280	6,200	206	3,747
Norway	40	693	—	—	—	—	—	—	2	69
Peru	186	4,280	59	1,623	157	3,980	70	1,883	1	57
Philippines[2]	66	1,622	—	—	—	—	—	—	—	—
Spain	—	—	1	61	1	38	—	—	—	—
Sweden	57	1,000	54	2,273	51	2,300	64	2,807	60	1,965
Venezuela	4,232	110,367	3,503	107,848	2,763	94,476	2,540	83,287	3,189	103,641
Other	(1)	21	[3](1)	[3]24	22	2,086	4	164	3	144
Total[4]	19,596	522,262	18,054	559,525	13,335	436,777	12,504	395,791	14,097	420,799

[1] Less than 1/2 unit.

[2] Sinter made from raw materials supplied by Australia, Brazil, and other countries.

[3] Excludes 12 metric tons of iron oxide-based coloring preparations valued at $7,542, originally reported as fine ores from China. The 1 ton of material from Namibia that was reported in October was part of a meteorite and was valued at $10,881.

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

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY TYPE OF PRODUCT

Type of product	1991			1992			1993		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value[1] (dollars per ton)
Concentrates	398	8,765	22.00	374	7,511	20.09	1,176	21,731	18.48
Coarse ores	63	1,749	27.54	([2])	6	54.36	134	3,739	27.86
Fine ores	3,549	87,481	24.75	3,244	73,653	22.70	2,761	54,536	19.75
Pellets	9,317	338,493	36.33	8,880	314,372	35.40	9,794	332,973	34.00
Briquettes	([2])	31	86.01	—	—	—	15	1,407	93.24
Other agglomerates	2	54	27.49	2	76	39.27	213	6,263	29.36
Roasted pyrites	5	205	44.79	4	173	47.62	3	150	43.34
Total[3]	13,335	436,777	32.75	12,504	395,791	31.65	14,097	420,799	29.85

[1] Unit values shown are calculated from unrounded data.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS OF IRON ORE AND AGGLOMERATES IN 1993, 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	—	—	254	—	—	—	254
Brazil	231	48	2,109	442	42	—	2,872
Canada	945	16	—	6,381	101	—	7,442
Chile	—	—	—	—	68	—	68
Mauritania	—	—	206	—	—	—	206
Sweden	—	—	47	13	—	—	60
Venezuela	—	71	145	2,958	15	—	3,189
Other	—	—	—	—	3	3	6
Total[1]	1,176	134	2,761	9,794	228	3	14,097

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

Source: Bureau of the Census.

TABLE 16

AVERAGE UNIT VALUE FOR SELECTED IMPORTS OF IRON ORE AND AGGLOMERATES IN 1993

Type of product	Country of origin	Average unit value[1] (dollars per metric ton gross weight)
Coarse ores	Venezuela	26.62
Fine ores	Brazil	20.10
Do.	Canada	—
Do.	Mauritania	18.06
Do.	Venezuela	23.54
Pellets	Brazil	34.69
Do.	Canada	32.03
Do.	Peru	—
Do.	Venezuela	32.77

[1] Weighted averages of individual Customs values.

Source: Bureau of the Census.

TABLE 17

U.S. IMPORTS OF IRON ORE AND AGGLOMERATES, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore	6,062	158,193	3,559	99,849	3,027	89,515	3,100	93,350	3,199	87,380
Charleston	524	14,858	563	16,629	638	22,293	445	14,895	581	17,961
Chicago	2,795	52,162	1,654	32,561	1,124	24,708	1,240	26,624	2,007	41,328
Cleveland	1,557	48,401	1,931	66,811	1,641	56,805	809	28,085	603	17,434
Detroit	528	24,773	978	42,185	344	13,679	409	15,044	465	17,417
Houston-Galveston	28	519	(1)	18	21	556	31	737	38	968
Mobile	2,284	68,830	3,480	121,704	2,571	97,363	2,537	91,562	2,588	94,472
New Orleans	1,845	30,830	1,910	37,308	1,113	26,138	1,221	27,916	1,364	33,711
Philadelphia	3,968	123,112	3,967	141,970	2,826	104,883	2,709	97,477	3,244	109,926
Other	4	584	12	488	30	836	(1)	102	8	202
Total[2]	19,596	522,262	18,054	559,525	13,335	436,777	12,504	395,791	14,097	420,799

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS OF PELLETS, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value
Brazil	170	5,092	121	3,593	442	14,174
Canada	[r]6,977	[r]259,325	6,566	237,602	6,381	221,345
Germany	([1])	([1])	—	—	—	—
Peru	155	3,894	69	1,798	—	—
Sweden	—	—	13	655	13	530
U.S.S.R.[2]	19	1,940	—	—	—	—
Venezuela	1,997	68,243	2,113	70,723	2,958	96,923
Total[3]	9,317	338,493	8,880	314,372	9,794	332,973

[r] Revised.

[1] Revised to zero.

[2] Dissolved in Dec. 1991.

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

Source: Bureau of the Census.

TABLE 19
IRON ORE, IRON ORE CONCENTRATES, AND IRON ORE AGGLOMERATES: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Gross weight[3]					Metal content[4]				
	1989	1990	1991	1992	1993e	1989	1990	1991	1992	1993e
Albania[5]	1,179	930	e750	200	150	e520	e410	r e350	e88	85
Algeria	2,748	2,941	2,344	r2,560	2,500	1,374	1,470	e1,170	r e1,250	1,225
Argentina	1,017	992	r259	r4	10	539	r681	r171	r2	5
Australia	r105,810	r110,508	r117,134	e117,170	[6]120,534	r67,313	r69,766	r68,732	e72,650	[6]74,767
Austria	2,410	2,301	r2,120	r1,627	1,500	761	653	481	e370	300
Azerbaijan	—	—	—	r400	300	—	—	—	r220	150
Bolivia	14	125	102	r55	12	9	79	72	r35	8
Bosnia and Herzegovina	—	—	—	e500	250	—	—	—	e150	100
Brazil	157,900	152,300	r150,500	r e151,000	151,000	r e102,300	r e99,900	r e100,000	r e100,000	100,000
Bulgaria	1,613	1,079	r e800	r e800	800	r483	321	r182	r e180	180
Canada[7]	r40,509	r34,855	36,383	r32,697	30,568	r25,924	r21,959	22,921	21,506	20,000
Chile	r9,030	r7,903	r8,692	r8,270	8,500	e5,478	e5,035	r5,824	r5,540	5,690
China	r171,850	r168,300	r176,070	r197,600	234,660	51,560	50,490	52,820	67,900	74,622
Colombia	573	628	r607	r674	[6]715	e260	e283	e295	300	316
Croatia	—	—	—	e75	70	—	—	—	24	22
Czech Republic[8]	—	—	—	—	160	—	—	—	—	39
Czechoslovakia[9]	1,780	1,831	1,738	r1,414	—	r525	r540	r e526	r412	—
Egypt	2,562	2,405	2,144	r2,400	2,400	e1,500	e1,500	e1,300	1,260	1,450
France	r9,368	8,729	7,472	r5,707	[6]3,520	r2,810	2,793	e2,316	r1,697	1,098
Germany: Western states	r106	r83	120	r109	75	r15	12	17	r15	11
Greece[5]	2,013	2,113	2,024	e1,500	1,416	820	861	815	e610	575
Guatemala	7	6	5	1	3	4	3	3	1	2
India	53,418	54,579	57,638	e54,000	61,000	33,440	34,200	35,600	33,800	38,200
Indonesia	143	145	173	r288	341	83	84	100	145	197
Iran[10]	2,296	3,240	4,890	r5,647	[6]9,870	e1,300	e1,800	e2,700	e3,000	4,800
Japan	41	34	31	r40	10	25	21	19	r24	6
Kazakhstan	—	—	—	r e17,300	17,000	—	—	—	11,000	9,350
Korea, North e	9,500	r10,000	10,000	10,500	10,500	4,400	r4,700	4,700	4,900	4,900
Korea, Republic of	334	298	222	r222	650	187	180	134	r134	390
Liberia	11,700	4,050	1,100	1,742	—	7,087	e2,490	710	1,000	—
Macedonia	—	—	—	r e20,000	20,000	—	—	—	r e1	1
Malaysia	193	344	376	320	[6]223	118	210	229	195	136
Mauritania	12,110	11,590	10,246	r8,202	[6]9,300	e7,150	e6,800	e6,500	r e5,330	5,890
Mexico[11]	r15,000	r15,000	r13,000	r15,000	15,000	r7,000	r7,112	r6,596	r7,236	7,547
Morocco	176	148	99	r83	82	107	90	60	r51	51
New Zealand[12]	2,367	2,296	2,265	r2,934	2,300	e1,300	e1,300	e1,300	e1,300	1,300
Nigeria	e300	374	398	e400	400	e150	e180	e200	e200	200
Norway	2,358	2,081	2,209	2,152	2,100	1,532	1,352	1,435	1,403	1,360
Peru	4,507	3,307	3,593	r2,848	2,848	2,923	2,147	r2,331	r1,820	1,820
Poland	7	2	([13])	—	—	e2	e1	e([13])	—	—
Portugal e [14]	13	12	e11	e10	8	e6	e4	e4	r e2	1
Romania	2,482	2,002	r e1,400	r1,250	[6]904	r645	r275	r199	r180	[6]130
Russia	—	—	—	r86,700	75,000	—	—	—	45,000	40,000
Serbia and Montenegro	—	—	—	e400	400	—	—	—	128	128
Slovakia[8]	—	—	—	—	1,300	—	—	—	—	350

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]				
	1989	1990	1991	1992	1993^{e}	1989	1990	1991	1992	1993^{e}
South Africa, Republic of[15]	29,958	30,291	28,958	28,226	^{6}29,385	19,461	19,689	18,819	18,350	19,100
Spain[16]	^{r}4,563	^{e}3,030	^{e}3,920	^{r}3,648	3,600	^{r}2,128	^{r}1,438	1,840	^{r}1,715	1,700
Sweden	21,763	19,877	19,328	^{r}19,277	^{6}18,728	14,124	12,901	^{r}11,088	^{r}9,785	9,800
Thailand	177	129	240	^{r}427	450	98	71	132	^{r}235	250
Tunisia	280	291	295	^{r}291	290	^{e}148	^{e}154	^{e}156	^{r} ^{e}151	150
Turkey	4,518	^{r}4,925	^{r}5,335	^{r}5,917	^{6}5,070	2,453	^{r}2,689	^{r} ^{e}2,900	^{e}3,200	2,800
Ukraine	—	—	—	75,700	70,000	—	—	—	^{e}40,000	39,500
U.S.S.R.	241,348	236,000	199,000	—	—	134,789	^{e}132,000	^{e}110,000	—	—
United Kingdom	34	55	59	^{r}29	18	^{e}8	12	13	^{r}6	4
United States[16]	59,032	56,408	56,596	55,593	55,651	37,413	35,695	35,333	35,251	35,116
Venezuela	^{r}18,053	^{r}20,119	^{r}21,196	^{r}18,070	16,851	^{r}11,796	^{r}13,146	^{r}13,849	^{r}11,807	11,010
Yugoslavia	5,080	4,132	^{e}2,574	—	—	1,305	^{e}1,578	^{e}900	—	—
Zambia[17]	(14)	1	(14)	1	—	(14)	(14)	(14)	(14)	—
Zimbabwe	1,143	1,259	1,136	^{r}1,179	375	^{r} ^{e}686	^{e}730	^{e}660	^{r} ^{e}710	225
Total	^{r}1,013,383	^{r}984,048	^{r}955,552	^{r}963,159	988,797	^{r}554,058	^{r}539,804	^{r}516,502	^{r}512,269	517,058

^{e}Estimated. ^{r}Revised.

[1] Table includes data available through Aug. 8, 1994.

[2] In addition to the countries listed, Cuba and Vietnam may also produce iron ore, but definitive information on output levels, if any, is not available.

[3] Insofar as availability of sources permits, gross weight data in this table represent the nonduplicative sum of marketable direct-shipping iron ores, iron ore concentrates, and iron ore agglomerates produced by each of the listed countries. Concentrates and agglomerates produced from imported iron ores have been excluded under the assumption that the ore from which such materials are produced has been credited as marketable ore in the country where it was mined.

[4] Data represent actual reported weight of contained metal or are calculated from reported metal content. Estimated figures are based on latest available iron content reported, except for the following countries for which grades are U.S. Bureau of Mines estimates: Albania and North Korea.

[5] Nickeliferous iron ore.

[6] Reported figure.

[7] Series represent gross weight and metal content of usable iron ore (including byproduct ore) actually produced, natural weight.

[8] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[9] Dissolved Dec. 31, 1992.

[10] Data are for year beginning Mar. 21 of that stated.

[11] Gross weight calculated from reported iron content based on grade of 66% Fe.

[12] Concentrates from titaniferous magnetite beach sands.

[13] Less than 1/2 unit.

[14] Includes manganiferous iron ore.

[15] Includes magnetite ore as follows, in thousand metric tons: 1989—6,594; 1990—5,613; 1991—5,658; 1992—4,647; 1993—4,338.

[16] Includes byproduct ore.

[17] Entry discontinued in 1993. Iron ore used for mineral processing only.

TABLE 20
SELECTED PRICES FOR IRON ORE IN THE JAPANESE MARKET

(F.o.b. shipping port basis. U.S. cents per dry long ton of iron unless otherwise specified)

Country and producer	Ore type	(April 1-March 31) Fiscal year 1990	Fiscal year 1991	Fiscal year 1992	Fiscal year 1993
Australia:					
Hamersley Iron Pty. Ltd. and Mount Newman Mining Co. Pty. Ltd.	Lump ore	39.15	41.48	38.84	38.84
Do.	Fines	31.03	33.49	31.85	31.85
Robe River Iron Associates	do.	26.88	29.01	27.37	27.37
Savage River Mines Ltd.	Pellets	46.63	47.13	43.81	43.81
Brazil:					
Cia. Nipo-Brasileira de Pelotizacao (Nibrasco)	do.	49.28	49.81	46.30	46.30
Cia. Vale do Rio Doce (Carajas)	Fines	27.82	30.03	29.06	29.06
Do.	Lump ore	35.94	38.08	33.13	33.13
Cia. Vale do Rio Doce (Itabira)	do.	29.69	31.46	29.46	29.46
Mineraes Brasileiras Reunidas S.A.	do.	29.05	30.78	28.82	28.82
Do.	Fines	28.36	30.61	29.11	29.11
Samarco Mineracao S.A.	Pellet feed	22.88	24.70	23.99	23.99
Canada: Iron Ore Co. of Canada (Carol Lake)	Concentrates	26.53	28.63	27.70	27.70
Chile:					
Minera del Pacifico S.A. (El Algarrobo)	Pellets	44.40	45.79	43.15	43.15
Minera del Pacifico S.A. (El Romeral)	Fines	21.55	23.26	22.12	22.12
India:					
Minerals and Metals Trading Corp. (Bailadila)	Lump ore	37.74	39.99	[r]37.45	37.54
Do.	Fines	29.81	32.17	30.59	30.59
Peru: Empresa Minera del Hierro del Peru S.A.	Pellets	35.94	36.32	(1)	(1)
South Africa, Republic of:[2]					
South African Iron and Steel Industrial Corp. Ltd.	Lump ore	30.21	32.01	30.27	30.27
Do.	Fines	23.62	25.49	24.24	24.24

[r] Revised.

[1] No quotation published.

[2] Price per dry metric ton unit.

Sources: The TEX Report (Tokyo) and Iron Ore Manual, 1993-94.

TABLE 21

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY IN 1993

	Number			Rated capacity (million metric tons, gross weight)
	Sites	Plants[1]	Units	
North America:				
Canada	5	6	13	26.44
Mexico	5	6	6	9.50
United States[2]	10	18	50	66.55
Total	20	30	69	102.49
South America:				
Argentina	1	1	4	1.00
Brazil	3	8	8	25.00
Chile	1	1	1	4.20
Peru	1	2	2	3.20
Venezuela	1	1	2	6.60
Total	7	13	17	40.00
Europe:				
Belgium[3]	1	1	1	.80
Czech Republic	1	1	1	.25
Netherlands[3]	1	1	1	3.80
Norway[4]	2	3	3	3.20
Sweden[5]	3	3	4	10.80
Turkey	1	1	1	1.30
U.S.S.R.[6]	7	13	NA	80.00
Yugoslavia[7]	1	1	1	.60
Total	17	24	NA	100.75
Africa:				
Liberia[8]	1	1	1	3.00
Morocco[9]	1	1	1	.85
Nigeria[3]	1	1	1	1.45
South Africa, Republic of	1	1	1	.60
Total	4	4	4	5.90
Asia:				
Bahrain[3]	1	1	1	4.00
China[10]	4	4	NA	4.50
India[11]	1	1	1	3.00
Iran	1	1	1	2.50
Japan[3]	1	2	2	4.40
Total	8	9	NA	18.40

See footnotes at end of table.

TABLE 21—Continued

IRON ORE: WORLD PELLETIZING CAPACITY, BY CONTINENT AND COUNTRY IN 1993

	Number			Rated capacity (million metric tons), gross weight)
	Sites	Plants[1]	Units	
Oceania: Australia[12]	2	2	6	4.00
World total	58	82	NA	271.54

NA Not available.

[1] Staged additions are treated at some mining complexes as if they were separate plants. Site data exclude plants that have had no production since 1982. Plants that produce 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-million-metric-ton-per-year (Mmt/yr) Republic plant, which has been on care and maintenance since 1981.

[3] Pellets produced from imported direct-shipping ores and/or concentrates.

[4] The older of the two plants operated by A/S Sydvaranger at Kirkenes has been idle since 1986. In addition, 0.50-Mmt/yr plant operated by Norsk Jernverk at Mo-i-Rana was shut down in Jan. 1987 for an indefinite period, leaving only one plant in Norway on-line.

[5] In early 1988, the capacity of the Svappavaara plant was upgraded from 2.8 to 3.5 Mmt/yr. The 0.3-Mmt/yr steel belt plant at Malmberget is used for both research and development purposes as well as ordinary production.

[6] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[7] The Skopje plant operated by Rudnici i Zelezara was recently idled.

[8] Excludes the No. 1 pelletizing plant (capacity of 2.4 Mmt/yr) of the Bong Mining Co. The No. 1 plant has been idle since 1980.

[9] The Nador plant operated by Société d'Exploitation des Mines du Rif (SEFERIF) has been idle for several years.

[10] Based on incomplete information.

[11] There is an additional plant with a capacity of 1.8 Mmt/yr at Mandovi in Goa, but it has been closed since 1982. The owner was planning to reopen the facility using high-grade blue dust from the Bellary Hospet area of Karnataka as feed.

[12] There is an additional plant with a capacity of 3 Mmt/yr at Dampier in Western Australia, but it has been closed since 1980.

Sources: Association of Iron Ore Exporting Countries (Geneva, Switzerland), Commodities Research Unit Ltd. (London, United Kingdom), International Iron and Steel Institute (Brussels, Belgium), Metal Bulletin Books Ltd. (Surrey, United Kingdom), Roskill Information Services Ltd. (London, United Kingdom), United Nations Commission on Trade and Development (UNCTAD), UNCTAD Trust Fund Project on Iron Ore Information, and U.S. Bureau of Mines.

FIGURE 1

U.S. IRON ORE PRODUCTION AND IMPORTS FOR CONSUMPTION

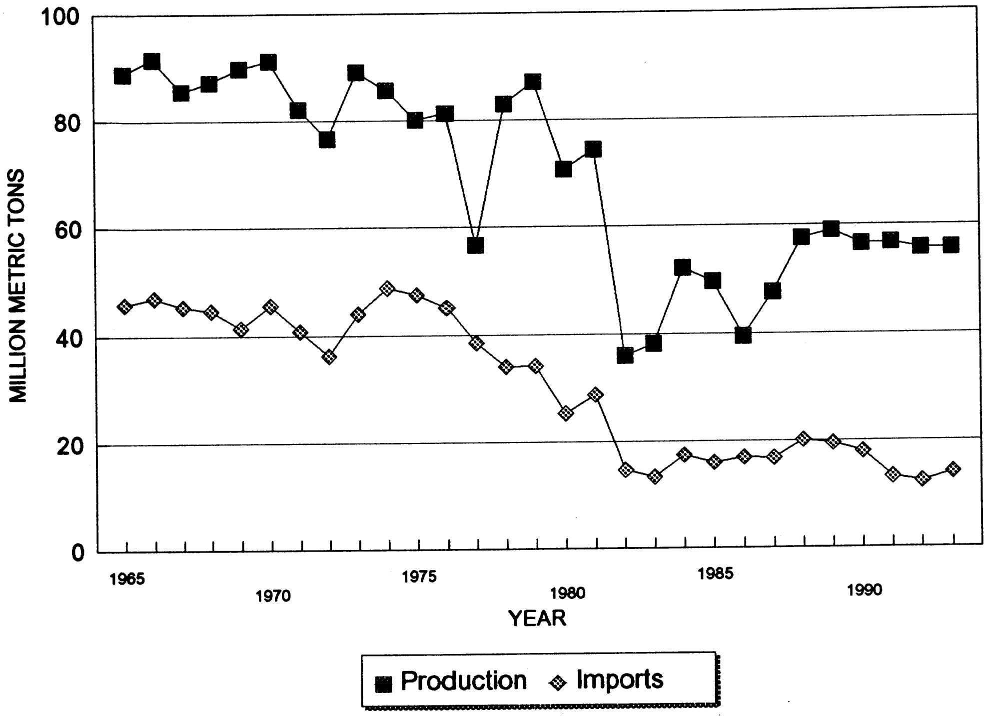


FIGURE 2

CONSUMPTION OF IRON ORE IN U.S. SINTERING PLANTS

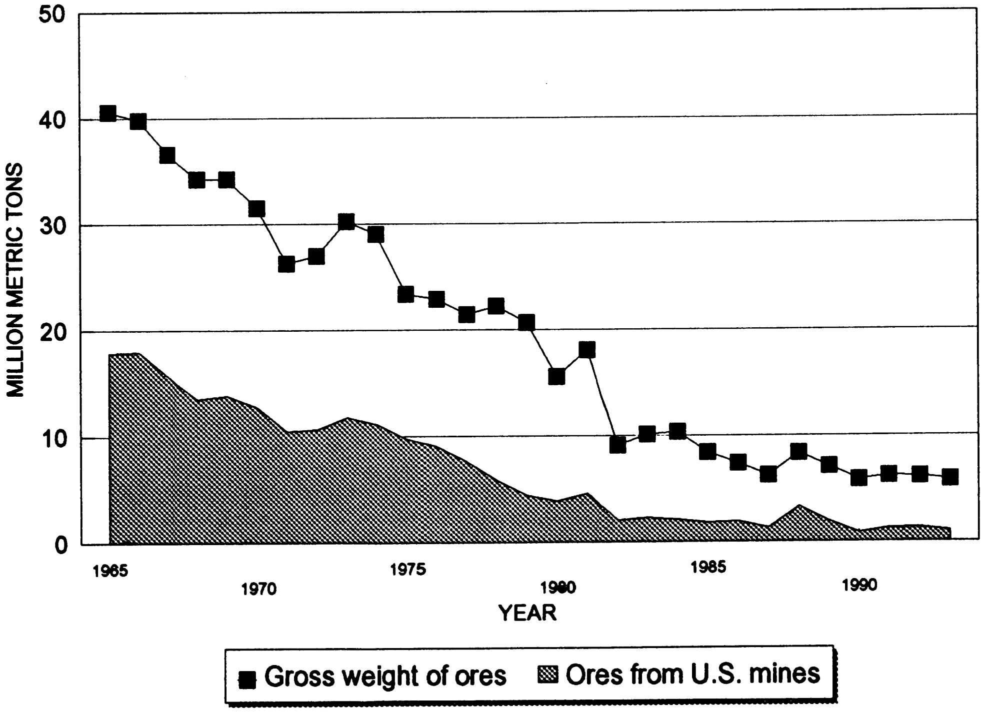


FIGURE 3
WORLD DIRECT-REDUCED IRON PRODUCTION

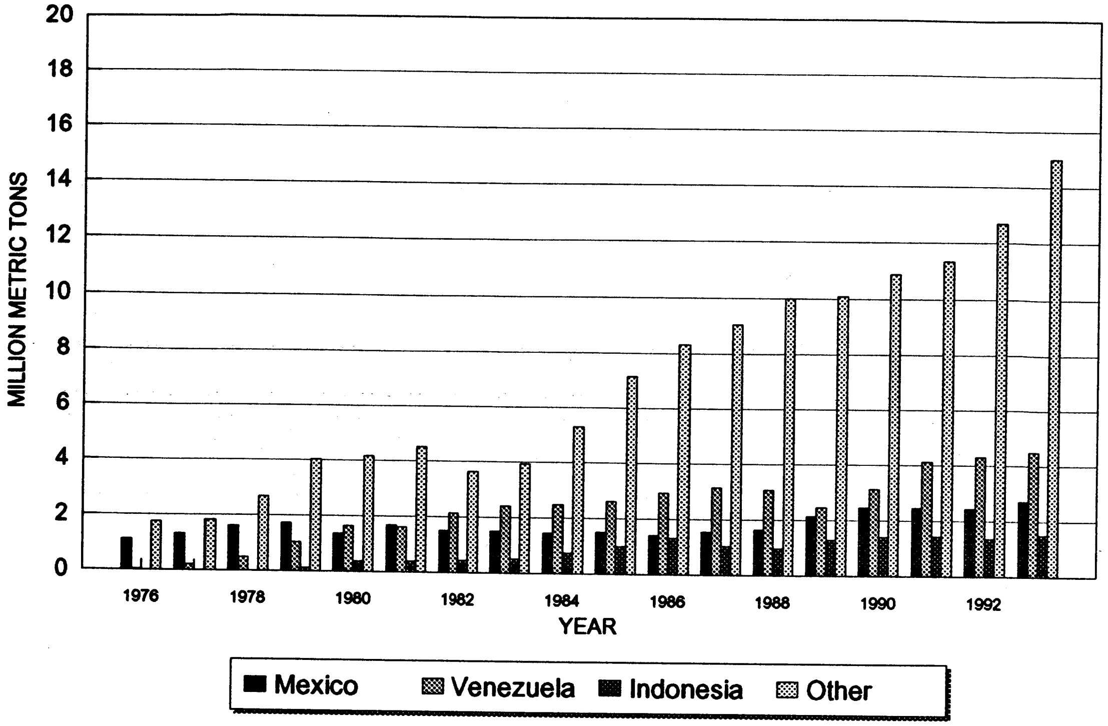
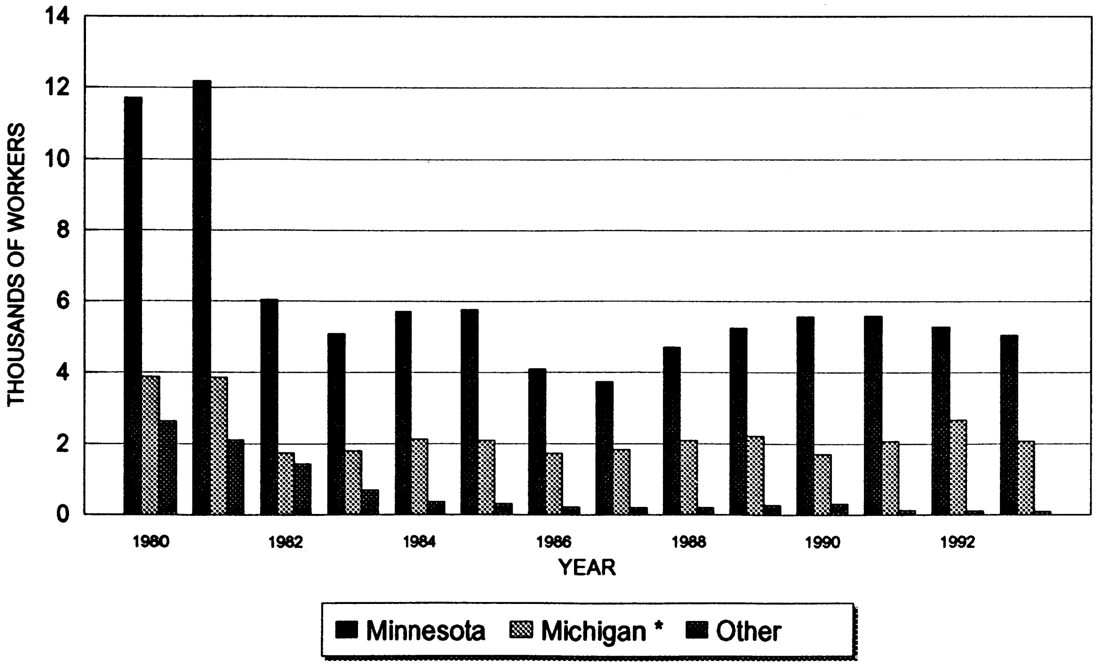


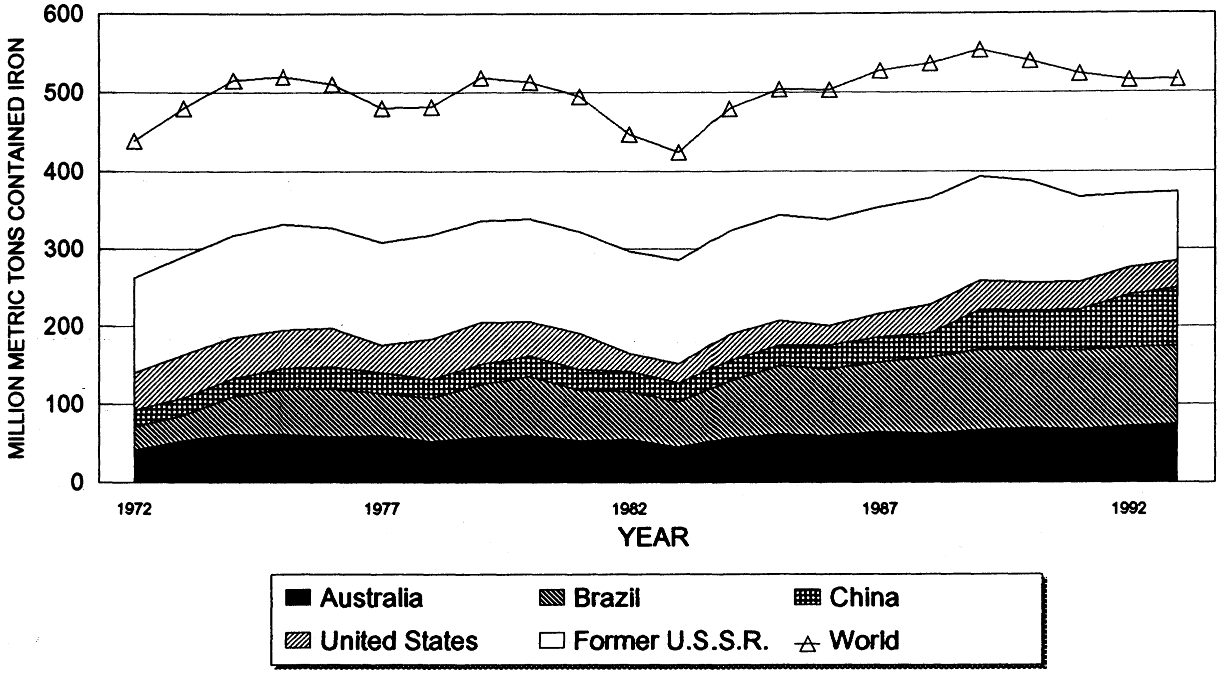
FIGURE 4
EMPLOYMENT AT IRON MINES AND BENEFICIATION PLANTS



* Includes workers in Wisconsin for years prior to 1984.

FIGURE 5

COMPARISON OF U.S. IRON ORE PRODUCTION WITH TOTAL PRODUCTION FOR THE WORLD



IRON AND STEEL

By Gerald W. Houck

Mr. Houck, a physical scientist with 37 years of industry and U.S. Bureau of Mines experience, is the commodity specialist for iron and steel. International data tables were prepared by Harold Willis, international data analyst, and Ted Spittal, international data coordinator. Ferroalloys survey data were prepared by Jo-Ann Sterling, statistical assistant, and David Kulha, management analyst.

Iron and steel are vital to the United States for both national security and economic well-being. They are the basic metals of an industrial society. Although there are many acceptable substitutes for many of their uses, in the short term, there are no practical substitutes on a large scale because of the cost and lack of availability of alternative materials.

Data tables on ferroalloys production and consumption are contained in this chapter. Ferroalloys are alloys of iron that contain a sufficient amount of one or more other chemical elements to be useful as an agent to introduce these other elements into a molten metal, usually steel. The reader is referred to the Annual Reports dealing with specific elements, especially those for chromium, manganese, and silicon, for analysis and detail with respect to the ferroalloys industry.

Consistent with international usage, the U.S. Bureau of Mines is reporting all data on iron and steel in metric units, unless otherwise noted.

This was another poor year for the U.S. steel industry. Despite strong increases in both production and shipments of steel, the industry reported an aggregate loss at the operating income level. Production of raw steel in the United States increased 5.3%, to 88.8 million metric tons, from 84.3 million tons produced in 1992. Net shipments of steel mill products by U.S. companies increased more than 8%, to 80.8 million tons, from 74.6 million tons in 1992.

Imports of steel mill products increased about 14%, to 17.7 million tons, from 15.5 million tons in 1992. Imports captured 18.7% of the apparent consumption of steel mill products, up from 18.0% in 1992. Imports of fabricated steel products, such as fasteners, wire, and fabricated structural steel, totaled 2.1 million tons, representing another 2% of the U.S. steel market.

Exports of steel mill products declined to 3.6 million tons from 3.9 million tons in 1992.

Prices of steel mill products increased slightly in 1993, after declining for the three previous years. The Bureau of Labor Statistics' Producer Price Index for steel mill products increased about 2% to 108.2 (1982 base=100.0).

World production of raw steel in 1993 was 725 million tons, up less than one-half percent from that of 1992. Production in the former U.S.S.R. continued to decline—almost 19% in 1993 alone and over 40% from production levels prior to 1990. Production in Japan was down more than 10%, and production in Western Europe declined about 4%. In China and in the other developing nations of Asia, Africa, and the Middle East, however, growth continued at a vigorous pace; production in China increased 13%.

DOMESTIC DATA COVERAGE

Data regarding U.S. production of iron and steel, and shipments of steel mill products are those reported by the American Iron and Steel Institute (AISI). These data can be regarded as representing 100% of the raw steel producers in the United States.

BACKGROUND

Definitions, Grades, and Specifications

Iron is the most useful and most abundant, as well as the cheapest of the metallic elements. It is also the most versatile and most widely studied and understood. Its many uses are based on the properties of its alloys; iron is never used by itself. Some of its useful alloys include the word "iron;" viz., pig iron, wrought iron, gray iron, malleable iron, ductile iron; others are known as "steel." The term "steel" was originally applied to an alloy of iron that would become very hard if cooled rapidly from a high temperature. Early steelmakers did not know that a carbon content from about 0.3% to about 1% is required for producing these properties, but by trial and error they developed empirical methods to produce metals of the proper carbon content.

Today, iron refers to alloys that contain too much carbon to be formable by forging or rolling. "Pig iron" contains about 4.5% carbon and is useful only for steelmaking or for remelting into cast iron products. Gray iron, malleable iron, and ductile iron are categories of cast iron and are produced by the foundry industry.

In modern terminology, steel refers to an alloy of iron that is malleable at some temperature and contains carbon, manganese, and often other alloying elements. Steel containing only carbon and manganese is called "carbon steel;" steel containing metallic elements such as chromium, molybdenum, or nickel is termed "alloy steel;" steel containing sufficient chromium to confer a superior corrosion resistance is called "stainless steel." Hundreds of individual alloy specifications have been developed to produce combinations of strength, ductility, hardness, toughness, magnetic permeability, and corrosion resistance to meet the needs of modern consumers. These alloy specifications are called "grades."

The malleability property of steel allows it to be produced by rolling or forging into a variety of product forms. Examples of forms include structural shapes (such as beams and angles), rails (such as railroad rails), round bars, wire, various types of pipe and tubular products, and flat-rolled products. In every case, the product is produced on specialized equipment in a range of sizes to suit intended applications.

For some products, metallic or nonmetallic coatings are applied to the product by the steel producer. Additionally, various thermal treatments may be used to meet the customer's requirements.

"Steel mill products" refers to products produced by a steel mill, either by forging or rolling, in the form normally delivered for fabrication or use. Some companies purchase semifinished steel mill products from other steel companies and use these semifinished products to produce steel mill products. To avoid double counting steel mill product shipments under these circumstances, steel mills identify any shipments of steel mill products to other companies that are reporters of steel mill product shipments. The accumulated shipments of all companies, less the shipments to other reporting companies, are identified as "net" shipments.

Regarding the reporting of imports and exports, "fabricated steel products" are products produced from steel mill products, but not including products that incorporate steel products along with other materials. Examples of fabricated steel products are fabricated structural steel and steel fasteners. "Other iron and steel products" refers to products that are not produced from steel mill products. Examples of other iron and steel products include iron or steel castings and direct-reduced iron (DRI).

Industry Structure

Integrated Steel Producers.— Integrated steel producers are those that smelt iron ores to crude liquid iron in blast furnaces and refine the iron, with some scrap, in basic oxygen furnaces, producing liquid steel. The liquid steel is mostly cast into semifinished products in continuous casting machines, although 14% of U.S. production in 1993 was cast in ingot form and subsequently rolled into semifinished form. The integrated steel industry in the United States in 1993 consisted of 15 companies operating ironmaking and steelmaking facilities at 22 locations. Several of these companies also operated nonintegrated plants and/or other steelmaking facilities at the same locations.

The product mix of the integrated producers consists predominantly of flat products: sheet and strip, some of which is galvanized or tin-plated. Some integrated producers made structural shapes and bar products as well, but, for the most part, these products are produced by nonintegrated mills.

Nonintegrated Steel Producers.— Nonintegrated steel producers melt raw materials, primarily scrap, in electric furnaces. Broadly speaking, there are two subcategories of nonintegrated mills: minimills and specialty mills. "Minimills" is a term used to describe steel producers that utilize modern technology in a plant built to produce a limited product line with maximum efficiency. These plants always incorporate electric melting of low-cost raw materials, continuous casting, and a hot-rolling mill, often closely coupled to the casting operation. It was once accepted that minimills produced only simple bar products such as reinforcing bars, wire rods, and small structural shapes. Today, however, minimills have become dominant in all long products, including special quality bars and large structural shapes. In recent years, the minimill concept has been successfully applied to the production of flat-rolled steel with the development of thin-slab (50-mm), continuous casting machines, closely coupled to a hot-strip mill to produce commercial quality hot bands. In the United States, two flat-roll minimill plants utilizing the thin slab casting technology were in operation, and a third plant was under construction. Plans to construct at least four additional similar plants in the United States had been announced.

The largest of the minimill plants have steelmaking capacity greater than that of the smallest of the integrated plants, and at least one of the minimill companies operated multiple minimills with cumulative steelmaking capability exceeding that of all but the largest of the integrated mills.

The second category of nonintegrated mills, specialty mills, is less well defined. Specialty mills definitely include the producers of stainless steel, alloy electrical steel, tool steel, and high-temperature alloys. In addition, this category includes producers of forging ingots and a variety of steel plants that, although not producing a large quantity of steel, are a significant part of what is called "the steel industry."

Overall, the nonintegrated sector of the industry consisted of about 65 companies with 94 raw-steelmaking locations.

Substitutes

Iron, as steel or cast iron, is the most widely used metal in the world because of its high strength-to-cost ratio. In applications where strength is not the major requirement, iron competes with less expensive nonmetallic materials or more expensive materials having some property advantage. Where weight reduction is required, aluminum, plastics, and occasionally magnesium or titanium may be substituted; motor vehicles and airplanes are obvious examples. In construction, concrete, usually reinforced with steel, and wood are frequently substituted for steel. In packaging, steel cans, pails, and household goods were largely replaced with aluminum, glass, plastics, and paper, but drums and other containers used for more severe applications are almost invariably made of steel.

ANNUAL REVIEW

Legislation and Government Programs

Trade Agreements.—From October 1, 1984, until March 31, 1992, the import of steel products into the United States was limited by a program of "Voluntary Restraint Agreements (VRA's)," which were negotiated following an investigation conducted by the U.S. International Trade Commission (ITC) in which imports of certain steel products were found to be a substantial cause of serious injury, or threat thereof, to certain domestic industries. The President determined that imposing countervailing duties under the Trade Act of 1974 was not in the national economic interest and directed the U.S. Trade Representative to negotiate VRA's with countries whose exports to the United States had increased significantly in previous years due to an unfair surge in imports.

Agreements were negotiated with the European Community (EC) and 16 individual nations. Although the structure of the agreements varied from one country to another, each involved an agreement by the foreign Government to limit exports of certain steel products to the United States. To bring the agreements into effect, U.S. steel producers withdrew pending unfair trade petitions, and the U.S. Government suspended antidumping and countervailing duties that were in effect on the products covered by the agreements. The VRA's initially covered a 5-year period ending September 30, 1989. In July 1989, the President announced a "Steel Trade Liberalization Program" extending the VRA program for 2½ years, to terminate March 31, 1992. Negotiations resulted in new agreements with the EC and the 16 other countries.

Anticipating the expiration of the VRA's, the United States, along with more than 30 other countries, has negotiated in an effort to reach a "Multilateral Steel Agreement." The principal U.S. objectives for a multilateral agreement include prohibitions against most subsidies, the elimination of tariff and nontariff barriers to trade, and the establishment of an effective mechanism to resolve disputes. Agreement on the Multilateral Steel Agreement was not reached before the expiration of the VRA's on March 31, 1992.

Following the expiration of the VRA's, some U.S. steel companies filed new countervailing duty and antidumping suits, claiming injury to the domestic steel industry as a result of government-subsidized or unfairly traded steel imported into the United States from numerous countries, including those that have been the source of most of the imported steel in the U.S. market. The most important of these suits were filed on June 30, 1992, dealing with hot-rolled, cold-rolled, and galvanized carbon steel sheets and hot-rolled carbon steel plates. Claims of subsidization were made against imported steel from 13 countries, and claims of unfair trade were made against 20 countries. The countries against whom the charges were filed had exported to the United States more than 5.8 million tons of the covered products during 1991. The products involved are the most important products of the integrated steel companies and account for more than half of all steel products shipped in this country.

To dispose of unfair trade cases such as these, the U.S. Department of Commerce (DOC) is responsible for determining whether there was subsidization or unfair trade, and if so, the value of it in relation to the value of the products imported. This determination establishes the percentage amount of a countervailing duty or antidumping duty that may be assessed. The ITC is responsible for determining whether the subsidization or unfair trade resulted in injury to the U.S. industry.

In these cases, the DOC made preliminary determinations that there was indeed illegal subsidization and unfair trade, and the ITC determined preliminarily that there was injury to the U.S. industry in most of the cases. As a result, effective December 7, 1992, in the subsidy cases, and effective February 6, 1993, in the antidumping cases, importers of the covered products were required to make cash deposits or to post bond equal to the amount of the estimated dumping margins. Recovery of the deposit or bond is subject to final calculation of the duties and to a final determination of injury by the ITC. The duties are determined and applied on a company-specific basis and differ widely. For example, the duties for hot-rolled plate range from 1.47% to 109.22%.

The International Trade Commission announced its final determination on the question of injury on July 27, 1993. The result was mixed. The Commission found that the U.S. industry was being harmed by virtue of imports of plate products from Belgium, Brazil, Canada, Finland, Germany, Mexico, Poland, Romania, Spain, Sweden and the United Kingdom, and corrosion-resistant (galvanized) product from Australia, Canada, France, Germany, Japan, and the Republic of Korea. In the case of cold-rolled steel products, injury to the U.S. industry was found only as a result of imports from Germany, the Republic of Korea, and the Netherlands; imports from 10 other countries that had been determined to be either illegally subsidizing or unfairly pricing their products were determined to be causing no injury to U.S. industry.

The most disappointing decision for the U.S. steel companies was the Commission's decision that there was no injury in any of the cases involving hot-rolled carbon steel flat products, the highest volume category under investigation. The commission decided that the total U.S. market for hot-rolled products includes hot-rolled steel used internally by steel companies to produce cold-rolled, corrosion-resistant, and other coated steel products. The steel companies had argued that the market for hot-rolled steel includes only product sold as hot-rolled to unrelated customers. By the Commissioners' reasoning, the market was much larger; as a result, the impact of the unfairly traded product was deemed insufficient to injure the domestic industry.

In the cases for which injury was affirmed by the Commission, the duties were effective for imports on or after December 7, 1992, in the countervailing duty cases and February 4, 1993 in the unfair pricing cases. Imports of the products under investigation were unusually high during the period immediately preceding February 4, as importers had rushed as much material as possible into the country to avoid the threatened duties. From February 4 until the date of the decision, exports of the products under investigation from the countries charged with unfair pricing or countervailable subsidies essentially stopped; however imports of the same products from other nations not charged in the suits began to increase.

Following the decisions, imports commenced again, but at a more moderate level, because of the risk that the Commission's decisions would be overturned on appeal to the U.S. Court of International Trade. Imports continued from the non-traditional supplier nations. Overall, imports of finished steel products in 1993 were about the same as during 1992.

Research Programs.—The U.S. Department of Energy continued its research and development efforts under the Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988, commonly known as the Metals Initiative. Work continued on six projects in steel processing carried over from prior years, and a seventh project was selected for inclusion in the program. A requirement of the program is that industry sponsors provide cost-sharing contributions equal to a minimum of 30% of the total cost of any project.

The most notable of the steel projects was the Direct Steelmaking Project, managed and jointly sponsored by AISI. The objective of the project was to develop a coal-based, energy efficient, economically competitive direct steelmaking process. The advantages of such a process would be: (1) more effective use of domestic raw materials; (2) continuous, rather than batch operations; (3) elimination of coke and the environmental impacts related to coke; (4) ease of startup and shutdown; and (5) facilitation of incremental capacity increases and adaptation to market conditions by modular design.

The process being investigated was an in-bath smelting process, coupled to continuous refining. Coal is injected into a molten bath of partially reduced iron ore, and the key to the success of the process is the efficient use of the energy of the gases generated. The carbon in the coal is a reductant for the iron ore and a source of thermal energy. Carbon monoxide is released, which must be partially combusted within the vessel to provide heat for the process. The partially combusted smelter off-gas also serves as the fuel and the reductant for a prereduction furnace to produce hot wustite pellets from hematite. During fiscal year 1993, a pressurized pilot smelting vessel with offgas treatment and dust recycling facilities was installed in place of the original horizontal smelter. Initial operation showed promise by achieving the expected efficiency improvement. Based on the success of the research to date, a steel company has submitted a proposal to construct such a plant.

The Direct Steelmaking Project has many features in common with other processes under investigation in other countries. See discussion under Technology in this report.

The Department of Energy agreed to support a new project at the pilot smelter plant, also with joint sponsorship from AISI. It is entitled Steel Plant Waste Oxide Recycling and Resource Recovery by Smelting. This project is aimed at developing a process to recover the more than 3 million tons of blast furnace and basic oxygen furnace dusts and the 0.5 million tons of rolling mill sludge that the steel industry generates each year. The project is scheduled to be completed in fiscal year 1995.

Other steel-related projects that were studied within the Metals Initiative included (1) Development of Superplastic Steel Processing to enable complex parts to be forged from a single large piece of metal. This project is managed by Lawrence Livermore National Laboratory, with cost-sharing by Caterpillar, Inc. and North Star Steel Co.; (2) Electrochemical Dezincing of Steel Scrap, by Argonne National Laboratory with cost-sharing by Metal Recovery Industries (U.S.), Inc. In fiscal 1993, a pilot plant in East Chicago, IN, was used to dezinc more than 600 tons of automotive stamping plant galvanized steel scrap, with more than 90 percent effectiveness in removing zinc. (3) Direct Strip Casting, under investigation by Armco Inc. with additional sponsorship by Westinghouse Electric Corp. and North American Refractories. During 1993, modifications were made to the caster which resulted in greater strip thickness and improved quality. Nonetheless, Armco withdrew from the project and the research is being brought to an orderly conclusion. (4) Rapid Analysis of Molten Metal Using Laser Produced Plasma, at Lehigh University, with sponsorship by AISI, the Electric Power Research Institutes (EPRI), and an industrial consortium of nine companies. The objective this program was to develop a probe that can be immersed in molten steel to produce an elemental analysis in less than one minute. Current practice requires removal of a molten sample, which must be frozen and analyzed in a laboratory, a sequence that requires a minimum of 4 to 8 minutes. (5) The final project, named Advance Process Control for the Steel Industry, is to develop sensor and control system technology to improve quality, reduce energy consumption, and reduce costs of steel production. The program, cosponsored by AISI, comprises six separate projects, conducted collaboratively by national laboratories, universities and private companies. The six projects address various steelmaking phases from primary steelmaking through finish processing.

The Department of Energy announced that it had selected for funding under its Clean Coal Technology Program a project to demonstrate a new process to produce both electric power and pig iron from a range of U.S. coals and iron ores. The

Clean Coal Technology Program provides funding to demonstrate new technologies for the environmentally sound and efficient use of coal. The project, proposed by Centerior Energy Corporation, would demonstrate the COREX direct ironmaking process, developed by Deutsche Voest-Alpine Industrieanlagenbau GMBH (DVAI,) and the production of power from a combined cycle powerplant fueled by the export gas from the COREX process. Other sponsors of the proposed project were the LTV Steel Company, at whose plant the demonstration project would be built; DVAI; Air Products and Chemicals, Inc.; and EPRI. The total estimated project cost was $825 million, with DOE to provide $150 million and the corporate sponsors $675 million. The proposed plant would produce 2,900 metric tons per day of pig iron plus 150 megawatts of electric power.

Production

Production of raw steel in the United States increased 5.3%, to 88.8 million metric tons, from 84.3 million tons produced in 1992. Raw steel production capability was estimated by AISI as 99.7 million tons, down from 102.6 million tons in 1992. Production in 1993 represented 89.1% of estimated capability, compared with 82.2% in 1991.

Net shipments of steel mill products by U.S. companies increased about 8%, to 80.8 million tons, from 74.6 million tons in 1992.

Electric arc furnace steelmaking was utilized for 34.9 million tons, 39.4% of total steelmaking in 1993. Basic oxygen steelmaking was utilized for 53.8 million tons, 60.6% of raw steel production, compared with 52.3 million tons and 61.6% of production in 1992.

The trend toward the use of continuous casting continued. Continuous casting production was 76.1 million tons, 85.7% of production, compared with 66.9 million tons, 79.3% in 1992.

Consumption and Uses

Shipments of steel mill products by U.S. companies were up 8.2%, to 80.8 million tons, but export shipments continued to drop; exports were down 20% from those of 1992. Shipments to domestic customers were up more than 9%. Shipments to the largest single end-use market—the automotive market—were up 15%, appliances were up 6%, service centers and distributors increased 11%, and construction products rose about 10%.

Shipments of steel for containers, packaging, and shipping materials increased 10%, reversing a two-year decline in shipments to this market area.

Shipments for oil and gas drilling, mining, quarrying, and lumbering were about the same as the 1992 level, as were shipments for industrial and agricultural machinery, equipment, and tools.

Markets and Prices

Prices for steel mill products, which had declined for 3½ years, reached a nadir in December 1992 and increased steadily through 1993. On a year-to-year average basis, the Bureau of Labor Statistics' Producer Price Index for steel mill products was up by only 2% in 1993 at 108.2 (1982 base=100), but the increase during the year, from the low of 105.1 in December 1992 through 111.1 in December 1993, was 5.7%. Additional price increases were announced, effective in January 1994, and the outlook was for further price increases in 1994.

Foreign Trade

Exports of steel mill products declined to 3.6 million tons, from 3.9 million tons in 1992. Canada was again the nation receiving the largest amount of U.S. exported steel, 1.5 million tons, with Mexico again in second place, receiving 0.9 million tons. Exports to Mexico were down from 1.3 million tons in 1992; the decline in exports to Mexico exceeded the overall decline in exports.

Imports of steel mill products increased to 17.7 million tons from 15.5 million tons in 1992, an increase of about 14%. Brazil, Canada, the European Union (EU), and Japan were major sources for steel mill product imports. Increased imports from the EU accounted for almost all of the year-to-year increase. Imports from Japan and the Republic of Korea actually decreased, with imports from Japan dropping 33 percent to the lowest level in 30 years.

An important development in 1993 was a marked increase in the tonnage of imported semifinished steel. During the period 1985 through 1992, imports of semifinished steel had been about 2 million metric tons per year. This steel, primarily in the form of slabs suitable for rolling into sheet or plate mill products, was imported and utilized mostly by companies that lack their own steelmaking facilities. In 1993, imports of semifinished steel increased to 4.5 million tons, but almost all of the increased tonnage is believed to have been imported by companies within the steel industry itself to supplement their steelmaking capacity. Excluding this major increase in imports of semifinished steel, steel mill product imports in 1993 were 13.2 million tons, slightly less than in 1992.

The increase in imports of semifinished steel by steel companies must be taken into consideration in evaluating total consumption of steel mill products in the United States and the share of the market represented by imported steel. To avoid counting both the imported semi-finished steel and the products produced from it, it is necessary to subtract from domestic consumption the amount of semifinished steel consumed by companies that also produce raw steel. For 1993, this amount is estimated to have been 2.5 million tons. For years prior to 1993, the amount was less than 0.5 million tons per year. Therefore, the share of the U.S. steel market represented by imported steel was 19% in 1993.

World Review

World production of pig iron and DRI in 1993 totaled 527.9 million tons, an increase of 2% compared with that of 1992. Production increased about 1% in Japan and was down about 1% in the EU. In the eastern European states that were formerly part of the communist bloc, excluding those that were part of the former U.S.S.R., production was about the same as in 1992, ending the 40% slide in production that began in 1990. The steel—producing countries of this region are Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia.

In the countries that were formerly part of the U.S.S.R., however, the decline in steel production continued and also represented about a 40% drop from production prior to 1990. Kazakhstan, Russia, and Ukraine account for almost all the steel production in this region.

Production of pig iron in China increased about 21% to an estimated 87.3 million tons. This year, China stands as the top pig iron-producing nation in the world. The Republic of Korea and Taiwan are other major iron-producing nations that achieved double-digit growth in 1993. Australia and India showed continued growth.

Direct-Reduced Iron.—World production of DRI increased to almost 24 million tons in 1993, with a 14% increase in the latest year and 65% during the past 5 years. Direct reduction of iron ore has proved to be a cost-effective way for developing countries, especially those with an abundance of natural gas, to encourage economic growth.

World capacity for DRI production was estimated to be 37 million tons, with an additional 3 million tons under construction. In India, one gas-based plant and several small coal-based DRI plants were started up, bringing India's capacity for DRI to 3.6 million tons. An additional 1.8 million tons of capacity is under construction in India, with completion planned for 1994 and 1995.

In Iran, about 1.7 million tons of capacity was started up in 1992; an additional 1 million tons was added in 1993, and 1.8 million tons is scheduled for 1994, which would bring Iran's total capacity for DRI to 5.8 million tons.

Gas-based plants were started up in Malaysia (1.2 million tons) and Indonesia (0.6 million tons.)

A United States minimill company began construction of a gas-based direct-reduction plant in Trinidad. The plant will utilize a technology never before used in a production scale operation, and produce a unique form of DRI in which all of the reduced iron (excluding about 7% or 8% of the iron that remains in oxide form in all DRI products) will be in the form of iron carbide (Fe_3C), rather than in elemental form. The resultant product, which will be called "iron carbide," will be imported to the United States to serve as a high-quality charge material for the production of flat-rolled products in the minimills operated by the company.

Steel.—World production of steel was 725.1 million tons, up slightly from that of 1992. The world picture, however, was mixed, with strong growth in the Pacific rim nations of Australia, China, India, the Republic of Korea, and Taiwan and moderate growth in Latin America and North America, offset by continued collapse in the newly independent states of the former U.S.S.R. The 12 newly independent states had combined steel production of 96 million tons, down 19% from that of 1992. As recently as 1989, the U.S.S.R. had produced more than 160 million tons of raw steel.

In the former Soviet satellite states of Eastern Europe, the slump in steel production was arrested, with 1993 production of 29 million tons, about equal to that of 1992. The six nations of this region—Bulgaria, Czech Republic, Hungary, Poland, Romania and Slovakia—had produced about 52 million tons of raw steel in 1989.

The most interesting development has been the explosive growth in steel demand and production in China. In 1993, raw steel production increased almost 10% to 88.7 million tons. China, during this decade, has achieved the status of one of the world's largest producers of steel, with tonnage output rivaling that of the United States and Japan. Moreover, the expansion of China's steel industry has been based on internal demand; in addition to its own output, China imported over 30 million tons of steel mill products in 1993.

Production of steel continued to increase in the Republic of Korea. This nation is also experiencing high internal growth, but in contrast to China, much of Korea's steel output is exported.

OUTLOOK

The outlook for 1994 is for further declines in pig iron and steel production in the newly independent states of the former U.S.S.R. Strong growth is expected to continue in China, the Republic of Korea, the Far East, and the Middle East. The major economies of the EU are recovering from a recession, and European steel production is likely to increase. In Japan, production should recover from the depressed levels of 1993.

For the long term, little growth of steel consumption is expected in the United States or countries with highly developed economies. Steel consumption tends to expand much more slowly than overall economic growth and to contract when economic growth is weak. The outlook for the U.S. steel industry is more uncertain. Imports have tended to capture an increasing share of the U.S. market, except when restrained by such devices as VRA's. Even though U.S. companies have made great progress in modernizing their mills, adopting efficient technology, and reducing their costs, they have been unable to achieve profitability due to persistently low prices caused by intense competition by foreign and domestic producers.

An important part of the competition to the integrated U.S. steel industry is that posed by minimills producing flat-rolled steel. As described earlier, one steel company, Nucor Corp., has demonstrated that flat-rolled steel can be produced in a minimill at lower cost than that attainable by the integrated process.

Buoyed by the success of its first plant, in Crawfordsville, IN, Nucor started up a second flat-roll minimill, in Hickman, AR, in 1992. Based on further success with the new processes, Nucor has doubled the capacity of the two plants, to a total of 4 million tons, and announced the intention to build two more plants, either alone or in joint venture with others, increasing its capacity to 8 million tons. Other companies, noting Nucor's success and optimism about the possibilities of minimill production of flat-rolled steel, have announced similar intentions.

Some observers of the industry predict that as much as 20 million tons of capacity will be built by about the year 2000. With little or no growth in the market, any new capacity will have to displace either imports or integrated production from the U.S. market.

The supply of raw material for increased minimill production may become a problem in the United States. Although the United States traditionally has an excess supply of scrap and is a net exporter of about 9 million tons per year, the supply of low-residual scrap necessary to produce flat-rolled steel and some other products may not be adequate. As noted in the section on DRI, imports of DRI are increasing. In early 1993, Nucor announced that it will construct a plant in Trinidad to produce iron carbide, a form of DRI, for use in its U.S. plants. The plant will have a capacity of about 300,000 tons per year. Other minimill operators and iron ore producers are reported to be considering direct-reduction plants to provide the necessary supply of low-residual raw materials for the growing flat-roll minimill sector of the industry.

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TABLE 1
SALIENT IRON AND STEEL STATISTICS

(Thousand metric tons)

	1989	1990	1991	1992	1993
United States:					
Pig iron:					
Production[1]	50,687	49,668	[r]44,123	47,377	48,155
Exports	11	14	15	33	27
Imports for consumption	443	347	434	497	828
Direct-reduced iron:					
Production	290	390	410	390	440
Exports	23	63	22	34	43
Imports for consumption	226	385	423	607	1,110
Raw steel production:[2]					
Carbon steel	78,227	78,553	70,651	74,805	78,803
Stainless steel	1,747	1,848	1,704	1,808	1,774
All other alloy steel	8,878	9,325	7,384	7,709	8,216
Total	88,852	89,726	[3]79,738	84,322	88,793
Capability utilization, percent	84.5	84.7	74.7	82.2	89.1
Steel mill products:					
Net shipments	76,294	77,093	71,528	74,607	80,759
Exports[4]	4,153	3,904	5,757	3,890	3,600
Imports[4]	15,713	15,575	14,375	15,490	17,691
Producer price index for steel mill products[5] (1982=100.0)	114.5	112.1	109.5	106.4	108.2
World production:[6]					
Pig iron	545,987	531,828	506,166	497,620	504,091
Direct-reduced iron	16,555	18,205	19,413	20,946	23,816
Raw steel	[r]784,092	[r]771,373	[r]736,424	[r]722,384	[e]725,129

[e] Estimated. [r] Revised.

[1] American Iron and Steel Institute (AISI).

[2] Raw steel is defined by AISI as steel in the first solid state after melting, suitable for rolling.

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

[4] Source: Bureau of the Census.

[5] Source: Bureau of Labor Statistics.

[6] Sources: U.S. Bureau of Mines and International Iron and Steel Institute.

TABLE 2
MATERIALS CONSUMED IN BLAST FURNACES AND PIG IRON PRODUCED

(Thousand metric tons)

Material	1989	1990	1991	1992	1993
Iron oxides:[1]					
Ores	3,211	2,479	1,918	2,035	1,963
Pellets	61,659	60,512	[r]52,534	60,138	60,730
Sinter[2]	13,664	12,226	[r]10,561	11,438	12,451
Total[3]	78,533	75,217	[r]65,013	73,611	75,144
Scrap[4]	3,006	2,527	1,939	[r]1,875	1,924
Coke[1]	26,467	24,946	22,496	22,664	21,537
Pig iron produced	50,687	49,668	44,123	47,377	48,155

[r] Revised.

[1] American Iron and Steel Institute.

[2] Includes sintered ore and pellet fines, dust, mill scale, and other revert iron-bearing materials; also some nodules.

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

[4] Mainly briquetted turnings and borings, shredded scrap, etc.; scrap produced at blast furnaces and remelted not included.

TABLE 3

DISTRIBUTION OF SHIPMENTS OF STEEL MILL PRODUCTS, BY PERCENT

	1989	1990	1991	1992	1993
Net shipments thousand metric tons	76,294	77,093	71,528	74,607	80,759
Shipments by steel type:					
Carbon steel	93.3	92.7	93.2	93.2	93.4
Alloy steel	4.9	5.5	5.0	5.0	4.9
Stainless steel	1.7	1.8	1.8	1.8	1.7
Steel mill products:					
Ingots, blooms, billets and slabs	2.48	2.33	3.23	3.00	2.89
Wire rods	4.94	5.09	5.54	5.49	5.45
Structural shapes-heavy	5.93	6.67	6.65	6.18	5.59
Steel piling	.44	.50	.55	.55	.48
Plates-cut lengths	6.05	6.04	5.42	5.30	5.36
Plates-in coils	2.73	3.31	3.38	3.33	3.11
Rails-standard	.54	.48	.48	.53	.61
Rails-other	.01	.01	.02	.01	.01
Railroad accessories	.11	.12	.11	.15	.14
Bars-hot-rolled	7.49	7.83	6.89	7.06	7.12
Bars-light-shaped	1.57	1.44	1.47	1.36	1.64
Bars-reinforcing	5.96	6.24	6.16	5.81	5.65
Bars-cold finished	1.75	1.75	1.70	1.77	1.77
Tool steel	.08	.07	.06	.08	.08
Pipe and tubing-standard pipe	1.40	1.39	1.23	1.29	1.28
Pipe and tubing-oil country goods	1.08	1.43	1.37	1.19	1.48
Pipe and tubing-line pipe	1.04	1.32	1.82	1.35	.92
Pipe and tubing-mechanical tubing	.96	1.02	.94	.96	1.00
Pipe and tubing-pressure tubing	.06	.06	.06	.06	.06
Pipe and tubing-stainless	.06	.05	.04	.04	.03
Pipe and tubing-structural	.14	.16	.19	.17	.20
Pipe for piling	.04	.04	.03	.04	.04
Wire	1.19	1.08	1.10	1.09	.90
Tin mill products-blackplate	.37	.32	.32	.28	.34
Tin mill products-tinplate	3.32	3.26	3.49	3.30	3.10
Tin mill products-tin-free steel	1.11	1.07	1.22	1.10	1.08
Tin mill products-tin coated sheets	.10	.09	.09	.09	.11
Sheets-hot-rolled	15.34	15.75	16.69	16.25	16.71
Sheets-cold-rolled	16.47	15.53	14.63	15.43	14.33
Sheets and strip-hot dip galvanized	10.16	9.27	8.76	9.97	10.91
Sheets and strip-electrogalvanized	2.56	2.43	2.66	2.91	3.64
Sheets and strip-other metallic coated	1.64	1.48	1.45	1.64	1.73
Sheets and strip-electrical	.58	.57	.58	.53	.50
Strip-hot rolled	1.29	.81	.68	.67	.70
Strip-cold rolled	1.03	.96	.96	1.01	1.05
Total-steel mill products (rounded)	100.00	100.00	100.00	100.00	100.00
Shipments by markets:					
Service centers and distributors	24.7	24.8	24.7	25.9	26.6
Construction	13.7	14.3	14.5	14.9	15.1
Automotive	14.0	13.1	12.7	13.5	14.3
Machinery	9.2	8.8	8.0	7.8	7.8
Containers	5.3	5.3	5.4	4.8	4.9
All others	33.1	33.7	34.7	33.1	31.3

Source: American Iron and Steel Institute.

TABLE 4
U.S. IMPORTS AND EXPORTS OF STEEL MILL PRODUCTS, BY COUNTRY

(Thousand metric tons)

Country	1989		1990		1991		1992		1993	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Argentina	191	40	171	19	177	21	78	16	131	13
Australia	246	47	278	[r]9	334	49	343	8	398	9
Austria	74	—	129	—	141	—	17	—	37	1
Brazil	1,252	26	1,335	14	1,375	14	1,449	22	1,284	22
Canada	2,699	579	2,606	1,580	2,657	1,520	3,840	1,280	4,354	1,524
China	16	373	13	7	12	[r]90	11	88	37	78
European Community	5,061	331	4,949	269	4,240	226	4,127	171	6,192	115
Finland	194	—	199	—	179	1	173	—	184	—
India[1]	—	—	—	—	30	13	40	18	119	24
Japan	3,314	524	2,826	411	2,558	[r]605	2,414	120	1,618	94
Korea, Republic of	901	658	1,205	279	1,286	790	1,453	116	911	25
Mexico	399	429	585	591	[r]453	1,159	385	1,276	767	861
Russia	—	—	—	—	—	—	3	31	170	32
South Africa, Republic of	—	—	—	—	—	11	227	40	368	4
Sweden	228	3	265	[r]3	273	2	311	1	251	1
Taiwan	128	127	174	17	117	396	56	46	64	235
Turkey	182	—	119	—	88	29	108	6	96	2
Ukraine	—	—	—	—	—	—	13	5	122	—
Venezuela	142	16	184	28	[r]85	102	86	44	131	23
All others	686	1,000	537	[r]676	[r]371	[r]728	[r]355	[r]601	454	539
Total[2]	15,713	4,153	15,575	3,904	14,375	5,757	15,490	3,890	17,691	3,600

[r] Revised.
[1] Previously included with "All others."
[2] Data may not add to totals shown because of independent rounding.

Source: American Iron and Steel Institute.

TABLE 5
U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1991	1992	1993
Steel mill products:			
Ingots, blooms, billets, and slabs	634	384	487
Wire rods	151	64	57
Structural shapes-heavy	368	268	290
Steel piling	9	9	6
Plates-cut lengths	251	176	168
Plates-in coils	412	196	99
Rails-standard	20	7	19
Rails-other	9	5	2
Railroad accessories	8	12	20
Bars-hot-rolled	209	197	246
Bars-light-shaped	45	42	59
Bars-concrete reinforcing	213	167	206

See footnotes at end of table.

TABLE 5—Continued

U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1991	1992	1993
Steel mill products—Continued:			
Bars-cold-finished	51	65	63
Tool steel	9	5	6
Pipe and tubing-standard pipe	34	39	37
Pipe and tubing-oil country goods	329	206	156
Pipe and tubing-line pipe	147	170	114
Pipe and tubing-mechanical tubing	9	13	13
Pipe and tubing-stainless	14	13	13
Pipe and tubing-nonclassified	126	144	158
Pipe and tubing-structural	19	23	21
Pipe for piling	6	7	5
Wire	81	82	82
Tin mill products-blackplate	4	4	6
Tin mill products-tinplate	137	253	175
Tin mill products-tin-free steel	34	54	64
Sheets-hot-rolled	1,450	359	136
Sheets-cold-rolled	367	324	328
Sheets and strip-hot-dip galvanized	163	146	142
Sheets and strip-electrogalvanized	112	124	101
Sheets and strip-other metallic coated	91	112	123
Sheets and strip-electrical	76	43	47
Strip-hot-rolled	66	75	42
Strip-cold-rolled	103	100	111
Total steel mill products[1]	5,757	3,890	3,600
Fabricated steel products:			
Structural shapes-fabricated	248	194	203
Rails-used	41	19	35
Railroad products	20	23	28
Wire rope	4	4	8
Wire-stranded products	17	16	19
Wire-other products	[r]13	15	22
Springs	26	31	27
Nails and staples	13	16	16
Fasteners	153	178	166
Chains and parts	21	22	21
Grinding balls	45	40	29
Pipe and tube fittings	16	19	22
Other[2]	27	32	34
Total fabricated steel products[1]	[r]644	609	631
Total all steel products	[r]6,401	4,499	4,231
Cast iron and steel products:			
Cast steel pipe fittings	72	104	74
Cast iron pipe and fittings	13	16	16
Cast steel rolls	11	10	12

See footnotes at end of table.

TABLE 5—Continued

U.S. EXPORTS OF IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1991	1992	1993
Cast iron and steel products—Continued:			
Cast grinding balls	14	16	16
Granules-shot and grit	26	27	29
Other castings	29	29	32
Total cast iron and steel products[1]	165	201	180

[r] Revised.

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

[2] Includes shapes-cold formed, sashes and frames, fence and sign post, and architectural and ornamental work.

Source: American Iron and Steel Institute.

TABLE 6

U.S. IMPORTS OF PIG IRON, BY COUNTRY

(Metric tons)

Country	1989	1990	1991	1992	1993
Brazil	310,196	219,041	327,603	308,610	392,871
Canada	120,597	124,938	84,254	85,013	61,889
India[1]	—	—	132	—	—
Japan	—	—	—	—	26,349
Latvia	—	—	—	—	67,064
Lithuania	—	—	—	—	10,026
Mexico	—	—	—	—	89
Norway[1]	—	—	236	—	—
Russia[2]	—	—	—	[r]14,030	154,953
South Africa, Republic of	—	—	21,243	77,607	69,627
Switzerland[1]	—	—	—	6,288	10,970
Ukraine	—	—	—	—	34,330
U.S.S.R.[3]	—	—	770	4,999	—
Other	12,072	3,233	[r]80	([4])	—
Total	442,865	347,212	434,318	496,547	828,168

[r] Revised.

[1] Previously included in "Other."

[2] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[4] Revised to zero.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1991	1992	1993
Steel mill products:			
Ingots, blooms, billets, and slabs	2,048	2,172	4,529
Wire rods	750	1,014	1,234
Structural shapes-heavy	417	407	478
Steel piling	57	53	66
Plates-cut lengths	727	819	692
Plates-in coils	444	640	549
Rails and railroad accessories	141	147	120
Bars-hot-rolled	603	682	870
Bars-light-shaped	65	83	114
Bars-reinforcing	97	108	109
Bars-cold-finished	138	138	233
Tool steel	60	61	80
Pipe and tubing-standard pipe	759	529	549
Pipe and tubing-oil country goods	374	91	321
Pipe and tubing-line pipe	910	367	467
Pipe and tubing-mechanical tubing	154	134	178
Pipe and tubing-pressure tubing	33	25	34
Pipe and tubing-stainless	44	39	39
Pipe and tubing-nonclassified	6	4	10
Pipe and tubing-structural	190	206	262
Pipe for piling	11	5	7
Wire	355	391	479
Tin mill products-blackplate	117	138	77
Tin mill products-tinplate	282	292	236
Tin mill products-tin-free steel	104	120	115
Sheets-hot-rolled	1,924	2,427	2,059
Sheets-cold-rolled	1,712	1,931	1,923
Sheets and strip-hot-dip galvanized	1,154	1,567	1,152
Sheets and strip-electrogalvanized	224	290	185
Sheets and strip-other metallic coated	172	257	133
Sheets and strip-electrical	74	74	104
Strip-hot-rolled	96	125	135
Strip-cold-rolled	128	154	151
Total steel mill products[1]	14,375	15,490	17,691
Fabricated steel products:			
Structural shapes-fabricated	69	67	176
Rails-used	93	78	70
Railroad products	38	44	50
Wire rope	79	78	75
Wire-stranded products	99	112	122
Wire-other products	60	64	74
Springs	190	209	239
Nails and staples	263	311	324
Fasteners	619	639	730
Chains and parts	60	60	74

See footnotes at end of table.

TABLE 7—Continued

U.S. IMPORTS OF MAJOR IRON AND STEEL PRODUCTS

(Thousand metric tons)

	1991	1992	1993
Fabricated steel products—Continued:			
Pipe and tube fittings	118	78	83
Other	22	20	34
Total fabricated steel products[1]	1,709	1,762	2,054
Total all steel products	16,084	17,252	19,745
Cast iron and steel products:			
Cast steel pipe fittings	16	18	25
Cast iron pipe and fittings	23	23	21
Other products	148	149	182
Total cast products[1]	187	191	228

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

Source: American Iron and Steel Institute.

TABLE 8

U.S. IMPORTS OF STAINLESS STEEL

(Metric tons)

Product	1989	1990	1991	1992	1993
Semifinished	56,355	55,177	44,418	33,727	102,932
Plate	16,069	18,734	19,503	31,577	55,611
Sheet and strip	127,477	140,017	145,766	187,434	288,321
Bars and shapes	39,387	40,393	47,621	55,424	67,812
Wire and wire rods	39,024	37,608	38,965	53,256	56,859
Pipe and tube	33,800	42,837	43,743	38,657	39,494
Total[1]	312,112	334,766	340,015	400,077	611,030

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

Sources: International Trade Commission and American Iron and Steel Institute.

TABLE 9

U.S. SHIPMENTS OF IRON AND STEEL CASTINGS

(Thousand metric tons)

	1989	1990	1991	1992[r]	1993
Ductile iron castings	3,013	2,890	2,530	2,768	2,964
Gray iron castings	5,115	4,602	4,181	4,354	4,731
Malleable iron castings	271	263	238	230	252
Steel castings	1,074	1,028	868	894	926
Steel investment castings	43	36	33	35	33
Total	9,516	8,819	7,850	[1]8,282	8,906

[r] Revised.

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

Source: Bureau of the Census.

TABLE 10
COAL AND COKE AT COKE PLANTS[1]

(Thousand metric tons)

	1989	1990	1991	1992	1993
Coal: Consumption	36,748	35,269	30,712	29,362	28,416
Coke:[2]					
Production	25,442	25,054	21,814	21,237	21,030
Exports	984	519	671	582	757
Imports	2,097	694	997	1,578	1,392
Consumption, apparent	26,248	25,230	21,968	22,398	22,047

[1] Includes furnace and merchant coke plants.
[2] Coke production and consumption do not include breeze.

Source: Energy Information Administration, Quarterly Coal Report (DOE/EIA-0121).

TABLE 11
PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1989	1990	1991	1992	1993[e]
Albania	179	96	[e]50	[e]10	10
Algeria	[r]1,300	1,037	877	[r][e]900	900
Argentina:					
Pig iron	2,062	1,883	1,366	[r]971	980
Direct-reduced iron	1,166	1,034	954	[r]1,013	1,000
Australia	6,094	6,125	5,647	[e]6,000	6,500
Austria	3,823	3,452	3,439	3,067	3,000
Belgium	[r]8,868	9,416	9,354	[r]8,524	8,000
Bosnia and Herzegovina	—	—	—	[r]150	100
Brazil:					
Pig iron	24,363	21,141	22,695	23,152	23,900
Direct-reduced iron	258	260	226	230	240
Bulgaria	1,484	1,143	[r]943	[r][e]900	900
Burma:[e]					
Pig iron	3	(5)	[r]1	[r](5)	(5)
Direct-reduced iron	20	20	20	20	20
Canada:					
Pig iron	10,139	7,346	8,268	8,621	[6]8,633
Direct-reduced iron	710	730	553	639	[6]758
Chile	679	675	703	[e]750	700
China	58,200	62,380	[r]67,200	[r]72,000	87,300
Colombia	297	323	305	[r]308	[6]238
Croatia	—	—	—	[r][e]40	40
Czech Republic[7]	—	—	—	—	5,000
Czechoslovakia[8]	9,911	9,667	8,479	8,039	—
Egypt:					
Pig iron	1,105	1,100	[e]1,250	[e]1,200	[6]1,130
Direct-reduced iron	817	710	[e]620	[e]850	800
Finland	2,284	2,283	2,331	2,452	2,400
France	15,071	14,415	[r]13,646	13,051	13,000

See footnotes at end of table.

TABLE 11—Continued

PIG IRON[1] AND DIRECT-REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1989	1990	1991	1992	1993[e]
Georgia	—	—	—	[e]500	100
Germany:					
Pig iron:					
Eastern states[9]	2,732	2,163	—	—	—
Western states	32,112	29,585	—	—	—
Total	34,844	31,748	30,608	28,538	27,000
Direct-reduced iron: Western states[e]	353	310	260	250	250
Hungary	[r]1,927	1,697	[r]1,314	1,176	1,200
India:					
Pig iron	12,080	12,645	14,176	[r][e]15,000	15,400
Direct-reduced iron[e]	[6]340	750	1,180	1,440	2,200
Indonesia: Direct-reduced iron[e]	[6]1,262	1,300	1,350	1,400	1,400
Iran:					
Pig iron	[e]250	1,267	1,952	2,053	[6]1,961
Direct-reduced iron	40	264	470	709	[6]1,631
Iraq: Direct-reduced iron[e]	200	170	—	—	—
Italy	11,795	[r]11,883	[r]10,856	[r]10,462	12,000
Japan	80,197	80,229	79,985	73,144	[6]73,738
Kazakhstan	—	—	—	[r][e]4,300	3,500
Korea, North[e]	6,500	6,500	6,500	6,600	6,600
Korea, Republic of	14,846	15,339	18,510	19,323	22,000
Libya: Direct-reduced iron[e]	90	500	780	850	850
Luxembourg[9]	[r]2,684	[r]2,645	2,463	2,256	2,250
Macedonia	—	—	—	[r]20	20
Malaysia: Direct-reduced iron[e]	[6]570	600	600	600	600
Mexico:					
Pig iron	3,230	[r]3,645	[r]3,039	3,404	[6]3,423
Direct-reduced iron	2,164	2,525	2,462	2,394	[6]2,736
Morocco[e]	15	15	15	15	15
Netherlands[9]	5,163	4,960	4,696	4,852	4,800
New Zealand: Direct-reduced iron	493	549	594	384	406
Nigeria: Direct-reduced iron[e]	143	140	140	140	100
Norway	240	54	61	80	80
Pakistan[e]	1,000	1,000	1,100	1,100	1,200
Paraguay	63	61	60	[e]60	60
Peru:					
Pig iron	199	93	207	[r]147	147
Direct-reduced iron	46	29	24	[e]20	20
Poland	9,488	8,658	6,355	[r]6,351	6,400
Portugal	377	339	251	402	385
Qatar: Direct-reduced iron[e]	[6]531	530	530	530	530
Romania	9,052	6,355	[r]4,536	[r]3,111	3,000
Russia:					
Pig iron	—	—	—	[e]44,000	41,000
Direct-reduced iron[10]	—	—	—	[e]1,580	1,500
Saudi Arabia: Direct-reduced iron	1,205	1,085	1,117	[e]1,610	2,000
Serbia and Montenegro	—	—	—	[r]512	500
Slovakia[7]	—	—	—	—	3,000

See footnotes at end of table.

TABLE 11—Continued

PIG IRON[1] AND DIRECT REDUCED IRON:[2] WORLD PRODUCTION, BY COUNTRY[3]

(Thousand metric tons)

Country[4]	1989	1990	1991	1992	1993[e]
South Africa, Republic of:					
Pig iron	6,543	6,257	6,968	6,498	6,500
Direct-reduced iron	772	882	863	[r]854	860
Spain	[r]5,535	5,542	5,404	5,076	5,000
Sweden	2,638	2,736	2,812	2,735	2,600
Switzerland[e]	70	70	70	70	70
Taiwan	5,780	5,474	5,561	[r]5,292	[6]6,116
Trinidad and Tobago: Direct-reduced iron	612	697	710	[r]680	675
Tunisia[e]	140	140	140	140	140
Turkey	3,523	4,827	4,594	[r]4,508	4,500
Ukraine	—	—	—	35,300	27,000
U.S.S.R.:[11]					
Pig iron	113,928	110,163	89,400	—	—
Direct-reduced iron[e] [10]	1,700	1,600	1,500	—	—
United Kingdom	12,638	12,277	11,883	11,351	11,000
United States:					
Pig iron	50,687	49,668	44,123	47,377	[6]48,155
Direct-reduced iron	290	390	410	390	[6]440
Venezuela:					
Pig iron	489	314	—	—	—
Direct-reduced iron	2,773	[r]3,085	4,050	4,300	4,800
Yugoslavia[12]	2,899	2,313	[e]1,600	—	—
Zimbabwe[e]	[r]525	521	[r]535	[r]507	500
Grand total	[r]561,762	[r]550,077	[r]525,741	[r]517,278	527,907
Of which:					
Pig iron	[r]545,207	[r]531,917	[r]506,328	[r]496,395	504,091
Direct-reduced iron	16,555	[r]18,160	19,413	[r]20,883	23,816

[e]Estimated. [r]Revised.

[1] Production is pig iron unless otherwise specified.

[2] Direct-reduced iron is obtained from ore by reduction of oxides to metal without melting.

[3] Table excludes ferroalloy production except where otherwise noted. Table includes data available through July 21, 1994.

[4] In addition to the countries listed, Vietnam has facilities to produce pig iron and may have produced limited quantities during 1989-93, but output is not reported and available information is inadequate to make reliable estimates of output levels.

[5] Less than 500 tons.

[6] Reported figure.

[7] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[8] Dissolved Dec. 31, 1992.

[9] Includes blast furnace ferroalloys.

[10] All production in the U.S.S.R. from 1989-91 came from Russia.

[11] Dissolved in Dec. 1991.

[12] Dissolved in Apr. 1992.

TABLE 12
RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1989	1990	1991	1992	1993[e]
Albania[e]	112	65	35	5	5
Algeria	943	836	1,393	[e]1,400	1,400
Angola[e]	10	10	10	10	9
Argentina	3,909	[r]3,636	[r]2,972	[r][e]2,900	2,950
Australia	6,735	6,666	6,018	[r]6,868	7,700
Austria	4,718	4,292	4,186	3,946	3,900
Azerbaijan	—	—	—	[e]300	200
Bangladesh[4]	86	75	58	[r]36	32
Belarus	—	—	—	[r][e]544	800
Belgium	10,952	11,419	[r]11,335	[r]10,334	10,300
Benin[e]	2	8	8	8	8
Bosnia and Herzegovina	—	—	—	[r][e]135	115
Brazil[5]	25,055	20,567	[r]22,616	[e]24,000	25,000
Bulgaria	2,899	2,185	1,615	[r][e]1,550	1,400
Canada	15,458	12,281	12,987	13,924	[6]14,387
Chile[5]	800	772	805	[r]994	950
China[e]	61,200	66,100	70,570	80,000	88,680
Colombia	706	701	[r]652	[r]657	715
Croatia	—	—	—	[e]100	500
Cuba[e]	[6]336	270	[r]250	[r]200	100
Czech Republic[7]	—	—	—	—	7,500
Czechoslovakia[8]	15,465	[r]14,775	[r]12,071	[r]10,520	—
Denmark	625	610	633	591	600
Dominican Republic	55	36	39	[e]35	35
Ecuador	23	20	[r]20	[r][e]20	20
Egypt	2,114	2,235	2,541	[e]2,500	2,500
El Salvador[e]	[6]12	12	11	11	12
Finland	2,921	2,861	2,890	3,077	3,100
France	19,335	[r]19,015	[r]18,434	17,961	[6]17,179
Georgia	—	—	—	[e]700	200
Germany:					
Eastern states	7,829	5,546	—	—	—
Western states	41,073	38,435	—	—	—
Total	48,902	43,981	42,169	[r]39,711	[6]37,600
Greece	[r]957	[r]999	980	[r]924	900
Guatemala	[r]22	[r]21	[r]23	[e]18	20
Honduras[e]	8	8	8	7	7
Hong Kong[e]	320	350	350	350	350
Hungary	3,356	2,963	1,931	1,559	1,600
India[4]	[r]12,782	[r][e]15,313	[r][e]17,500	[r][e]18,450	18,500
Indonesia	2,383	2,892	3,250	[r]3,171	3,200
Iran	1,081	1,425	2,203	[r]2,917	[6]3,672
Iraq[e]	300	150	20	100	200
Ireland	324	326	[r]307	257	325
Israel[e]	118	144	160	160	160
Italy	25,213	25,439	25,046	24,904	[6]25,701
Jamaica	[r]37	[r]24	[r][e]25	[r][e]25	25

See footnotes at end of table.

TABLE 12—Continued
RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1989	1990	1991	1992	1993[e]
Japan	[r]107,909	110,339	109,649	98,131	99,600
Jordan	177	179	200	[r]244	240
Kazakhstan	—	—	—	[r] [e]5,800	4,300
Korea, North[e]	[r]7,300	8,000	8,000	8,100	8,100
Korea, Republic of	21,873	23,125	26,001	28,054	33,000
Latvia	—	—	—	[e]246	300
Libya	[e]10	[r]492	[r]718	822	820
Luxembourg	3,721	3,560	3,379	3,068	3,100
Macedonia	—	—	—	[r] [e]50	50
Malaysia[e]	1,125	1,200	1,200	[r]1,600	1,800
Mexico	7,851	8,726	7,883	8,435	[6]9,189
Moldova	—	—	—	[r] [e]400	600
Morocco[e]	7	7	7	7	7
Netherlands	5,681	5,412	5,171	5,438	[6]6,000
New Zealand	608	[e]765	[e]700	[r]759	[6]850
Nigeria	213	133	137	[e]140	140
Norway	678	376	438	446	440
Pakistan[e]	1,000	1,000	1,000	1,000	1,100
Paraguay	[r]55	[r]48	[r]61	[r]86	[6]86
Peru	401	284	418	[r]338	338
Philippines[e]	300	300	250	250	250
Poland	15,094	13,625	[r]10,432	[r]9,867	[6]9,937
Portugal	762	[r]744	541	749	750
Qatar	550	580	[r]561	[r]588	580
Romania	[r]14,411	[r]9,761	[r]7,110	5,372	5,000
Russia	—	—	—	67,000	58,000
Saudi Arabia	1,810	1,833	1,850	1,900	2,000
Serbia and Montenegro	—	—	—	[r]665	650
Singapore	495	489	[e]490	[e]500	500
Slovakia[7]	—	—	—	—	3,000
Slovenia	—	—	—	[r] [e]300	300
South Africa, Republic of	9,337	8,619	9,358	9,061	[6]8,610
Spain	[r]12,765	[r]12,718	12,933	12,295	12,800
Sweden	4,692	4,454	4,248	4,356	4,300
Switzerland	916	970	955	1,050	1,000
Syria[e]	70	70	70	70	70
Taiwan	9,047	9,747	10,957	[r]10,705	12,038
Thailand	689	685	711	[r]779	800
Trinidad and Tobago	294	372	444	[r]553	515
Tunisia	[r]187	[r]177	[r]193	[r]181	190
Turkey	7,934	[r]9,322	[r]9,335	[r]10,253	[6]11,436
Ukraine	—	—	—	[r] [e]41,700	30,500
U.S.S.R.[9]	160,096	154,414	132,666	—	—
United Kingdom	18,813	17,908	[r]16,474	16,050	16,000
United States	88,852	89,726	79,738	84,322	[6]88,793
Uruguay	[r]37	[r]38	[r]44	[r]53	[6]53
Uzbekistan	—	—	—	[e]800	600

See footnotes at end of table.

TABLE 12—Continued

RAW STEEL:[1] WORLD PRODUCTION, BY COUNTRY[2]

(Thousand metric tons)

Country[3]	1989	1990	1991	1992	1993[e]
Venezuela	2,941	3,176	3,119	3,200	3,250
Vietnam	[r]84	[r]102	[r]142	[r]175	190
Yugoslavia[10]	[r]4,383	[r]3,835	[r]2,139	—	—
Zimbabwe	650	580	[r]581	[r]547	400
Total	[r]784,092	[r]771,373	[r]736,424	[r]722,384	725,129

[e]Estimated. [r]Revised.

[1] Steel formed in first solid state after melting, suitable for further processing or sale; for some countries, includes material reported as "liquid steel," presumably measured in the molten state prior to cooling in any specific form.

[2] Table includes data available through July 21, 1994.

[3] In addition to the countries listed, Burma, Ghana, and Mozambique are known to have steelmaking plants, but available information is inadequate to make reliable estimates of output levels.

[4] Data are for year ending June 30 of that stated.

[5] Excludes castings.

[6] Reported figure.

[7] Formerly part of Czechoslovakia; data not reported separately until 1993.

[8] Dissolved on Dec. 31, 1992. Production in Czechoslovakia from 1989-92 came from the Czech Republic and Slovakia.

[9] Dissolved in Dec. 1991.

[10] Dissolved in Apr. 1992.

TABLE 13

GOVERNMENT INVENTORY OF FERROALLOYS, DECEMBER 31, 1993

(Metric tons of alloy, unless otherwise stated)

Alloy	Stockpile grade	Nonstock pile grade	Total
Ferrochromium:			
High-carbon	739,526	621	740,147
Low-carbon	273,945	11,560	285,505
Ferrochromium-silicon	51,699	1,242	52,941
Ferrocolumbium (kilograms contained columbium)	271,434	150,820	422,254
Ferromanganese:			
High-carbon	986,351	—	986,351
Medium-carbon	23,617	—	23,617
Ferrotungsten (kilograms contained tungsten)	385,404	532,732	918,136
Silicomanganese	209	—	209

TABLE 14
PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1993

Producer	Plant location	Products[1]	Type of furnace
FERROALLOYS (except ferrophosphorus)			
AMAX Inc., Climax Molybdenum Co. Div.	Langeloth, PA	FeMo	Metallothermic.
American Alloys, Inc.	New Haven, WV	FeSi, Si	Electric.
Applied Industrial Minerals Corp. (AIMCOR)	Bridgeport, AL	FeSi	Do.
Astech Corp.	Wenatchee, WA	Si	Do.
Bear Metallurgical Inc.	Butler, PA	FeMo, FeV	Metallothermic.
Cabot Corp.	Revere, PA	FeCb, NiCb	Do.
Cyprus Minerals Co.	Green Valley, AZ	FeMo	Do.
Elkem A/S, Elkem Metals Co.	Alloy, WV, Ashtabula, OH, Marietta, OH, Niagara Falls, NY	FeB, FeCr, FeMn, FeSi, Mn, Si, SiMn, other[2]	Electric and electrolytic.
Galt Alloys Inc.	Canton, OH	FeTi, FeAl	Electric.
Glenbrook Nickel Co.	Riddle, OR	FeNi	Do.
Globe Metallurgical Inc.	Beverly, OH, Selma, AL, Springfield, OR	FeSi, Si	Do.
HTP Co.	Sharon, PA	FeTi	Metallothermic.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi, silvery pig iron	Electric.
Kerr-McGee Chemical Corp.	Hamilton (Aberdeen), MS	Mn	Electrolytic.
Macalloy Corp.	Charleston, SC	FeCr	Electric.
Metallurg Inc., Shieldalloy Metallurgical Corp.	Cambridge, OH, Newfield, NJ	Cr, FeAl, FeB, FeCb, FeTi, FeV, other[2]	Electric and metallothermic.
Reading Alloys Inc.	Robesonia, PA	FeCb	Metallothermic.
Satra Concentrates	Steubenville, OH	FeCr, FeCrSi	Slag conversion.
Simetco	Montgomery, AL	Si	Electric.
SKW Alloys Inc.	Calvert City, KY, Niagara Falls, NY	FeCr, FeCrSi, FeSi, Si	Do.
Strategic Minerals Corp. (STRATCOR), U.S. Vanadium Corp.	Niagara Falls, NY	FeV	Do.
Teledyne Inc., Teledyne Wah Chang, Albany Div.	Albany, OR	FeCb	Metallothermic.
FERROPHOSPHORUS			
FMC Corp., Industrial Chemical Div.	Pocatello, ID	FeP	Electric.
Monsanto Co., Monsanto Industrial Chemicals Co.	Soda Springs, ID	do.	Do.
Occidental Petroleum Corp.	Columbia, TN	do.	Do.

[1] Cr, chromium metal; FeAl, ferroaluminum; FeB, ferroboron; FeCb, ferrocolumbium; FeCr, ferrochromium; FeCrSi, ferrochromium-silicon; FeMn, ferromanganese; FeMo, ferromolybdenum; FeNi, ferronickel; FeP, ferrophosphorus; FeSi, ferrosilicon; FeTi, ferrotitanium; FeV, ferrovanadium; FeW, ferrotungsten; FeZr, ferrozirconium; Mn, manganese metal; NiCb, nickelcolumbium; Si, silicon metal; SiMn, silicomanganese.

[2] Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

TABLE 15
U.S. FERROALLOY PRODUCTION[1] AND SHIPMENTS[2] IN 1993

(Metric tons, gross weight, unless otherwise specified)

	1993		
	Net production	Net shipments	Stocks, December 31
Ferrophosphorus	17,795	35,565	8,088
Ferrosilicon[3]	323,351	329,635	75,719
Silicon metal	158,570	164,400	6,630
Other[4]	215,716	213,818	54,978
Total	715,432	743,418	145,415

[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.

TABLE 16
REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ADDITIVES IN 1993, BY END USE[1]

(Metric tons of alloys unless otherwise specified)

End use	FeMn	SiMn	FeSi	FeTi	FeP	FeB
Steel:						
Carbon	271,963	80,074	[2]64,204	2,061	5,558	682
Stainless and heat-resisting	[2]15,092	4,575	[2]96,071	2,096	(3)	24
Other alloy	[2]47,906	22,028	[2]37,925	472	824	308
Tool	(4)	(4)	(4)	—	—	—
Unspecified	1,238	572	3,337	—	—	—
Total steel[5]	336,200	107,249	201,537	4,628	6,381	1,013
Cast irons	9,525	1,530	219,217	96	1,262	(6)
Superalloys	[7]132	—	[8]90	504	—	(6)
Alloys (excluding alloy steels and superalloys)	18,943	2,747	W	704	328	169
Miscellaneous and unspecified	(6)	(6)	195,467	(6)	(6)	(6)
Grand total[5]	364,801	111,526	616,312	5,933	7,971	1,182
Total 1992	[r]363,463	[r]114,294	[r]598,874	[r]4,941	[r]8,411	919
Percent of 1992	100	98	103	120	95	129
Consumer stocks, December 31	[9] [10]30,448	6,996	39,456	649	1,246	190

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."
[1] FeMn, ferromanganese, including spiegeleisen and manganese metal; SiMn, silicomanganese; FeSi, ferrosilicon, including silicon metal, silvery pig iron, and inoculant alloys; FeTi, ferrotitanium, including other titanium material; FeP, ferrophosphorus, including other phosphorus materials; FeB, ferroboron including other boron materials.
[2] Part included with "Steel: Unspecified."
[3] Included with "Steel: Other alloy."
[4] Included with "Steel: Unspecified."
[5] Data may not add to totals shown because of independent rounding.
[6] Included with "Alloys (excluding alloy steels and superalloys)."
[7] Part included with "Alloys (excluding alloy steels and superalloys)."
[8] Part included with "Miscellaneous and unspecified."
[9] Includes some producer stocks.
[10] Part withheld to avoid disclosing company proprietary data.

TABLE 17
REPORTED U.S. CONSUMPTION OF FERROALLOYS AS ALLOYING ELEMENTS IN 1993, BY END USE[1]

(Metric tons of contained elements unless otherwise specified)

End use	FeCr	FeMo	FeW	FeV	FeCb	FeNi
Steel:						
Carbon	[2]6,798	175	—	1,413	819	—
Stainless and heat-resisting	[2]167,555	210	39	33	317	20,232
Other alloy	[2]18,738	1,463	40	1,770	1,019	W
Tool	[2]1,148	W	377	373	(3)	—
Unspecified	204	—	—	10	6	—
Total steel[4]	194,443	1,848	456	3,599	2,162	20,232
Cast irons	3,702	739	—	21	—	W
Superalloys	[2]4,834	W	(3)	13	294	—
Alloys (excluding alloy steels and superalloys)	[2]985	[2]94	—	[2]309	W	W
Miscellaneous and unspecified	12,869	415	(5)	30	21	997
Total[4]	216,833	3,096	474	3,973	2,477	21,229
Total 1992	[r]217,653	2,797	[r]474	[r]4,079	[r]2,467	[r]21,193
Percent of 1992	100	111	100	97	100	100
Consumer stocks, December 31	16,685	235	29	329	NA	1,708

[r] Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1] FeCr, ferrochromium, including other chromium ferroalloys and chromium metal; FeMo, ferromolybdenum, including calcium molybdate; FeW, ferrotungsten, including scheelite; FeV, ferrovanadium, including other vanadium-carbon-ironferroalloys; FeCb, ferrocolumbium, including nickel columbium; FeNi, ferronickel.

[2] Part included with "Miscellaneous and unspecified."

[3] Included with "Steel: Unspecified."

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

[5] Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 18
FERROALLOY PRICES IN 1993

	High	Low	Average[1]
Standard-grade ferromanganese[2]	500.00	475.00	486.03
Medium-carbon ferromanganese[3]	51.00	47.00	49.45
Silicomanganese[4]	26.50	19.75	23.35
Charge-grade ferrochromium[3]	40.00	35.50	38.53
High-carbon ferrochromium[3]	38.50	33.50	37.17
Low-carbon ferrochromium[3]	79.00	62.00	71.98
50%-grade ferrosilicon[3]	45.00	37.50	40.76
75%-grade ferrosilicon[3]	45.00	35.50	40.61
Silicon metal[4]	68.50	59.00	66.40
Ferromolybdenum[5]	3.45	2.95	3.12
Molybdenum oxide[5]	2.83	1.82	2.33
Ferrovanadium[6]	10.45	7.70	8.43

[1] Annual weighted average.

[2] Dollars per long ton.

[3] Cents per pound of contained element.

[4] Cents per pound.

[5] Dollars per pound of contained element.

[6] Dollars per kilogram of contained element.

Source: Platt's Metals Week.

TABLE 19

U.S. EXPORTS OF FERROALLOYS AND FERROALLOY METALS IN 1993

Alloy	Quantity (metric tons)	Content (metric tons)	Value (thousands)
Ferroalloys:			
Ferrochromium with greater than 4% carbon	10,071	5,992	$7,804
Ferrochromium with less than 4% carbon	4,391	2,673	5,374
Ferrochromium-silicon	800	280	759
Ferrocolumbium	815	(1)	7,313
Ferromanganese with greater than 2% carbon	8,172	(1)	4,871
Ferromanganese, other	9,868	(1)	9,971
Silicomanganese	9,420	(1)	6,717
Ferromolybdenum	374	224	2,958
Ferronickel	1,019	669	2,313
Ferrophosphorus	1,806	(1)	1,035
Ferrosilicon (greater than 55% silicon)	10,996	6,707	9,471
Ferrosilicon, other	28,510	14,199	27,288
Ferrovanadium	291	219	2,776
Ferrozirconium	20	(1)	54
Ferrotungsten and ferrosilicon-tungsten	1	(2)	8
Ferroalloys, n.e.c.	2,028	(1)	2,821
Total ferroalloys	88,582	XX	91,533
Metals:			
Chromium	472	(1)	4,476
Manganese	3,835	(1)	9,397
Silicon:			
Less than 99% silicon	7,395	7,144	11,295
99% to 99.99% silicon	1,117	1,106	1,716
Greater than 99.99% silicon	2,106	2,106	120,286
Total ferroalloy metals	14,925	XX	147,170
Grand total	103,507	XX	238,703

XX Not applicable.

[1] Not recorded.

[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS FOR CONSUMPTION OF FERROALLOYS AND FERROALLOY METALS IN 1993

(Metric tons)

Alloy	Gross weight	Content	Value (thousands)
Chromium alloys:			
Ferrochromium containing 4% or more carbon	324,225	190,136	$129,117
Ferrochromium containing less than 4% carbon	62,790	39,325	54,699
Ferrochromium-silicon	8,751	3,307	6,180
Total chromium alloys	395,766	232,768	189,996
Manganese alloys:			
Ferromanganese containing more than 4% carbon	281,442	217,160	112,166
Ferromanganese containing more than 1% to 2% carbon	56,233	45,176	42,333
Ferromanganese containing 1% or less carbon	9,734	8,634	13,096
Silicomanganese	316,091	208,266	133,413
Total manganese alloys	663,500	479,236	301,008
Silicon alloys:			
Less than 55% silicon containing more than 2% magnesium	2,631	1,267	3,836
Less than 55% silicon, n.e.c.	24,867	10,320	5,186
55% to 80% silicon, containing more than 3% calcium	657	434	731
55% to 80% silicon, n.e.c.	171,383	128,921	100,170
80% to 99% silicon	576	555	605
Total silicon alloys	200,124	141,497	110,534
Other ferroalloys:			
Ferrocerium and other cerium alloys	203	(1)	1,965
Ferromolybdenum	3,480	2,190	12,725
Ferronickel	37,281	13,223	66,489
Ferroniobium (columbium)	3,367	(1)	28,997
Ferrophosphorus	9,973	(1)	2,325
Ferrotitanium and ferrosilicon-titanium	48,428	(1)	8,068
Ferrotungsten and ferrosilicon-tungsten	860	652	2,827
Ferrovanadium	2,773	1,628	12,235
Ferrozirconium	267	(1)	506
Ferroalloys, n.e.c.	16,521	(1)	24,909
Total other ferroalloys	123,153	XX	161,046
Total ferroalloys	1,382,533	XX	762,578
Metals:			
Chromium	6,170	(1)	37,902
Manganese, unwrought	10,354	(1)	14,832
Manganese, other	4,616	(1)	7,559
Silicon, less than 99% silicon	44,264	43,202	43,269
Silicon 99% to 99.99% silicon	27,082	26,795	35,013
Silicon, greater than 99.99% silicon	886	886	47,331
Total ferroalloy metals	93,372	XX	185,906
Grand total	1,475,905	XX	948,484

XX Not applicable.
[1] Not recorded.

Source: Bureau of the Census.

TABLE 21

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993^{e}
Albania: Electric furnace, ferrochromium	38,800	24,000	$^{r e}$25,000	^{e}15,000	10,000
Argentina: Electric furnace:					
Ferromanganese	24,441	24,344	^{r}26,337	^{r}4,524	5,000
Silicomanganese	21,160	21,805	^{r}14,564	^{r}30,790	31,000
Ferrosilicon	35,667	23,641	^{r}14,437	$^{r e}$19,000	19,500
Silicon metal^{e}	10,000	10,000	10,000	10,000	10,000
Other	5,805	6,310	$^{r e}$5,400	$^{r e}$5,400	5,400
Total^{e}	97,073	86,100	^{r}70,738	^{r}69,714	70,900
Australia: Electric furnace:^{e}					
Ferromanganese	[4]67,000	70,000	^{r}45,000	55,000	75,000
Silicomanganese	55,000	65,000	^{r}74,000	^{r}75,000	75,000
Ferrosilicon	20,000	20,000	^{r}19,000	20,000	20,000
Silicon metal	9,000	33,000	30,000	30,000	30,000
Total	151,000	188,000	^{r}168,000	^{r}180,000	200,000
Austria: Electric furnace:					
Ferronickel	7,000	8,100	8,600	6,100	6,100
Other	8,000	3,900	3,400	5,900	5,900
Total	15,000	12,000	12,000	12,000	12,000
Belgium: Electric furnace, ferromanganese^{e}	^{r}30,000	^{r}25,000	^{r}25,000	^{r}25,000	25,000
Bosnia and Herzegovina: Electric furnace:					
Ferrosilicon	—	—	—	^{r}5,000	1,000
Silicon metal	—	—	—	^{r}2,000	200
Other	—	—	—	500	—
Total	—	—	—	^{r}7,500	1,200
Brazil: Electric furnace:					
Ferromanganese	180,668	170,504	169,103	^{r}178,937	169,000
Silicomanganese	208,262	216,779	272,046	^{r}299,995	273,000
Ferrosilicon	286,994	229,408	190,864	^{r}243,838	240,000
Silicon metal	116,779	131,614	106,002	^{r}93,734	95,000
Ferrochromium	113,267	83,753	82,225	^{r}91,829	85,000
Ferrochromium-silicon	8,938	4,973	4,524	^{e}4,500	4,500
Ferronickel	34,997	34,257	^{r}34,069	^{r}34,000	34,000
Other	81,901	68,026	^{r}76,484	$^{r e}$76,654	76,654
Total	1,031,806	939,314	^{r}935,317	$^{r e}$1,023,487	977,154
Bulgaria: Electric furnace:^{e}					
Ferromanganese[5]	30,000	—	—	—	—
Ferrosilicon	14,000	^{r}16,200	^{r}25,200	^{r}18,000	18,000
Other	1,000	^{r}1,800	^{r}2,800	^{r}2,000	2,000
Total	45,000	^{r}18,000	^{r}28,000	^{r}20,000	20,000
Canada: Electric furnace:^{e}					
Ferromanganese[5]	185,000	^{r}[4]185,066	45,000	—	—
Ferrosilicon	88,370	90,000	106,850	^{r}55,000	55,000
Other	106,000	100,000	95,000	^{r}22,000	22,000
Total	379,370	^{r}375,066	246,850	^{r}77,000	77,000

See footnotes at end of table.

TABLE 21—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
Chile: Electric furnace:					
Ferromanganese	7,492	3,587	[r]6,779	[r]7,460	7,500
Silicomanganese	180	985	[r]1,674	[r]1,564	1,600
Ferrosilicon	6,370	4,662	[r]5,516	[e]5,600	5,700
Ferrochromium	2,840	1,868	[r]2,509	[r]2,100	2,140
Ferromolybdenum	2,990	2,283	[r]2,673	[r][e]3,200	3,260
Total	19,872	13,385	[r][e]19,151	[r][e]19,924	20,200
China:[e]					
Blast furnace:					
Ferromanganese	240,000	[r]330,000	[r]500,000	[r]550,000	550,000
Other	160,000	170,000	170,000	180,000	200,000
Electric Furnace:					
Ferromanganese	120,000	[r]150,000	[r]180,000	[r]200,000	220,000
Silicomanganese	240,000	[r]370,000	[r]415,000	[r]420,000	450,000
Ferrosilicon	900,000	[r]727,000	[r]817,000	[r]834,000	870,000
Ferrochromium	(6)	(6)	(6)	(6)	(6)
Other	722,000	[r]653,000	[r]468,000	[r]466,000	510,000
Total	2,382,000	2,400,000	2,550,000	[r]2,650,000	2,800,000
Colombia: Electric furnace, ferronickel	41,454	43,847	49,824	49,828	49,800
Croatia: Electric furnace:					
Ferrochromium	—	—	—	56,456	[4]27,336
Ferromanganese	—	—	—	[r][e]10,000	10,000
Silicomanganese	—	—	—	[r][e]40,000	40,000
Total	—	—	—	[r][e]106,456	77,336
Czech Republic:[7] Electric furnace, total	—	—	—	—	1,000
Czechoslovakia: Electric furnace:					
Ferromanganese[e][5]	100,159	101,660	90,000	[r]70,000	—
Ferrosilicon	20,997	20,474	[e]15,000	[e]15,000	—
Silicon metal[e]	5,000	5,000	5,000	5,000	—
Ferrochromium	29,844	31,866	[r]33,860	37,756	—
Other[e][8]	10,000	10,000	10,000	10,000	—
Total[e]	166,000	169,000	153,860	[r]137,756	—
Dominican Republic: Electric furnace, ferronickel	78,170	71,753	72,655	[r]68,838	59,600
Egypt: Electric furnace:					
Ferrosilicon	7,800	7,922	[e]7,900	[e]7,900	7,900
Ferromanganese	—	—	—	[e]10,000	30,000
Total	7,800	7,922	[e]7,900	[e]17,900	37,900
Finland: Electric furnace, ferrochromium	169,000	157,000	190,000	187,000	[4]218,370
France:					
Blast furnace:					
Ferromanganese	[r]325,000	[r]324,000	[r][e]320,237	[e]300,000	250,000
Electric furnace:					
Ferromanganese	[e]27,000	[r]36,000	[e]30,000	[e]60,000	30,000
Silicomanganese[9]	[r][e]58,967	61,900	[e]30,000	[r]80,000	80,000
Ferrosilicon	125,390	117,490	105,800	[r]98,000	98,000

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
France—Continued:					
Electric furnace—Continued:					
Silicon metal[e]	72,000	64,000	64,000	60,000	60,000
Ferrochromium[e]	18,100	25,000	23,100	6,694	—
Other[e] [10]	60,000	70,000	50,000	[r]36,000	36,000
Total[e]	[r]686,457	[r]698,390	[r]623,137	[r]640,694	554,000
Georgia: Electric furnace:					
Ferromanganese	—	—	—	[e]100,000	100,000
Silicomanganese	—	—	—	[r][e]50,000	50,000
Other	—	—	—	[e]10,000	10,000
Total	—	—	—	[r][e]160,000	160,000
Germany:[e]					
Blast furnace, Western states:					
Ferromanganese	305,000	250,000	220,000	[r]130,000	100,000
Electric furnace:					
Ferromanganese:[5]					
Eastern states	67,000	[r][e]65,317	—	—	—
Western states	45,000	38,000	—	—	—
Total	112,000	[r]103,317	40,000	30,000	20,000
Ferrosilicon:					
Eastern states	25,000	24,000	—	—	—
Western states	55,000	46,000	—	—	—
Total	80,000	70,000	50,000	20,000	20,000
Silicon metal, Eastern states	3,000	3,000	2,600	500	500
Ferrochromium:					
Eastern states	22,000	21,000	—	—	—
Western states	[r]33,350	[r]37,500	—	—	—
Total	[r]55,350	[r]58,500	[r]33,650	[r][4]26,520	[4]16,400
Other:[8]					
Eastern states	13,000	12,000	—	—	—
Western states	66,000	54,000	—	—	—
Total	79,000	66,000	40,000	30,000	30,000
Grand total	[r]634,350	[r]550,817	[r]386,250	[r]237,020	186,900
Greece: Electric furnace:					
Ferrochromium	43,579	30,300	[e]10,500	—	—
Ferronickel	[r]61,900	60,500	64,020	65,000	45,000
Total	[r]105,479	90,800	[e]74,520	65,000	45,000
Hungary:[11] Electric furnace:[e]					
Ferrosilicon	[r]9,000	9,000	[r]7,000	7,000	7,000
Silicon metal	2,000	2,000	[r]1,000	[r]1,000	1,000
Other	1,000	1,000	1,000	1,000	1,000
Total	[r]12,000	12,000	[r]9,000	[r]9,000	9,000
Iceland: Electric furnace, ferrosilicon	72,007	62,791	50,299	[r]51,651	52,000
India: Electric furnace:					
Ferromanganese	[r]157,776	[r]201,194	[r][e]211,000	[r][e]198,000	150,000
Silicomanganese	72,229	[r]57,361	[r][e]70,000	[r][e]93,000	80,000
Ferrosilicon	[r]74,472	[r]64,035	[r]39,099	[r][e]39,000	53,000

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
India: Electric furnace—Continued:					
Ferrochromium	[r]151,167	[r]168,511	[r]219,477	[r]256,831	[4]244,370
Ferrochromium-silicon	11,384	7,000	8,800	[e]9,000	8,000
Other	[r]386	[e]400	6,767	[e]6,500	7,500
Total	[r]467,414	[r]498,501	[r][e]555,143	[r][e]602,331	542,870
Indonesia: Electric furnace:					
Ferronickel	26,058	25,025	[e]25,000	[e]26,000	26,000
Ferromanganese	—	—	—	—	10,000
Total	26,058	25,025	[e]25,000	[e]26,000	36,000
Italy: Electric furnace:					
Ferromanganese	[r]40,958	[r]41,837	14,145	[r][e]10,000	10,000
Silicomanganese[e]	47,000	56,000	55,000	50,000	50,000
Ferrosilicon	65,171	[r]39,761	12,648	[e]12,000	12,000
Silicon metal	[e]19,000	[e]13,000	16,200	[r]10,000	10,000
Ferrochromium	[r]87,331	53,000	[r]47,192	[r]60,315	[4]53,504
Other[e] [12]	15,000	14,500	14,500	[r]12,000	12,000
Total[e]	[r]274,460	[r]218,098	[r]159,685	[r]154,315	147,504
Japan: Electric furnace:					
Ferromanganese	394,055	452,434	463,722	361,941	[4]382,912
Silicomanganese	122,192	77,465	87,229	96,360	[4]64,758
Ferrosilicon	74,936	62,599	62,362	37,656	29,000
Ferrochromium[13]	324,371	293,345	270,786	267,857	208,000
Ferronickel	275,341	234,311	295,422	237,350	212,000
Other[14]	11,111	12,078	12,317	12,179	12,870
Total	1,202,006	1,132,232	1,191,838	1,013,343	909,540
Kazakhstan: Electric furnace:					
Ferrosilicon	—	—	—	[r][e]500,000	450,000
Ferrochromium	—	—	—	[e]400,000	400,000
Ferrochromium-silicon	—	—	—	[e]40,000	40,000
Other	—	—	—	[e]20,000	20,000
Total	—	—	—	[r][e]960,000	910,000
Korea, North: Electric furnace:[e]					
Ferromanganese[5]	70,000	70,000	70,000	70,000	70,000
Ferrosilicon	30,000	30,000	30,000	30,000	30,000
Other[8]	20,000	20,000	20,000	20,000	20,000
Total	120,000	120,000	120,000	120,000	120,000
Korea, Republic of: Electric furnace:					
Ferromanganese	85,329	84,000	94,893	[r]85,867	99,000
Silicomanganese	[r]87,105	[r]82,763	74,173	[r]82,582	84,000
Ferrosilicon	4,582	2,000	—	55	—
Total	[r]177,016	[r]168,763	169,066	[r][e]168,504	183,000
Macedonia:[15] Electric furnace:					
Ferrochromium	—	—	—	[r]3,958	[4]4,376
Ferrochromium-silicon	—	—	—	[r][e]1,500	—
Ferrosilicon	—	—	—	[r][e]30,000	20,000
Silicon metal	—	—	—	[r][e]1,000	1,000
Total	—	—	—	[r][e]36,458	25,376

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
Mexico: Electric furnace:					
Ferromanganese	[r]113,000	[r]123,000	[r]98,000	[r]79,000	70,000
Silicomanganese	[r]91,000	[r]65,000	[r]51,000	[r]51,000	55,000
Ferrosilicon	9,474	7,000	6,000	5,000	400
Ferrochromium	2,569	275	72	[e]70	70
Other	92	250	105	300	300
Total	[r]216,135	[r]195,525	[r]155,177	[r]135,370	125,770
New Caledonia: Electric furnace, ferronickel	142,500	126,500	137,600	[r]125,900	145,500
Norway: Electric furnace:					
Ferromanganese	220,591	213,266	173,212	202,680	200,000
Silicomanganese	270,305	223,310	226,737	213,106	210,000
Ferrosilicon	398,744	397,520	377,455	367,034	350,000
Silicon metal	100,194	76,601	[e]65,000	[e]60,000	60,000
Ferrochromium	—	[e]60,000	[e]83,000	102,000	[4]80,000
Other[e] [9]	14,000	14,000	14,000	14,000	14,000
Total[e]	1,003,834	984,697	939,404	958,820	914,000
Peru: Electric furnace:[e]					
Ferromanganese	[4]1,145	900	1,000	1,000	1,000
Ferrosilicon	[4]281	500	600	600	600
Total	[4]1,426	1,400	1,600	1,600	1,600
Philippines: Electric furnace:[e]					
Ferromanganese	—	—	5,000	5,000	5,000
Ferrosilicon	9,000	10,000	10,000	10,000	10,000
Ferrochromium	82,000	56,000	[4]23,730	27,400	12,000
Total	91,000	66,000	38,730	42,400	27,000
Poland:					
Blast furnace:					
Spiegeleisen	906	140	[e]140	[e]140	130
Ferromanganese	90,267	71,000	57,400	[e]50,000	40,000
Electric furnace:					
Ferromanganese	1,427	5,400	[e]5,000	[e]5,000	5,000
Silicomanganese[e]	25,000	25,000	25,000	25,000	25,000
Ferrosilicon	83,210	88,600	[e]80,000	[e]75,000	70,000
Silicon metal[e]	10,000	10,000	[4]9,000	9,000	9,000
Ferrochromium	[r]28,222	[r]13,679	[r]1,928	[r]35,222	[4]38,499
Other[8]	60,718	33,100	30,000	[e]25,000	20,000
Total[e]	[r]299,750	[r]246,919	[r]208,468	[r]224,362	207,629
Portugal: Electric furnace:					
Ferromanganese	[16]13,170	[16]12,480	[r]—	[r]—	—
Romania: Electric furnace:[e]					
Ferromanganese	80,000	[r]60,000	[r]40,000	[r][4]27,130	27,000
Silicomanganese	40,000	[r]30,000	[r]30,000	[r][4]28,159	28,000
Ferrosilicon	50,000	[r]40,000	30,000	[r][4]23,318	21,000
Silicon metal	[r]4,400	[r]4,000	[r]1,000	[r][4]430	400
Ferrochromium	26,849	20,633	20,380	[4]6,977	[4]3,907
Total	[r]201,249	[r]154,633	[r]121,380	[r][4]86,014	80,307

See footnotes at end of table.

TABLE 21—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
Russia:					
Blast furnace:					
Spiegeleisen	—	—	—	[e]10,000	8,000
Ferromanganese	—	—	—	[e]200,000	150,000
Ferrophosphorus	—	—	—	[e]30,000	25,000
Electric furnace:					
Ferrosilicon	—	—	—	[e]500,000	500,000
Silicon metal	—	—	—	[e]60,000	60,000
Ferrochromium	—	—	—	[r][e]400,000	400,000
Ferrochromium-silicon	—	—	—	[e]60,000	60,000
Ferronickel	—	—	—	[r][e]65,000	50,000
Other	—	—	—	[e]60,000	50,000
Total	—	—	—	[r][e]1,385,000	1,303,000
Serbia and Montenegro: Electric furnace:					
Ferronickel	—	—	—	[r]5,000	5,000
Slovakia: Electric furnace:[7]					
Ferromanganese	—	—	—	—	65,000
Ferrochromium[17]	—	—	—	—	47,000
Electric furnace, total	—	—	—	—	120,000
Total	—	—	—	—	232,000
Slovenia: Electric furnace:					
Ferrochromium	—	—	—	[r]17,104	[4]9,000
Ferrochromium-silicon	—	—	—	[r]—	—
Ferrosilicon	—	—	—	[r][e]14,000	12,000
Calcium-silicon	—	—	—	[r][e]400	200
Other	—	—	—	[e]5,000	—
Total	—	—	—	[r][e]36,504	21,200
South Africa: Electric furnace:					
Ferromanganese	394,000	404,000	[r]255,000	270,000	[4]393,000
Silicomanganese	258,000	234,000	235,000	[r]266,000	[4]268,000
Ferrosilicon	93,000	78,000	[r]68,300	[r]93,582	[4]102,097
Silicon metal	36,000	36,000	[r]39,800	[r]34,528	[4]38,279
Ferrochromium[18]	1,049,900	1,022,000	1,126,700	[r]664,856	650,000
Other[e]	2,000	1,000	1,000	1,000	1,000
Total[e]	1,832,900	1,775,000	[r]1,725,800	[r]1,329,966	1,452,376
Spain: Electric furnace:[e]					
Ferromanganese	50,000	52,220	50,000	50,000	50,000
Silicomanganese	40,000	38,440	40,000	40,000	40,000
Ferrosilicon	38,000	37,500	40,000	40,000	40,000
Silicon metal	11,500	9,000	9,000	10,000	10,000
Ferrochromium	29,000	15,000	6,000	—	2,390
Other	5,000	5,000	5,000	5,000	5,000
Total	173,500	157,160	150,000	145,000	147,390
Sweden: Electric furnace:					
Ferrosilicon	20,996	18,736	21,145	[e]22,000	22,000
Silicon metal	13,421	[e]10,000	—	—	—
Ferrochromium	153,800	117,680	120,884	[r]133,000	[4]127,543
Total	188,217	[e]146,416	142,029	[r][e]155,000	149,543

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
Switzerland: Electric furnace:[e]					
Ferrosilicon	3,000	3,000	3,000	3,000	3,000
Silicon metal	2,000	2,000	2,000	2,000	2,000
Total	5,000	5,000	5,000	5,000	5,000
Taiwan: Electric furnace:					
Ferromanganese	30,623	43,631	40,110	[r]37,802	[4]13,628
Silicomanganese	[r]25,510	20,587	12,801	[r]3,991	—
Ferrosilicon	19,277	15,501	6,252	[r]2,606	[4]689
Total	[r]75,410	79,719	59,163	[r]44,399	14,317
Turkey: Electric furnace:					
Ferrosilicon	4,970	5,225	[r]1,736	[r]1,250	1,250
Ferrochromium	59,715	[r]62,360	84,651	85,755	[4]90,030
Total	64,685	[r]67,585	[r]86,387	[r]87,005	91,280
Ukraine:					
Blast furnace:					
Ferromanganese	—	—	—	[e]50,000	50,000
Spiegeleisen	—	—	—	[e]5,000	4,000
Electric furnace:					
Ferromanganese	—	—	—	[r,e]100,000	100,000
Silicomanganese	—	—	—	[e]1,000,000	700,000
Ferrosilicon	—	—	—	[e]500,000	500,000
Ferronickel	—	—	—	[r,e]12,000	10,000
Other	—	—	—	[e]40,000	40,000
Total	—	—	—	[r,e]1,707,000	1,404,000
U.S.S.R.:[19]					
Blast furnace:					
Spiegeleisen	18,000	17,000	[e]15,000	—	—
Ferromanganese	[r]608,722	281,000	235,000	—	—
Ferrophosphorus	29,000	30,000	31,000	—	—
Electric furnace:[e][20]					
Ferromanganese	[4]414,100	[r]410,048	370,000	—	—
Silicomanganese	1,300,000	1,300,000	1,100,000	—	—
Ferrosilicon	1,872,600	1,860,000	1,600,000	—	—
Silicon metal	65,000	65,000	60,000	—	—
Ferrochromium	[r]828,000	[r]700,000	[r]700,000	—	—
Ferrochromium-silicon	100,000	100,000	100,000	—	—
Ferronickel	90,000	[r]85,000	[r]80,000	—	—
Other	160,000	160,000	140,000	—	—
Total[e]	[r]5,485,422	[r]5,008,048	[r]4,431,000	—	—
United Kingdom:					
Blast furnace, ferromanganese	[r]143,000	[r]144,000	178,400	[r]137,000	40,000
Electric furnace, other[e]	10,000	10,000	10,000	10,000	10,000
Total[e]	[r]153,000	[r]154,000	188,400	[r]147,000	50,000
United States: Electric furnace:					
Ferromanganese[22]	W	W	W	W	W
Ferrosilicon	475,256	433,726	338,154	346,290	[4]323,351
Silicon metal	136,531	140,792	145,275	158,550	[4]158,570
Ferrochromium[21]	146,844	108,932	68,327	60,945	[4]63,018

See footnotes at end of table.

TABLE 21—Continued

FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

Country, furnace type,[2] and alloy type[3]	1989	1990	1991	1992	1993[e]
United States: Electric furnace—Continued:					
Ferronickel	682	7,333	14,251	18,167	[4]9,926
Other	171,137	183,910	211,266	189,501	[4]160,567
Total	930,450	874,693	777,273	773,453	715,432
Uruguay: Electric furnace, ferrosilicon[e]	250	250	250	250	250
Venezuela: Electric furnace:[e]					
Ferromanganese	—	—	1,000	9,000	10,000
Silicomanganese	[4]32,387	[r]31,000	[r]31,000	[r]32,000	30,000
Ferrosilicon	[4]54,873	55,000	55,000	56,000	56,000
Total	[4]87,260	[r]86,000	[r]87,000	[r]97,000	96,000
Yugoslavia:[23] Electric furnace:					
Ferromanganese	33,868	31,822	[e]20,000	—	—
Silicomanganese	52,588	60,601	[e]50,000	—	—
Ferrosilicon	122,179	103,188	[e]80,000	—	—
Silicon metal	15,897	12,661	[e]10,000	—	—
Ferrochromium	90,428	82,687	[r,e]91,000	—	—
Ferrochromium-silicon	3,815	4,199	[e]3,000	—	—
Ferronickel	17,102	11,850	[e]7,000	—	—
Calcium-silicon	144	835	[e]1,000	—	—
Other	11,199	10,462	[e]9,000	—	—
Total	347,220	318,305	[r,e]271,000	—	—
Zimbabwe: Electric furnace:					
Ferrochromium	[r]173,000	[r]222,102	[r]186,774	[r]190,994	140,000
Ferrochromium-silicon	25,000	16,612	27,755	[r]20,282	10,000
Total	[r]198,000	[r]238,714	[r]214,529	[r]211,276	150,000
Grand total	[r]19,939,970	[r]18,806,848	[r]17,658,423	[r]16,615,038	15,877,244
Of which:					
Blast furnace:					
Spiegeleisen[24]	18,906	17,140	15,140	15,140	12,130
Ferromanganese[24]	[r]1,711,989	[r]1,400,000	[r]1,511,037	[r]1,417,000	1,180,000
Other	189,000	200,000	201,000	210,000	225,000
Total blast furnace	[r]1,919,895	[r]1,617,140	[r]1,727,177	[r]1,642,140	1,417,130
Electric furnace:					
Ferromanganese[25] [26]	[r]2,983,802	[r]3,075,710	[r]2,569,301	[r]2,263,341	2,353,040
Silicomanganese[25] [27]	[r]3,046,885	[r]3,037,996	[r]2,895,224	[r]2,978,547	2,635,358
Ferrosilicon	[r]5,170,866	[r]4,750,729	[r]4,276,867	[r]4,108,630	4,020,737
Silicon metal	[r]631,722	[r]627,668	575,877	[r]547,742	545,949
Ferrochromium[28]	[r]3,703,976	[r]3,408,491	[r]3,451,745	[r]3,136,639	2,932,953
Ferrochromium-silicon	149,137	132,784	144,079	[r]135,282	122,500
Ferronickel	[r]775,204	[r]708,476	[r]788,441	[r]713,183	652,926
Other	[r]1,558,483	[r]1,447,854	[r]1,229,712	[r]1,089,534	1,196,651
Total electric furnace	[r]18,020,075	[r]17,189,708	[r]15,931,246	[r]14,972,898	14,460,114

See footnotes at end of table.

TABLE 21—Continued
FERROALLOYS: WORLD PRODUCTION, BY COUNTRY, FURNACE TYPE, AND ALLOY TYPE[1]

(Metric tons)

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[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Table includes data available through Aug. 15, 1994.

[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." Where one or more of the individual ferroalloys listed separately in this footnote have been inseparable from other ferroalloys, owing to a nation's reporting system, deviations are indicated by individual footnotes.

[4] Reported figure.

[5] Includes silicomanganese.

[6] Included with other.

[7] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[8] Includes ferrochromium-silicon and ferronickel, if any was produced.

[9] Includes silicospiegeleisen.

[10] Includes ferronickel if any was produced.

[11] Hungary is believed to produce some blast furnace ferromanganese.

[12] Series excludes calcium silicide.

[13] Includes ferrochromium-silicon.

[14] Includes calcium-silicon, ferrocolumbium, ferromolybdenum, ferrotungsten, ferrovanadium, and other ferroalloys.

[15] Imports of ferronickel originating in Macedonia were reported in 1992 and 93, but information on the output of the Kavadarci operation was not available.

[16] Estimated figures based on reported exports and an allowance for domestic use.

[17] May include ferrosilicon-chromium and ferronickel, if any was produced.

[18] Includes production from Bophuthatswana. Includes net production of ferrochromium-silicon, if there was any.

[19] Dissolved in Dec. 1991.

[20] Soviet 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.

[21] U.S. output of ferrochromium includes high- and low-carbon ferrochromium, ferochromium-silicon, chromium metal, and other chromium materials.

[22] U.S. output of ferromanganese includes silicomanganese and manganese metal.

[23] Dissolved in Apr. 1992.

[24] Spiegeleisen for the western states of Germany is included with blast furnace ferromanganese.

[25] Ferromanganese includes silicomanganese (if any was produced) for countries carrying footnote 6 on "Ferromanganese" data line.

[26] U.S. production under "Other" for 1989-93.

[27] Includes silicospiegeleisen for France.

[28] Ferrochromium includes ferrochromium-silicon (if any was produced) for Japan, the Republic of South Africa, and the United States.

LEAD

By Gerald R. Smith

Mr. Smith, a physical scientist with 30 years of research and commodity experience with the U.S. Bureau of Mines, has been the acting commodity specialist for lead since March 1994. Domestic survey data were prepared by Fred Zeleznik and Lisa Conley, statistical assistants; and international data were prepared by Virginia Woodson, international data coordinator.

Domestic lead mine production declined by about 11% in 1993, continuing a 3-year decline in production. Missouri remained the dominant producing State with a 78% share, and Alaska, Idaho, and Montana contributed an additional 20%. Lead was produced at about 20 mines, employing approximately 1,500 people. The value of domestic mine production was approximately $250 million. Primary lead was processed at two smelter-refineries in Missouri, a smelter in Montana, and a refinery in Nebraska. About 82% of secondary lead was produced at 29 plants with annual capacities of 6,000 tons or more.

Legislation that would affect both primary and secondary lead producers was reintroduced in the U.S. House of Representatives in 1993. The legislation, entitled "The Lead-Based Paint Hazard Trust Fund Act of 1993," essentially a revamping of a 1992 bill, proposed a unitary tax of 45 cents per pound on all primary and secondary lead produced domestically and imported. The intent of this legislation was to provide a dedicated revenue of $1 billion per year for use in protecting against lead-based paint hazards in accordance with Title 10 of the Housing and Community Development Act of 1992. By yearend 1993, no significant advancement of this bill had occurred.

Lead was consumed in about 200 plants in the manufacture of end-use products, including batteries, ammunition, covering for power and communication cable, building construction materials, and solders for motor vehicles, metal containers, and electrical and electronic components and accessories.

Lead-acid batteries continued to be the overwhelmingly dominant use of lead, accounting for about 83% of reported lead consumption in 1993. The Battery Council International (BCI) reported a 1993 starting-lighting-ignition (SLI) battery production of 86.0 million units. This total includes both original equipment market and replacement market automotive-type batteries. An estimated 815,000 tons of lead were consumed in SLI batteries in 1993.

Disposals of lead from the National Defense Stockpile (NDS) took place for the first time since 1975, following passage of the FY 1993 Defense Authorization Bill (Public Law 102-484) in October 1992. The Bill provided for the eventual disposal of all the approximately 545,000 metric tons of refined lead now held in the NDS. Total sales of lead from the NDS during 1993, after sales were begun in June, amounted to about 35,000 metric tons.

London Metal Exchange (LME) and North American producer average prices in December 1993 were $0.003 per pound and $0.013 per pound, respectively, above those in the final month of 1992. A modest increase in prices occurred in the last half of the year, but the average LME and North American producer prices for 1993 were down by $0.036 and $0.034 per pound, respectively, compared with those of 1992.

Lead was mined in 51 countries, of which the top five accounted for 56% of the world total of 2,926 million tons. Australia was the largest producer, with 17% of the world total, followed by China (14%), the United States (12%), Peru (7%), and Canada (6%).

The world reserve base for lead was estimated by the U.S. Bureau of Mines at 130 million tons, and the world reserves at 63 million tons. Australia had about 27% of the reserve base and 16% of the reserves. The United States had about 17% of the reserve base and 16% of the reserves.

DOMESTIC DATA COVERAGE

Domestic data for lead are developed by the U.S. Bureau of Mines from five voluntary surveys. Typical of these are the combined secondary producer and consumer surveys, both monthly and annual. Of the 191 consuming companies to which a survey request was sent, 143 responded, representing 82% of the total U.S. lead consumption shown in tables 1, 6, 7, and 8. Of the 38 companies producing secondary lead, exclusive of copper base, to which a survey request was sent, 26 responded, representing 80% of the total refinery production of secondary lead, shown in tables 1, 5, and 9. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends. *(See table 1.)*

BACKGROUND

Lead is a soft, heavy metal, the most corrosion resistant of the common metals, and one of the oldest metals used by man. Among the nonferrous metals, in terms of tonnage, demand for lead is surpassed only by demand for aluminum, copper, and zinc. Some historians have theorized that the downfall of the Roman Empire was expedited by the debilitating effects on its citizens of drinking water carried in lead pipes. Buildings built in Europe four centuries ago still stand under their original lead roofs. Today's major use of lead is in lead-acid storage batteries. The electrical systems of vehicles, ships, and aircraft depend on such batteries for startup, and in some cases, batteries provide the actual motive power. Other batteries provide standby electrical power for emergencies, and very large lead-acid systems are designed to provide "peaking" power in such applications as commercial power networks and subway systems. An increasing use is in the uninterruptible power supply systems necessary for voltage control and emergency power in critical computer storage systems. Lead in gasoline, once the second largest use of lead in the United States, has been phased out to eliminate the health hazard it was found to present. Some nontransportation applications of lead include increasing use for soundproofing in office buildings, schools, and hotels and earthquake shock dampening in building foundations. It is widely used in hospitals to block X-ray and gamma radiation and is employed to shield against nuclear radiation both in permanent installations and when radioactive source material is being stored and/or transported.

ANNUAL REVIEW

Legislation and Government Programs

Authorization providing for the disposal of the entire 601,162 short tons (st) (545,365 metric tons (mt)) of refined lead held in the National Defense Stockpile (NDS) was included in the FY 1993 Defense Authorization Bill passed on October 23, 1992. Subsequently, the Annual Materials Plan (AMP) for FY 1993, submitted to the Congress by the Department of Defense (DoD), proposed the sale of 52,000 st (47,174 mt) of lead. Actual sales of lead from the NDS were begun in June 1993. By the end of FY 1993, September 30, 1993, the quantity of refined lead sold from the NDS was 22,174 st (20,116 mt). For FY 1994, beginning October 1, 1993, the DoD proposed the sale of an additional 35,000 st (31,751 mt) of lead. Further sales of lead in the first three months of FY 1994 amounted to 16,338 st (14,822 mt), leaving about 562,000 st (510,000 mt) of lead in the NDS by yearend 1993.

Pending completion of rulemaking pertaining to the use of lead solder in food cans, the Food and Drug Administration (FDA) announced emergency action on April 1, 1994, to limit lead levels in the food packaged in such cans. Specifically, the FDA action set permissible levels of 80 parts per billion (ppb) for lead in fruit beverages, such as juices, nectars, and drinks packed in lead-soldered cans, and 250 ppb for all other foods packed in lead-soldered cans.

Subsequent to the emergency action relating to lead-soldered food cans, the FDA issued its proposed rulemaking on the use of lead-soldered food cans on June 21, 1993. In that rule, the FDA proposed to prohibit the use of lead solder in cans that contained food, applying the rule to both domestic and imported foods. The FDA tentatively concluded that available toxicological and lead exposure data demonstrated that this use of lead may be injurious to human health. Furthermore, the FDA proposed to revoke any "prior sanction" that may exist for the use of lead in metal food packaging. FDA defined "prior sanction" as an "explicit approval granted with respect to use of a substance in food prior to September 6, 1958," the date of enactment of the Food Additives Amendment. Before that date, the FDA had approved specific uses of various food-contact materials or food ingredients by issuing letters and statements indicating that, in FDA's view, these substances "were not considered unsafe," "did not present a hazard," or "were not objected to for use."

In related action on lead in food packaging, the FDA withdrew its earlier published rulemaking proposals to establish tolerance levels (December 6, 1974) and action levels (August 31, 1979) for lead in evaporated milk products. FDA's action, published on June 21, 1993, was prompted by the fact that the evaporated milk industry had not only improved its product handling during the last decade to limit lead contamination in these products, but also had converted its production facilities from the use of lead-soldered venthole cans to the use of lead-free welded cans in 1986.

On June 22, 1993, revised legislation pertaining to the "Lead-Based Paint Hazard Abatement Trust Fund" was introduced in the U.S. House of Representatives. The revised legislation proposed a unitary tax of 45 cents per pound on all primary and secondary lead produced domestically and imported, whereas prior "Trust Fund" legislation introduced in 1991 had proposed the imposition of a 75 cents per pound tax on all primary lead and a 37 cents per pound tax on all secondary lead. The original legislation was restructured because of concerns that were raised by the Joint Tax Committee and witnesses during hearings held in 1992, pertaining to the effects such taxation would have on the domestic lead industry. The intent of this legislation was to provide a dedicated revenue, estimated at $1 billion per year, for exclusive use in protecting against lead-based paint hazards in accordance with Title 10 of the Housing and Community Development Act of 1992. By yearend 1993, no significant advancement of this legislation had occurred.

On May 4, 1993, the Occupational Safety and Health Administration (OSHA) issued its interim final rule on "Lead Exposure in Construction." This rule amended OSHA standards for occupational health and environmental controls by adding specific employee protection requirements for workers exposed to lead. The added standard reduced the permitted level of exposure to lead for construction workers from 200 micrograms to 50 micrograms per cubic meter of air as an 8-hour time-weighted average (TWA). The standard also included requirements addressing exposure assessment, methods of compliance, respiratory protection, hygiene facilities and practices, medical surveillance and removal protection, recordkeeping, and employee information and training. A lead level of 30 micrograms per cubic meter of air as an 8-hour TWA was established as the level at which employers must initiate certain compliance activities. This interim rule became effective on June 3, 1993, and was mandated by and issued under the Housing and Community Development Act of 1992.

Issues

Congressional discussions during 1993 on an economic stimulus package related to improving the highway infrastructure raised concerns about worker protection against exposure to lead hazards. Specifically, concerns were expressed at a hearing of the U.S. House of Representatives Energy and Commerce Committee's Subcommittee on Health and the Environment that the stimulus package would increase lead poisoning among workers involved in activities to remove lead-based paint from bridges, if such activities were implemented before the Environmental Protection Agency (EPA) was able to establish accredited worker and contractor training requirements. Similar concern was expressed for other economic stimulus packages, such as Farmers Home Administration grants for low-income housing, the National Trust for Historic Preservation, the Museum Properties deferred maintenance projects, and the Federal Building Energy Efficiency projects, all of which will involve construction workers in the disturbance of lead-based paint. EPA was scheduled to set training and certification standards for workers and contractors, including those engaged in paint removal and demolition activities, by April 1994. The standards were required to be provided by EPA as mandated in the Residential Lead-Based Hazard Reduction Act passed in 1992.

During 1993, the Organization for Economic Cooperation and Development (OECD) continued its discussions on means whereby lead hazard risk might be reduced within its member countries. The OECD Chemicals Group, operating under a 1990 agreement to proceed with a pilot risk reduction program for lead and five other chemicals, published a monograph on lead risk reduction in May 1993. According to information in the monograph, several OECD member countries had either begun efforts or had expanded present programs to reduce lead risks.

Consistent with the OECD Chemicals Group efforts, the OECD Secretariat initiated a second phase of risk reduction activity. The aim of this phase was to identify possible further national and/or collective international risk reduction activities for lead. OECD member delegates, meeting in May 1993, subsequently requested that the OECD Secretariat, in consultation with OECD member countries, work toward developing a binding form of OECD lead risk reduction for its member countries. An OECD Working Group emerged at the May 1993 meeting to draft an initial outline of the general scope and content of a possible binding lead risk reduction action. The Working Group met again in November 1993 to consider proposals for inclusion in any such action. The proposals addressed risk reduction as it applied to lead products, recycling, new and existing uses, point source controls, abatement and clean-up programs, technology transfer, reporting requirements, and monitoring and assessment programs. Further OECD discussions on the matter of a binding lead risk reduction action were planned for 1994.

Production

Primary.—In 1993, domestic mine production of lead decreased by about 42,000 metric tons, or 11%, from the 1992 level, continuing a 3-year decline in domestic production. The further decline in production was attributed to the closure of Kennecott Mining Co.'s Greens Creek Mine in southeastern Alaska, as well as to cutbacks at Cominco American Inc.'s Magmont Mine in Bixby, MO, and The Doe Run Co.'s Buick Mine in Iron, MO. Countering these declines was an increase in production at Cominco Alaska Inc.'s Red Dog Mine in the northwest arctic region of Alaska. Missouri's share of the total mined lead production was 78%, about 4% higher than in 1992. Production in Alaska, Idaho and Montana accounted for an additional 20% of U.S. mine output. The top 12 mines listed in table 3 produced more than 98% of the total, and Asarco Incorporated, Doe Run, and Cominco (American/Alaska) accounted for slightly more than 91% of the domestic mine production of lead in 1993. *(See tables 2 and 3.)*

Fluor Corp., Irvine, CA, formally announced at the end of 1993 plans to sell its Doe Run subsidiary based in St. Louis, MO. Doe Run, the Nation's only fully integrated primary lead producer, had assets that include six mines and four mills in southeast Missouri, estimated by industry analysts to be valued at approximately $225 million. The plans to sell Doe Run's assets followed a late 1992 action by Fluor Corp. to classify Doe Run as a "discontinued operation" for tax purposes. Several sales options reportedly were being considered, including employee buyout, spin off as a separate company to Fluor Corp. shareholders with a public offering of Doe Run shares, and direct sale to a third party. By yearend 1993, no third-party buyer had been found.

Asarco Inc. operated two mines in southern Missouri that produced more than 90% of the concentrate feed for its nearby Glover, MO, smelter and refinery. Record production of 123,000 metric tons of contained lead was achieved at the mines during 1993, exceeding 1992 production by 16%, according to the company's annual report to stockholders. Refinery production at the Glover facility declined by about 5% to 124,000 tons in 1993, owing to equipment failures early in the year. Asarco's Omaha, NE, refinery, which received the bullion output from its East Helena, MT, custom smelter, produced 73,500 tons of lead in 1993, down 2% from production in 1992, owing to interruptions in deliveries of concentrate from its South American source, the Quiruvilca Mine in Peru. Asarco's East Helena and Omaha processing circuit also was supplied with concentrate from the company's Leadville, CO, mine. At yearend, Asarco reported reserves in

Missouri of 19.7 million tons grading 4.83% lead at Sweetwater and 6.4 million tons grading 5.72% lead at West Fork. *(See table 4.)*

Production from the Magmont Mine at Bixby, MO, a 50-50 joint-venture of Cominco American Inc., the operator, and Dresser Industries Inc., continued to decline in 1993 in preparation for the planned closing of the mine in 1994. According to the Annual Report of the parent company, Cominco Ltd. (Canada), orebody depletion had resulted in a 17% decrease in production from that of 1992 and had reduced the workforce at the mine to a minimum. Prolonged low market prices for lead also had caused the mine to be operated at a net loss for the year. Pillar and sill recovery at the mine accounted for the bulk of the year's production. Fifty percent of the lead concentrate produced was sold in Missouri, with most of the remainder being stockpiled, although a small portion was sold to foreign smelters. In 1993, Magmont milled 631,000 tons of ore grading 7.0% lead, which yielded 56,000 tons of concentrate. Cominco Ltd.'s wholly owned subsidiary, Cominco Alaska Inc., made operational changes in the grinding circuit at its Red Dog Mine, near Kotzebue in northwest Alaska, to improve overall metal production. As a result, annual throughput was increased to about 1.7 million tons in 1993 from 1.44 million tons in 1993, yielding 44,200 tons of lead concentrate in 1993 compared with 25,400 tons in 1992. At yearend, published ore reserves (measured and indicated) at Magmont were 2.5 million tons grading 8.3% lead, and at Red Dog were 56.8 million tons grading 5.5% lead.

In mid-1993, Kennecott Mining Co, announced the indefinite closure of its 54%-owned Greens Creek zinc/lead/silver mine in southeastern Alaska, owing to low prices. During the closure, all operating and environmental permits were to be maintained and mine development work and engineering studies were to continue, pending improvement in prices.

Secondary.—Domestic secondary production in 1993 was estimated to have declined by about 1.5% from a near-record high in 1992. Secondary lead accounted for 73% of domestic lead production in 1993, reflecting a continued high level of lead-acid battery recycling. Battery Council International statistics indicated that the recycling rate for lead-acid batteries was 94.4%, according to data available for 1992.

A significant portion of the decline in secondary production during 1993 was in the recovery of lead by nonbattery recyclers. These recyclers, who mainly produced specialty alloys for such uses as solders, brass or bronze ingots, and bearing metals, continued to experience higher costs and lower profit margins in their operations.

In late 1993, RSR Corp., Dallas, TX, announced plans to build a new $60 million auto and industrial lead-acid battery recycling plant in Aiken County, SC. The facility was to be the first greenfield lead-acid battery recycling operation in the southeastern United States and was to be capable of processing 6 million batteries annually. Company plans called for the facility to have an electric arc furnace, a reverberatory furnace, and a refinery. Desulfurization and crystallization techniques will be used to convert the battery acid into sodium sulfate salts for use in the paper, glass, and detergent production industries. The source of obsolete batteries is expected to come from an 8-state area in the southern United States through existing conversion agreements with battery scrap dealers. By yearend, RSR was awaiting permitting approval from the South Carolina Department of Health and Environmental Control. RSR expected permitting and construction time for the new facility to take from 3 to 5 years.

GNB Battery Technologies Inc., Atlanta, GA, announced in late 1993 that it was suspending indefinitely plans for a proposed greenfield secondary lead smelter in Waynesboro, GA. The decision coincided with a fine that had been levied by EPA on GNB's facility in Columbus, GA. In a subsequent agreement with EPA, the company planned to begin installation of new pollution control equipment at the Columbus facility.

Refined Metals Corp., Longview, TX, closed indefinitely its secondary smelters in Memphis, TN, and Beech Grove, IN, at the beginning of the year. The combined capacity of the two smelter operations was about 50,000 tons per year. *(See table 5.)*

Consumption and Uses

Reported consumption of lead increased by 9% in 1993 compared with that of 1992. This increase was due mainly to a nearly 6% increase in demand for original equipment starting-lighting-ignition (SLI) batteries, and replacement SLI batteries. The latter increase was attributed to abnormally low winter and high summer temperatures. Other increases in demand occurred in the end-use sectors that included ammunition, bearings for electrical and electronic equipment, cable covering for power and communication, sheet lead for medical radiation shielding, and solder for motor vehicles, containers, and electronic components.

The Battery Council International (BCI) reported a 1993 SLI battery production of 86.0 million units, compared with 81.1 million units in 1992 and 77.8 million units in 1991. The total includes both original equipment market (OEM) and replacement market automotive-type batteries. Using the BCI estimate of 20.9 pounds per unit, the SLI offtake for 1993 was about 815,300 tons of lead. SLI batteries include those used for buses and trucks, tractors, marine, golf carts, motorcycles, aircraft, mine equipment, floor care, and military equipment. Lead consumption in lead-acid batteries for uses other than SLI, such as for stationary, industrial, and motive power applications, was 211,000 tons in 1993, compared with 145,000 tons in 1992, and 184,000 tons in 1991. *(See tables 6, 7, 8, 9, and 12, 13, 14, 15.*

World Review

Statistics published by the International

Lead and Zinc Study Group (ILZSG) suggest that world production and consumption of refined lead remained essentially unchanged at approximately 5.4 million tons and 5.1 million tons, respectively, in 1993. As a result of the continued excess production, however, commercial stocks of refined lead reached 0.79 million tons, equivalent to 8 weeks of world consumption, at the end of 1993. This compared with 0.74 million tons, or 7 weeks of consumption, at the end of 1992, and 0.54 million tons, or 5 weeks of consumption, at the end of 1990.[1] Stagnant consumption, coupled with rising commercial stocks, were indicative of the continuing world recession in 1993. Lead prices thus continued to decline through the first half of the year. A modest increase in prices occurred in the last half of the year, but the average annual LME and North American producer prices were down by $0.036 and $0.034 per pound, respectively, compared with prices in 1992.

During 1993, numerous lead producing mines, smelters and refineries either were closed for part of the year or were forced to operate below capacity, owing principally to a drop in demand and declining prices in the early part of the year. In Canada, Cominco Ltd. closed its Trail, British Columbia, smelter for 2 months, and curtailed operations at its Sullivan Mine, also in British Columbia, for about 3 months. Noranda Ltd. implemented a summer shutdown of its Brunswick Mine, in New Brunswick, and indefinite closure of its Heath Steele Mine, also in New Brunswick, subsequently closing its Belledune, New Brunswick, smelter-refinery for 6 weeks. Belledune derived about 80% of its concentrates from these two mines. The Faro and Sa Dena Has Mines, Yukon, operated by Curragh, Ltd., remained closed throughout the year and were placed in control of an interim receiver in September. Canada's Cominco Ltd. and Teck Corp. subsequently agreed to purchase a 50% interest in the Sa Dena Mine, but there were no immediate plans to reopen the mine. Curragh's Faro assets remained in receivership status at the end of the year. French-based Metaleurop closed its refineries at Noyelles-Godault, France, and Nordenheim, Germany for 2 months, and reduced output at its Oker, Germany, secondary lead smelter by nearly 50%. Germany's Metallgesellschaft closed its primary and secondary smelter unit at Stolberg for 3 months because of technical difficulties, but was operating near capacity at yearend. After an extended closure in early 1993, Italy's Porto Vesme primary lead smelter was reopened in October by its operator, Nuovo Samin, a part of ENI, an Italian Government-owned holding company. In a further response to low lead prices and high operating costs, Mexico's Empresa Frisco temporarily closed three of the four mines at its San Francisco de Oro mining and milling complex in Chihuahua State in early 1993. Also in Mexico, Minera Real Des Angeles closed its mine in Zacatecas for 5 months, then reopened at a reduced rate of production in the last quarter of the year. In Sweden, Boliden Mineral reduced production at its primary lead smelter in Ronnskar by about 20%. Boliden also was forced to suspend operations at its Aznalcollar Mine in Spain as a result of a prolonged drought in the southern Iberian Peninsula.

Mine Capacity.—During 1993, a decline in mine capacity resulted from the closure of two Italian mines. In February, Italy's ENI announced the closing of its Monteponi/Masua Mines in Sardinia. Production at these mines totaled about 16,000 tons of lead in concentrate in 1992.

Counter to these closings, Japan's Nippon Mining and Metals announced in late 1993 that the proposed Japanese-Australian project for development of the McArthur River zinc-lead property in Australia's Northern Territory was set to proceed. Planned production capacity was to be about 45,000 tons of lead in concentrate annually, with startup expected to occur in 1995. *(See table 10.)*

Metal Capacity.—Industrial Minera Mexico SA closed its 60,000-ton-per-year capacity primary lead refinery in Monterrey at the end of 1993. Reasons cited for the permanent closing of the facility were environmental pressures, diminishing raw material supplies, low lead prices, and the age of the facility.

In Japan, partners in the proposed Hachinohe lead-zinc smelter announced postponement of construction because of low prices and other economic factors. This Imperial Smelting Process plant had been scheduled to begin operation in late 1994 with a production capacity of 60,000 tons of lead annually. Feed material for the operation was to be derived from a variety of concentrate and scrap sources. *(See table 11.)*

Reserves.—Worldwide reserves of lead contained in demonstrated resources from both producing and nonproducing deposits believed to be economically viable at yearend were estimated at 63 million tons by the U.S. Bureau of Mines. Reserves for the two largest producers in the Western world, Australia and the United States, were about 10 million tons each. Canada, the fifth largest producer in the world in 1993, had reserves of 6 million tons. China, the second leading producer in 1993, had reserves of 7 million tons. The reserve base (reserves plus marginal economic deposits, measured and indicated) for Australia and the United States was 35 million tons and 22 million tons, respectively. In Canada, the reserve base was 13 million tons and in China, 11 million tons. Total world reserve base at the end of 1993 was estimated to be 130 million tons.

Current Research

According to information provided by the International Lead-Zinc Research Organization (ILZRO), Research Triangle Park, NC, lead-acid batteries appear to have a clear edge to become the main energy source for electric vehicles now under development by the three major domestic car makers. The development of these vehicles is in response to State legislation aimed at lowering air pollution resulting from existing vehicles powered by internal combustion engines. Factors such as cost considerations, the availability of battery components, and already established distribution and recycling procedures for lead in batteries, give lead-acid batteries an advantage over other more recently developed batteries. These include batteries such as nickel hydride, sodium sulfur, zinc air, and zinc bromine. California has emerged as the most aggressive State in the legislative drive to reach zero emissions, and has stipulated that 2% of total car sales in the State be pollution-free vehicles by 1998, increasing to 12% of total car sales by 2001.

The U.S. Naval Facilities Engineering Service Center, Port Hueneme, CA, and the U.S. Bureau of Mines (USBM) Salt Lake City, UT, Research Laboratory began collaborating on an effort to remove the lead hazard resulting from accumulation of spent bullets on military firing ranges. More than 300 such Navy and Marine Corps ranges exist where the soil is contaminated with lead in bullet fragments, down to ultrafine particle size. To remove this lead, USBM scientists have employed an approach that combines two basic mineral-processing procedures. First, gravity separation of the larger lead fragments and particles captures up to 99% of the lead in the soil. Next, leaching with acetic acid dissolves the remaining lead, leaving the soil suitable for reuse. By yearend, the U.S. Navy was focusing initially on a few of its most contaminated ranges as candidates for this cleanup process.

OUTLOOK

While overall economic growth was somewhat slower than anticipated in 1993, those sectors of the economy that were of particular importance to the demand for lead remained strong and were expected to continue as such in 1994. Specifically, although overall personal consumption was anticipated to increase by about 3% in 1994, consumption of durable goods, such as automobiles and appliances, was projected to rise nearly 7% in 1994. Total vehicle production in the United States rose by more than 10% to about 10.8 million units in 1993, and was forecast to increase by 5% in 1994. An anticipated growth of 4% in residential construction during 1994 also was expected to increase the demand for lead.

It was anticipated that the U.S. lead market would tighten during 1994 as consumption was expected to rise by about 8% compared with 1993, while mine production should remain static and total metal production from primary and secondary sources should increase by only 6%. The tightening physical market was forecast to continue pushing prices higher on both the U.S. and European markets during 1994. Contributing to the tightening market would be factors such as the strengthening demand in all regional markets, declining exports from Eastern bloc countries, and decreasing producer stocks in the Western world. Although secondary production of lead was expected to increase in 1994, as higher prices encourage more recycling, this was expected to be more than offset by a decline in primary production and total refined lead production in the world.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Other Sources

ABMS Non-Ferrous Metal Data.
American Metal Market (daily paper).
Engineering and Mining Journal.
International Lead and Zinc Study Group (ILZSG), special reports.
International Lead-Zinc Research Organization (ILZRO).
Lead Industries Association, Inc.
Metal Bulletin (London).
Metals Week.

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[1] International Lead and Zinc Study Group (London). Lead and Zinc Statistics. Monthly Bull., v. 34, No. 10, Oct. 1994.

TABLE 1
SALIENT LEAD STATISTICS

(Metric tons unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Production:						
Domestic ores, recoverable lead content		410,915	483,704	465,931	[r]397,076	355,185
Value	thousands	$356,476	$490,771	$343,948	[r]$307,337	$248,540
Primary lead (refined):						
From domestic ores and base bullion		379,034	385,637	323,851	283,988	310,072
From foreign ores and base bullion		17,421	18,020	21,863	20,803	24,942
Secondary lead (lead content)		891,341	922,197	884,624	[r]916,341	903,560
Exports (lead content):						
Lead ore and concentrates		57,038	56,600	87,953	72,323	41,766
Lead materials, excluding scrap		43,837	76,749	113,872	71,733	60,312
Imports for consumption:						
Lead in ore and concentrates		5,122	10,668	12,437	5,310	483
Lead in base bullion		5,782	2,713	419	218	18
Lead in pigs, bars, and reclaimed scrap		116,358	90,919	116,590	190,959	195,662
Stocks, Dec. 31:						
Primary lead[1]		15,623	25,525	9,089	20,543	14,289
At consumers and secondary smelters		82,356	86,340	71,685	[r]82,338	80,831
Consumption of metal, primary and secondary		1,277,604	1,275,226	1,246,344	[r]1,240,720	1,357,127
Price: Metals Week average, delivered, cents per pound		39.35	46.02	33.48	35.10	31.74
World:						
Production:						
Mine	thousand metric tons	[r]3,286.7	[r]3,352.2	[r]3,314.0	[r]3,109.4	2,926.3
Refinery[2]	do.	[r]3,240.2	[r]3,094.2	[r]3,094.7	[r]3,040.7	2,993.1
Secondary refinery	do.	[r]2,836.9	[r]2,813.0	[r]2,685.7	[r]2,475.9	2,426.7
Price: London Metal Exchange, pure lead, cash average, cents per pound		30.63	37.05	25.30	24.50	18.42

[e]Estimated. [r]Revised.

[1] American Bureau of Metal Statistics Inc.

[2] Primary metal production only; includes secondary metal production, where inseparable.

TABLE 2
MINE PRODUCTION OF RECOVERABLE LEAD IN THE UNITED STATES, BY STATE

(Metric tons)

State	1989	1990	1991	1992	1993
Missouri	366,931	380,781	351,995	r299,741	277,427
Montana	W	W	W	W	W
Nevada	—	830	W	—	—
New Mexico	W	W	193	W	—
South Dakota	4	—	—	—	—
Total[1]	410,915	483,704	465,931	r397,076	355,185

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

[1] Includes, for at least some of the years 1989-93, Alaska, Arizona, Colorado, Idaho, Illinois, Kentucky, New York, Tennessee, and Washington.

TABLE 3
LEADING LEAD-PRODUCING MINES IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of lead
1	Sweetwater	Reynolds, MO	ASARCO Incorporated	Lead ore.
2	West Fork	do.	do.	Lead-zinc ore.
3	Fletcher	do.	The Doe Run Co.	Lead ore.
4	Magmont	Iron, MO	Cominco American Inc.	Do.
5	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
6	Casteel[1]	Iron, MO	The Doe Run Co.	Lead ore.
7	Buick	do.	do.	Lead-zinc ore.
8	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Do.
9	Viburnum No. 29	Washington, MO	The Doe Run Co.	Lead ore.
10	Montana Tunnels	Jefferson, MT	Pegasus Gold Corp.	Zinc ore.
11	Leadville Unit	Lake, CO	ASARCO Incorporated	Do.
12	Greens Creek	Southeastern Alaska, AK	Kennecott Greens Creek Mining Co.	Do.
13	Balmat	St. Lawrence, NY	Zinc Corporation of America	Do.
14	Rosiclare	Hardin, IL	Ozark-Mahoning Co.	Fluorspar.
15	Van Stone	Stevens, WA	Equinox Resources	Zinc ore.
16	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Do.
17	Franklin 73	Clear Creek, CO	Franklin Consolidated Mines Inc.	Gold ore.
18	Coy	Jefferson, TN	ASARCO Incorporated	Zinc ore.

[1] Includes Brushy Creek Mill.

TABLE 4
REFINED LEAD PRODUCED AT PRIMARY REFINERIES IN THE UNITED STATES, BY SOURCE MATERIAL[1]

(Metric tons unless otherwise specified)

Source material		1989	1990	1991	1992	1993
Refined lead:						
Domestic ores and base bullion		379,034	385,637	323,851	283,988	310,072
Foreign ores and base bullion		17,421	18,020	21,863	20,803	24,942
Total		396,455	403,657	345,714	304,791	335,014
Calculated value of primary refined lead[2]	thousands	$343,932	$409,537	$255,174	$235,854	$234,425

[1] Total refined lead: American Bureau of Metal Statistics Inc.; domestic and foreign ores: U.S. Bureau of Mines calculations.

[2] Value based on average quoted price.

TABLE 5
LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

		1992	1993
KIND OF SCRAP			
New scrap:			
Lead-base		48,274	52,295
Copper-base		[r]7,147	[e]8,000
Tin-base		3	3
Total		[r]55,424	60,298
Old scrap:			
Battery-lead		[r]784,255	798,176
All other lead-base		68,051	37,086
Copper-base		[r]8,611	[e]8,000
Tin-base		—	—
Total		[r]860,917	843,262
Grand total		[r]916,341	903,560
FORM OF RECOVERY			
As soft lead		452,920	425,572
In antimonial lead		424,535	444,954
In other lead alloys		[r]23,125	17,031
In copper-base alloys		[r]15,758	[e]16,000
In tin-base alloys		3	3
Total		[r]916,341	903,560
Value[1]	thousands	[r]$709,084	$632,263

[e] Estimated. [r] Revised.

[1] Value based on average quoted price of common lead.

TABLE 6

U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1992	1993
	Metal products:		
3482	Ammunition: Shot and bullets	64,845	65,095
	Bearing metals:		
35	Machinery except electrical	W	W
36	Electrical and electronic equipment	310	425
371	Motor vehicles and equipment	[1]3,622	[1]3,508
37	Other transportation equipment	W	W
	Total bearing metals	4,785	4,829
3351	Brass and bronze: Billets and ingots	9,175	8,664
36	Cable covering: Power and communication	15,992	17,165
15	Calking lead: Building construction	1,045	961
	Casting metals:		
36	Electrical machinery and equipment	W	W
371	Motor vehicles and equipment	W	W
37	Other transportation equipment	2,884	2,457
3443	Nuclear radiation shielding	W	W
	Total casting metals	17,111	18,458
	Pipes, traps, other extruded products:		
15	Building construction	11,652	5,742
3443	Storage tanks, process vessels, etc.	(2)	(2)
	Total pipes, traps, other extruded products	11,652	5,742
	Sheet lead:		
15	Building construction	16,233	15,166
3443	Storage tanks, process vessels, etc.	(2)	(2)
3693	Medical radiation shielding	4,773	6,034
	Total sheet lead	21,006	21,200
	Solder:		
15	Building construction	3,449	3,285
	Motor vehicles, equipment, metal cans and shipping containers	4,118	4,974
367	Electronic components and accessories	4,539	4,890
36	Other electrical machinery and equipment	1,412	1,240
	Total solder	13,518	14,389
	Storage batteries:		
3691	Storage battery grids, post, etc.	[r]629,147	697,222
3691	Storage battery oxides	373,185	422,636
	Total storage batteries	[r]1,002,332	1,119,858
371	Terne metal: Motor vehicles and equipment	(3)	(3)
27	Type metal: Printing and allied industries	(4)	(4)
34	Other metal products[5]	3,024	5,363
	Total metal products	[r][6]1,164,486	1,281,724
	Other oxides:		
285	Paint	W	W
32	Glass and ceramics products	W	W
28	Other pigments and chemicals	9,922	9,874
	Total other oxides	63,225	63,581

See footnotes at end of table.

TABLE 6—Continued

U.S. CONSUMPTION OF LEAD, BY PRODUCT

(Metric tons)

SIC Code	Product	1992	1993
	Miscellaneous uses	13,009	11,822
	Grand total	[r]1,240,720	1,357,127

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in appropriate totals.

[1] Includes "Terne metal: Motor vehicles and equipment."

[2] Included with "Building construction" to avoid disclosing company proprietary data.

[3] Included with "Bearing metals: Motor vehicles and equipment."

[4] Included with "Other metal products" to avoid disclosing company proprietary data.

[5] Includes lead consumed in foil, collapsible tubes, annealing, galvanizing, plating, and fishing weights.

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

TABLE 7

U.S. CONSUMPTION OF LEAD IN 1993, BY STATE[1]

(Metric tons)

State	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total[2]
California, Oregon, Washington	58,311	34,794	10,762	—	103,867
Florida and Georgia	34,983	11,669	2,484	—	49,136
Illinois	27,477	39,267	6,776	597	74,117
Iowa, Michigan, Missouri	58,287	39,531	11,568	—	109,386
Ohio and Pennsylvania	128,788	73,145	47,690	2,209	251,832
Arkansas and Texas	92,430	33,974	15,116	—	141,520
Alabama, Louisiana, Mississippi, Oklahoma	22,735	7,659	19,192	1,249	50,835
Colorado, Indiana, Kansas, Kentucky, Minnesota, Nebraska, Tennessee, Wisconsin	268,421	75,366	44,913	1,217	389,917
Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, South Carolina, Vermont	101,062	54,883	30,305	267	186,517
Total[2]	792,495	370,286	188,807	5,539	1,357,127

[1] Includes lead that went directly from scrap to fabricated products.

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

TABLE 8
U.S. CONSUMPTION OF LEAD IN 1993, 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	63,633	71,234	21,459	5,539	161,865
Storage batteries	656,476	298,183	165,199	—	1,119,858
Other oxides	63,581	W	—	—	63,581
Miscellaneous	8,805	869	2,148	—	11,822
Total[2]	792,495	370,286	188,807	5,539	1,357,127

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

[1] Includes lead that went directly from scrap to fabricated products.

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

TABLE 9
STOCKS OF LEAD AT CONSUMERS AND SECONDARY SMELTERS IN THE UNITED STATES, DECEMBER 31

(Metric tons, lead content)

Year	Refined soft lead	Lead in antimonial lead	Lead in alloys	Lead in copper-base scrap	Total[1]
1989	48,592	28,960	4,564	239	82,356
1990	46,478	34,512	5,132	219	86,340
1991	33,230	33,599	4,664	191	71,685
1992	[r]38,571	[r]37,599	[r]6,006	162	[r]82,338
1993	37,904	35,687	7,120	120	80,831

[r] Revised.

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

TABLE 10
LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993e
Algeriae	1.4	1.1	0.9	0.9	0.9
Argentina	26.7	23.4	23.7	r e18.0	18.5
Australia	495.0	r570.0	r579.0	r572.0	505.0
Austria	1.6	1.5	r1.2	r.9	.6
Bolivia	15.7	19.9	20.8	r20.0	21.3
Bosnia and Herzegovina	—	—	—	r e2.0	.4
Brazil	14.0	9.3	7.3	e7.5	7.5
Bulgariae	[3]57.0	57.0	43.6	r39.0	39.0
Burmae	[3]5.2	4.4	4.7	4.8	3.0
Canada	r276.1	r241.3	r276.5	r343.8	[3]183.7
Chile	1.2	1.1	1.1	r.3	.3
Chinae	308.0	r315.0	r352.0	r330.2	405.0
Colombia	.4	.3	r.6	e.4	.4
Czech Republic[4]	—	—	—	—	1.0
Czechoslovakiae [5]	2.7	3.0	r3.4	r2.8	—
Ecuadore	.2	.2	.2	.2	.2
Finland	2.6	e1.7	e1.3	r.6	.5
France	1.1	1.2	1.7	—	—
Georgia	—	—	—	r e.8	.5
Germany: Western states	7.4	7.1	r5.9	r1.5	—
Greece	r24.5	r26.2	r31.7	r28.3	28.0
Greenland	24.1	16.0	—	—	—
Honduras	9.6	5.8	8.7	r e9.0	8.5
India	r24.3	r23.2	25.1	e25.0	40.0
Irane [6]	13.0	11.0	16.0	r25.0	25.0
Ireland	e32.1	35.3	39.9	r42.9	48.4
Italy	17.5	16.0	14.2	r e16.0	18.0
Japan	18.6	18.7	18.3	18.8	16.5
Kazakhstan	—	—	—	r e170.0	160.0
Korea, Northe	80.0	80.0	80.0	75.0	80.0
Korea, Republic of	16.5	14.9	12.6	r13.6	13.0
Macedonia	—	—	—	r e15.0	15.0
Mexico	r e170.0	r187.1	r167.7	r169.6	[3]158.2
Morocco	67.3	68.8	73.7	r76.6	76.0
Namibiae	[3]23.7	18.0	15.0	15.0	15.0
Nigeriae	—	.1	.1	.1	.1
Norway	3.2	3.0	3.5	3.8	3.7
Peru	192.2	187.8	199.8	r194.2	194.2
Poland	r65.8	61.3	r63.6	r63.0	63.0
Romania	r37.7	r24.7	r16.2	r16.8	16.8
Russia	—	—	—	r e40.0	50.0
Saudi Arabiae	.2	.3	.3	.3	.3
Serbia and Montenegro	—	—	—	r20.0	20.0
Slovakia[4]	—	—	—	—	1.8
Slovenia	—	—	—	r e2.0	—
South Africa, Republic of	78.2	69.4	76.3	r75.8	99.0
Spain	62.8	58.5	r e46.0	r47.0	26.2

See footnotes at end of table.

TABLE 10—Continued

LEAD: WORLD MINE PRODUCTION OF LEAD IN CONCENTRATES, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Sweden	89.0	98.3	91.1	106.2	[3]113.1
Tajikistan	—	—	—	[e]2.0	1.6
Thailand	25.1	22.2	16.7	[r]27.9	27.0
Tunisia	2.7	3.0	1.3	[r]1.4	1.3
Turkey	[r]14.1	[r]18.4	[r]15.3	[r]10.8	11.0
U.S.S.R.[7]	440.0	420.0	380.0	—	—
United Kingdom	2.2	1.4	1.0	[r] [e]1.0	.5
United States	420.2	496.5	476.9	[r]406.6	[3]362.4
Uzbekistan	—	—	—	[r] [e]40.0	40.0
Yugoslavia[8]	107.0	99.1	[e]90.0	—	—
Zambia[9]	8.8	9.6	9.1	[r] [e]5.0	5.0
Total[10]	[r]3,286.7	[r]3,352.2	[r]3,314.0	[r]3,109.4	2,926.3

[e] Estimated. [r] Revised.

[1] Table includes data available through Aug. 4, 1994.

[2] In addition to the countries listed, Uganda may produce lead, but available information is inadequate to make reliable estimates of output levels.

[3] Reported figure.

[4] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved Dec. 31, 1992. Production from 1989-92 came from the Czech Republic and Slovakia.

[6] Year beginning Mar. 21 of that stated.

[7] Dissolved in Dec. 1991.

[8] Dissolved in Apr. 1992.

[9] Pb content of ore milled in year beginning Apr. 1 of that stated.

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

TABLE 11
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993^{e}
Algeria:^{e}					
Primary	1.3	1.0	1.0	1.0	1.0
Secondary	1.4	3.5	3.5	3.5	4.0
Total	2.7	4.5	4.5	4.5	5.0
Argentina:					
Primary	^{r}13.7	$^{r\ e}$10.0	$^{r\ e}$10.0	^{r}14.6	15.0
Secondary	^{e}13.0	^{r}13.4	^{r}13.7	$^{r\ e}$15.0	14.5
Total^{e}	^{r}26.7	^{r}23.4	^{r}23.7	^{r}29.6	29.5
Australia:					
Primary	^{r}190.0	212.0	220.0	^{r}215.0	217.0
Secondary	^{r}15.0	^{r}17.0	^{r}19.0	^{r}17.0	17.0
Total	^{r}205.0	^{r}229.0	^{r}239.0	^{r}232.0	234.0
Austria:					
Primary^{e}	10.0	8.4	6.4	^{r}5.7	2.0
Secondary^{e}	12.0	15.1	16.3	^{r}18.2	13.0
Total	22.0	23.5	22.7	23.9	15.0
Belgium:					
Primary	72.7	^{r}68.8	78.1	^{r}75.3	79.0
Secondary	36.8	^{r}37.0	32.6	^{r}41.0	43.0
Total[2]	109.4	^{r}105.8	110.7	^{r}116.3	122.0
Bolivia: Primary	^{r}—	^{r}—	^{r}—	^{r}—	—
Brazil:					
Primary	32.5	30.1	22.0	$^{r\ e}$25.0	25.0
Secondary	53.3	45.3	42.0	^{e}42.0	42.0
Total	85.8	75.4	64.0	$^{r\ e}$67.0	67.0
Bulgaria:					
Primary^{e}	89.0	56.0	46.0	45.0	45.0
Secondary^{e}	12.5	10.6	^{r}10.2	10.0	10.0
Total	101.5	66.6	^{r}56.2	^{e}55.0	55.0
Burma: Primary	3.4	^{r}2.8	2.2	$^{r\ e}$2.1	14.0
Canada:					
Primary	157.3	87.2	106.4	^{r}255.2	^{3}232.0
Secondary	85.5	96.5	^{r}105.9	103.9	^{3}104.0
Total[2]	242.8	183.6	212.4	^{r}359.1	^{3}336.0
China:^{e}					
Primary	^{r}230.0	^{r}266.0	^{r}290.0	^{r}325.0	347.4
Secondary	^{r}30.0	^{r}30.0	^{r}40.0	^{r}40.0	40.0
Total	^{r}260.0	296.0	330.0	^{r}365.0	387.4
Colombia: Secondary^{e}	3.5	3.5	^{r}3.6	3.6	3.6
Czech Republic:[4] Secondary	—	—	—	—	20.0
Czechoslovakia:[5] Secondary	26.0	23.7	17.8	^{r}24.0	—
France:					
Primary	149.3	162.3	154.5	^{e}160.5	158.0
Secondary	^{r}278.3	^{r}270.5	$^{r\ e}$283.5	$^{r\ e}$284.1	280.0
Total[2]	^{r}427.6	^{r}432.7	^{r}438.0	^{r}444.6	438.0

See footnotes at end of table.

TABLE 11—Continued
LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Germany:					
Primary:					
Eastern states[e]	14.0	15.8	—	—	—
Western states	[r]170.2	[r]162.1	—	—	—
Total primary	[r][e]184.2	[r][e]177.9	[r]171.2	[r]175.3	[3]129.8
Secondary:					
Eastern states	[r]—	[r]—	—	—	—
Western states	[r]179.7	186.7	—	—	—
Total secondary	[r]179.7	[r]186.7	201.7	[r]179.0	[3]204.7
Total	[r]363.9	[r]364.6	372.9	[r]354.3	[3]334.5
Greece:					
Primary	5.6	—	—	—	—
Secondary	1.4	—	—	—	—
Total	7.0	—	—	—	—
Guatemala: Secondary	[r].2	[r].1	([6])	([6])	.1
Hungary: Secondary[e]	.1	.1	.1	.1	.1
India:					
Primary	21.3	29.9	[e]33.1	[e]30.0	20.0
Secondary	13.5	16.8	[e]20.3	[e]20.0	13.0
Total[2]	34.7	46.7	[e]53.4	[e]50.0	33.0
Iran: Secondary[e]	9.0	10.0	[r]8.0	[r]7.8	8.0
Ireland: Secondary	[e]12.0	[r][e]15.0	[r]11.6	12.0	12.0
Italy:					
Primary	74.2	[r]64.6	[r]111.7	[r]102.0	109.0
Secondary	112.0	[r]102.2	96.5	[r]84.3	88.0
Total	186.2	[r]166.8	[r]208.2	[r]186.3	197.0
Jamaica: Secondary[e]	1.0	1.0	1.0	1.0	.8
Japan:					
Primary	207.7	204.9	220.3	218.8	171.0
Secondary	124.6	122.3	112.1	111.4	87.0
Total[2]	332.4	327.2	332.4	330.2	258.0
Kazakhstan:					
Primary	—	—	—	[r][e]180.0	170.0
Secondary	—	—	—	[r][e][7]30.0	[7]25.0
Total	—	—	—	[r][e]210.0	195.0
Korea, North:[e]					
Primary	70.0	70.0	75.0	70.0	75.0
Secondary	5.0	6.0	5.0	5.0	5.0
Total	75.0	76.0	80.0	75.0	80.0
Korea, Republic of:[e]					
Primary	60.0	61.0	40.0	60.0	60.0
Secondary	20.9	14.0	40.0	30.0	25.0
Total	80.9	75.0	80.0	90.0	85.0

See footnotes at end of table.

TABLE 11—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Macedonia:					
Primary	—	—	—	[r] [e]6.0	6.0
Secondary	—	—	—	[r] [e]2.0	2.0
Total	—	—	—	[r] [e]8.0	8.0
Malaysia: Secondary[e]	16.0	16.0	16.0	16.0	16.0
Mexico:					
Primary	160.0	167.2	151.8	[r]162.6	[3]178.4
Secondary[e]	[r]75.0	[r]65.0	[r]10.0	[r]10.0	10.0
Total[e]	[r]235.0	[r]232.2	[r]161.8	[r]172.6	188.4
Morocco:[e]					
Primary	63.0	64.0	70.0	[r]68.0	66.0
Secondary	2.0	2.0	2.0	2.0	2.0
Total	65.0	66.0	72.0	[r]70.0	68.0
Namibia: Primary	44.2	35.1	33.4	31.7	[2]31.2
Netherlands: Secondary	41.5	44.1	[r]33.7	[r]23.5	24.2
New Zealand: Secondary[e]	5.0	5.0	5.0	5.0	5.0
Pakistan: Secondary[e]	2.0	2.5	2.5	[r]3.0	3.0
Peru:					
Primary	73.4	69.3	[r]74.5	82.5	82.5
Secondary[e]	5.0	5.0	5.0	5.0	5.0
Total[e]	78.4	74.3	[r]79.5	87.5	87.5
Philippines: Secondary	13.6	12.1	17.5	[e]16.8	17.0
Poland:					
Primary[e]	63.2	49.8	35.8	[r]38.7	52.4
Secondary[e]	15.0	15.0	15.0	15.0	15.0
Total	78.2	64.8	50.8	[r]53.7	67.4
Portugal: Secondary[e]	[r] [e]7.0	[r]6.0	5.0	[r]4.0	4.0
Romania:					
Primary	24.9	[r]15.7	[r]13.2	[r]14.4	14.0
Secondary	[r]16.2	[r] [e]5.0	[r] [e]4.0	[r]1.8	1.5
Total	[r]41.1	[r] [e]20.7	[r] [e]17.2	[r]16.2	15.5
Russia:					
Primary	—	—	—	[r] [e]35.0	40.0
Secondary	—	—	—	[e]40.0	30.0
Total	—	—	—	[r] [e]75.0	70.0
Serbia and Montenegro:					
Primary	—	—	—	[r] [e]18.0	15.0
Secondary	—	—	—	[e]5.0	5.0
Total	—	—	—	[r] [e]23.0	20.0
Slovenia:					
Primary	—	—	—	[r] [e]1.0	1.0
Secondary	—	—	—	[e]3.0	3.0
Total	—	—	—	[r] [e]4.0	4.0
South Africa, Republic of: Secondary	36.9	31.2	[r]30.5	[r]29.0	32.0
Spain:					
Primary[e]	[3]62.0	60.0	[r]110.0	[r]62.0	54.0
Secondary	[r]52.5	50.0	[r] [e]59.0	[r] [e]58.0	56.0
Total[e]	[r] [3]114.5	110.0	[r]169.0	[r]120.0	110.0

See footnotes at end of table.

TABLE 11—Continued

LEAD: WORLD REFINERY PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Sweden:					
Primary	48.7	[r]47.5	49.2	46.8	46.8
Secondary	22.7	[r]22.1	38.8	44.3	37.7
Total	71.4	[r]69.6	88.0	91.1	84.5
Switzerland: Secondary	1.5	5.7	[r]5.0	6.4	6.5
Taiwan: Secondary[e]	58.2	57.6	[r]20.0	[r]—	—
Thailand: Secondary	18.7	15.9	12.8	[r]18.9	18.5
Trinidad and Tobago: Secondary[e]	1.8	1.8	1.8	1.8	1.7
Tunisia:[e]					
Primary	2.2	2.2	.8	[r].9	.9
Secondary	.5	.5	[r].3	[r].3	.3
Total[2]	2.7	2.7	1.0	[r]1.2	1.2
Turkey:[e]					
Primary	4.6	5.4	5.4	6.0	3.0
Secondary	2.4	3.6	3.1	[r]3.0	2.0
Total	7.0	9.0	8.5	[r]9.0	5.0
U.S.S.R.:[e] [8]					
Primary	465.0	420.0	380.0	—	—
Secondary	280.0	280.0	250.0	—	—
Total	745.0	700.0	630.0	—	—
United Kingdom:					
Primary	[r]157.0	[r]155.9	164.3	198.8	194.0
Secondary	[r] [e]193.5	[r]173.5	146.7	148.0	151.0
Total	[r] [e]350.5	[r]329.4	311.0	346.8	345.0
United States:					
Primary	396.5	403.7	345.7	304.8	335.0
Secondary	891.3	[r]922.2	[r]884.6	[r]916.3	903.6
Total	1,287.8	[r]1,325.9	[r]1,230.3	[r]1,221.1	1,238.6
Venezuela: Secondary[e]	[r]14.0	[r]14.0	[r]15.0	[r]15.0	15.0
Yugoslavia:[9]					
Primary	99.6	82.0	[e]70.0	—	—
Secondary[e]	18.0	17.0	18.0	—	—
Total[e]	117.6	99.0	88.0	—	—
Zambia: Primary[10]	3.7	3.7	[r]2.6	3.0	2.6
Grand total[2]	[r]6,077.2	[r]5,907.2	[r]5,780.4	[r]5,516.5	5,419.8
Of which:					
Primary[2]	[r]3,240.2	[r]3,094.2	[r]3,094.7	[r]3,040.7	2,993.1
Secondary[2]	[r]2,836.9	[r]2,813.0	[r]2,685.7	[r]2,475.9	2,426.7

[e] Estimated. [r] Revised.

[1] Table includes data available through Aug. 4, 1994. 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] Data may not add to totals shown because of independent rounding.

[3] Reported figure.

[4] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from the Czech Republic.

[6] Less than 1/2 unit.

[7] Estimate based on a distribution of estimated secondary production in the former U.S.S.R.

[8] Dissolved in Dec. 1991.

[9] Dissolved in Apr. 1992.

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

TABLE 12
PRODUCTION AND SHIPMENTS OF LEAD PIGMENTS[1] AND OXIDES IN THE UNITED STATES

(Metric tons unless otherwise specified)

Product	1992				1993			
	Production		Shipments		Production		Shipments	
	Gross weight	Lead content	Quantity	Value[2]	Gross weight	Lead content	Quantity	Value[2]
White lead, dry	W	W	W	W	W	W	W	W
Litharge and red lead	75,895	70,355	70,569	$56,715,831	74,196	68,775	70,380	$56,559,132
Leady oxide	280,899	266,854	NA	NA	291,471	276,897	NA	NA
Total	356,794	337,209	NA	NA	365,667	345,672	NA	NA

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

[1] Excludes basic lead sulfate; withheld to avoid disclosing company proprietary data.

[2] At plant, exclusive of container.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF LEAD PIGMENTS AND COMPOUNDS, BY KIND

Kind	Quantity (metric tons)	Value (thousands)
1992		
White lead carbonate	88	$146
Red and orange lead	154	292
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,685	10,789
Litharge	17,119	10,919
Leady litharge	423	324
Glass frits (undifferentiated)	7,769	13,726
Total[1]	30,239	36,197
1993		
White lead carbonate	69	116
Red and orange lead	57	186
Chrome yellow and molybdenum orange pigments and lead-zinc chromates	4,541	10,798
Litharge	18,636	9,279
Leady litharge	508	333
Glass frits (undifferentiated)	7,082	12,928
Total[1]	30,892	33,640

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

Source: Bureau of the Census.

TABLE 14
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates (lead content):				
Australia	—	—	31	$10
Belgium	24,327	$8,110	14,314	1,135
Canada	4,692	3,134	6,115	3,542
Germany	16,799	4,082	—	—
Haiti	—	—	50	13
Italy	5,727	1,002	16,356	2,634
Japan	—	—	4,377	206
Korea, Republic of	1,078	810	457	263
Mexico	2,139	631	38	12
Morocco	3,451	567	—	—
Russia	5,129	1,334	—	—
Ukraine	8,981	2,532	—	—
Other	—	—	27	24
Total[1]	72,323	22,202	41,766	7,839
Ash and residues (lead content):				
Belgium	1,925	857	1,403	368
Canada	^{r}20	^{r}86	249	913
India	—	—	31	6
United Arab Emirates	180	74	—	—
Other	16	14	45	39
Total	2,141	1,031	1,728	1,326
Unwrought lead and lead alloys (lead content):				
Australia	38	35	—	—
Belgium	100	217	252	350
Brazil	49	108	3	17
Canada	5,865	4,221	4,634	2,671
Chile	454	450	3,363	8,290
Egypt	46	250	—	—
Germany	54	285	17	23
Hong Kong	224	182	8	110
Indonesia	3,506	2,022	4,025	1,717
Israel	1,617	1,044	481	349
Japan	7,292	4,305	4,864	2,397
Korea, Republic of	28,672	20,054	18,749	8,655
Malaysia	3,208	2,026	1,658	706
Mexico	225	182	164	214
Netherlands	48	57	30	26
New Zealand	45	35	—	—
Philippines	27	70	13	59
Saudi Arabia	49	50	39	18
Singapore	365	263	15	508
Taiwan	12,264	7,939	13,052	5,962

See footnotes at end of table.

TABLE 14—Continued

U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought lead and lead alloys (lead content)—Continued:				
Thailand	97	$592	—	—
Other	[r]95	[r]239	74	$169
Total[1]	64,340	44,624	51,443	32,240
Wrought lead and lead alloys (lead content):				
Australia	47	215	68	366
Canada	1,176	2,861	1,311	3,364
China	135	263	5	26
Costa Rica	—	—	97	211
France	26	718	9	486
Germany	62	180	189	223
Guyana	75	146	—	—
Haiti	46	269	43	139
Hong Kong	461	1,188	1,098	2,744
India	3	3	26	34
Indonesia	33	26	14	45
Japan	209	745	188	617
Korea, Republic of	147	821	974	934
Malaysia	11	274	235	573
Mali	—	—	77	611
Mexico	1,485	7,198	1,147	4,570
Netherlands	131	373	121	356
New Zealand	59	176	79	131
Niger	—	—	104	99
Nigeria	375	442	1	4
Panama	41	30	1	7
Peru	—	—	72	106
Philippines	36	160	12	34
Poland	—	—	52	202
Saudi Arabia	69	116	12	39
Singapore	56	247	15	98
Taiwan	155	1,560	729	2,026
Trinidad and Tobago	41	45	—	—
United Arab Emirates	152	705	3	25
United Kingdom	17	135	206	479
Venezuela	70	109	15	62
Other	[r]134	[r]633	237	1,090
Total[2]	5,251	19,637	7,141	19,703
Grand total[2]	144,056	87,494	102,078	61,108
Scrap (gross weight):				
Antigua and Barbuda	39	14	1	20
Austria	26	6	2	31
Bahamas, The	23	68	119	54
Belgium	135	384	30	3

See footnotes at end of table.

TABLE 14—Continued
U.S. EXPORTS OF LEAD, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Scrap (gross weight)—Continued:				
Brazil	2,392	417	4,679	643
Canada	48,771	8,386	38,683	6,838
China	820	500	1,549	372
Colombia	471	105	452	84
Costa Rica	—	—	30	24
Dominican Republic	26	60	(2)	4
France	168	69	14	3
Germany	269	117	105	35
Ghana	174	38	—	—
Hong Kong	109	37	656	323
India	1,379	292	970	237
Indonesia	126	20	—	—
Ireland	192	74	—	—
Israel	59	10	(2)	5
Japan	111	461	520	511
Korea, Republic of	1,457	949	2,682	3,000
Malaysia	68	36	134	59
Mexico	2,381	833	2,034	1,008
Netherlands	30	27	21	32
Philippines	1,337	74	107	42
Spain	314	42	26	15
Taiwan	572	584	522	149
Thailand	104	571	189	23
United Arab Emirates	—	—	39	4
United Kingdom	648	482	457	219
Venezuela	921	160	4	80
Other	[r]91	[r]350	76	613
Total[1]	63,212	15,165	54,101	14,431

[r] Revised.

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

[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1991 Quantity (metric tons)	1991 Value (thousands)	1992 Quantity (metric tons)	1992 Value (thousands)	1993 Quantity (metric tons)	1993 Value (thousands)
Ore and concentrates (lead content):[1]						
Canada	4,961	$1,384	370	$125	—	—
Germany	254	101	—	—	—	—
Honduras	(2)	9	639	156	—	—
Mexico	7,177	2,910	1,969	2,062	464	$345
Peru	—	—	2,332	1,079	19	2
Switzerland	45	62	—	—	—	—
Total	12,437	4,466	5,310	3,422	483	347
Base bullion (lead content):						
Canada	19	11	58	31	13	49
China	17	7	150	54	—	—
Mexico	364	252	11	9	5	13
Other	19	13	—	—	—	—
Total[3]	419	283	218	94	18	62
Pigs and bars (lead content):						
Australia	7,995	4,018	—	—	4,999	2,139
Belgium	21	12	(2)	3	303	346
Canada	83,627	50,960	124,715	70,480	130,769	58,483
France	—	—	—	—	56	46
Germany	25	79	2	1	330	478
Italy	—	—	38	48	—	—
Korea, Republic of	—	—	—	—	59	42
Mexico	22,614	12,688	56,102	30,709	40,311	16,118
Panama	79	29	58	25	—	—
Peru	500	228	9,797	5,124	18,311	6,845
Sweden	1,204	666	—	—	—	—
United Arab Emirates	113	342	11	43	384	545
United Kingdom	274	304	—	—	30	28
Other	r23	r24	—	—	19	31
Total[3]	116,473	69,351	190,723	106,433	195,572	85,100
Reclaimed scrap, including ash and residues (lead content):[4]						
Canada	117	28	216	54	58	29
Other	—	—	20	11	31	11
Total	117	28	236	65	90	39
Grand total[3]	129,446	74,128	196,487	110,013	196,162	85,548
Wrought lead, all forms, including wire and powders (gross weight):						
Canada	1,302	1,839	1,822	2,303	1,762	3,001
Chile	—	—	—	—	50	84
China	136	367	145	445	104	421
France	111	370	1	68	12	90
Germany	210	836	269	1,318	297	1,090
Hong Kong	70	195	164	534	196	530

See footnotes at end of table.

TABLE 15—Continued
U.S. IMPORTS FOR CONSUMPTION OF LEAD, BY COUNTRY

Country	1991		1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Wrought lead, all forms, including wire and powders (gross weight)—Continued:						
Italy	817	$982	379	$620	283	$521
Japan	47	539	66	1,149	55	552
Mexico	2,628	1,556	2,122	1,563	1,595	1,290
Namibia	—	—	1,002	454	1,000	448
Netherlands	46	131	19	159	22	233
Panama	—	—	64	26	—	—
Peru	133	100	765	436	168	131
South Africa, Republic of	—	—	—	—	1,000	448
Taiwan	160	469	151	399	124	374
United Arab Emirates	60	128	20	42	19	41
United Kingdom	177	548	70	687	169	644
Venezuela	26	16	—	—	5	5
Other	[r]39	[r]384	[r]35	[r]344	28	385
Total[3]	5,962	8,460	7,094	10,548	6,889	10,288

[r] Revised.

[1] Also includes other lead-bearing materials containing greater than 5 troy ounces of gold per short ton, or greater than 100 troy ounces of total precious metals per short ton.

[2] Less than 1/2 unit.

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

[4] Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

LIME

By M. Michael Miller

Mr. Miller, a physical scientist with 16 years of minerals experience with the U.S. Department of the Interior, has been the commodity specialist for lime since 1989. Domestic survey data were prepared by Kelly Dorney, statistical assistant; and the world production table was prepared by Amy Burk, international data coordinator.

Lime is an important chemical with hundreds of chemical, industrial, and environmental uses in the United States. Its history probably dates back at least 4,000 to 6,000 years. The ancient Egyptians utilized lime as an ingredient in mortar and plaster. The Greeks, Romans, and Chinese utilized lime for construction, agriculture, bleaching, and tanning. Its uses began expanding with the advent of the industrial revolution, but it remained primarily a construction commodity until the rapid growth of the chemical process industries at the beginning of the 20th century. At the turn of the century, more than 80% of lime consumed in the United States went for construction uses, but now more than 90% of lime is consumed for chemical and industry uses.

Lime is a basic chemical that ranked fifth in total production in the United States in 1993. It is produced in 33 States and Puerto Rico, and its major uses are in steelmaking; pulp and paper manufacturing; construction; and the treatment of water, sewage, and smokestack emissions.

Total lime sold or used by domestic producers, excluding that from Puerto Rico, increased by about 733,000 metric tons (808,000 short tons) to 16.9 million tons (18.7 million short tons) in 1993. Production included the commercial sale or captive production of quicklime, hydrated lime, and dead-burned refractory dolomite. These products were valued at more than $977 million. Commercial sales increased by 795,000 tons (876,000 short tons) to a record high of 15.1 million tons (16.6 million short tons), while captive production decreased by 62,000 tons (68,000 short tons) from 1992 levels. *(See table 1.)*

DOMESTIC DATA COVERAGE

To comply with Federal law and Executive Order 12770, the U.S. Bureau of Mines (USBM) has decided on the following transition plan for the mandated conversion of the remaining commodity publications not currently being reported in metric units. For the 1993 Commodity Annual Reports and 1994 Mineral Industry Surveys, all data will be published in metric units with an additional total line showing traditional English units. Beginning with the 1994 Commodity Annual Reports and the 1995 Mineral Industry Surveys, all data will be published in metric units only.

Domestic production data for lime are developed by the USBM from two separate, voluntary surveys of U.S. operations. The survey used to prepare this report is the annual "Lime" survey. Of the 118 operations to which the annual survey request was sent, 105 responded, representing 89% of the total sold or used by producers shown in table 2. Production for eight nonrespondents was provided based on the monthly survey. Production for five nonrespondents was estimated using reported prior-year production figures.

BACKGROUND

Definitions and Specifications[1]

Lime is a manufactured product made by calcining limestone (calcium carbonate or a combination of calcium and magnesium carbonate) or other calcium carbonate materials at temperatures ranging from 980° C to 1,300° C (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 1,540° C to 1,730° C (2,800° F to 3,150° F). All of these products are called lime.

Quicklime is commercially available by the carload, in bulk, or in paper bags, in the following standard sizes:

1. *Lump Lime*—the product exceeds 6.4 centimeters (2.5 inches) in diameter. Although sizes can vary, the typical size is 13 by 20 centimeters (5 by 8 inches). This largest size of quicklime is strictly a product of vertical kilns.

2. *Crushed or Pebble Lime*—the product ranges in size from 0.64 centimeter to 5.72 centimeters (0.25 inch to 2.25 inches), but the specific product size is more precise. This size has traditionally been a product of rotary kilns, but is now available from vertical kilns as either a primary product or as a result of crushing lump lime.

3. *Ground Lime*—the product is generally ground from larger size material. A typical product size passes nearly 100% through a No. 8 sieve and 40% to 60% through a No. 100 sieve.

4. *Pulverized Lime*—the product is the result of further grinding. A typical product size passes nearly 100% through a No. 20 sieve and 85% to 95% through a No. 100 sieve. This is usually a secondary product and is produced by intense grinding and classification.

5. *Pelletized Lime*—the pellets or briquets are of uniform 2.5-centimeter (1-inch) size, molded from quicklime fines. Hydrated lime is shipped in bulk tank trucks, rail cars, and in 23-kilogram (50-pound) paper bags. As a result of the hydration process, it is of fine particle size. A typical product size passes 85% or more through a No. 200 sieve, and a few special applications may require a product passing 95% to 98% through a No. 325 sieve.

Because of the differences in limestones, a rigid standardization of lime material specifications is impossible. Few plants manufacture lime with exactly the same properties; as a result, lime specifications are by necessity quite general in their provisions.

Technology[2]

Lime manufacture involves three main processes: stone preparation, calcination, and hydration. Stone preparation involves quarrying or mining (including drilling, blasting, and conveying broken stone), crushing, and screening to provide the proper size kiln feed. Care is taken to avoid contamination with undesirable impurities, such as iron oxide, silica, and alumina. Although most lime manufacturers produce their own stone, some purchase the stone for kiln feed from commercial limestone producers.

Calcination is a simple chemical reaction. It is the addition of heat to limestone to cause thermal decomposition in which the coproducts of CaO (quicklime) and CO_2 (carbon dioxide) are formed. This process is performed in a kiln, of which there are a wide variety of systems in use. The two basic kiln designs are rotary and vertical (or shaft). There are a few other miscellaneous designs, but the majority of commercial kilns are of rotary or vertical design. A rotary kiln is a long cylindrical kiln with a refractory lining, inclined at a slight angle, rotated at a slow speed, and fired by fuel at the lower end. The calcareous raw material (kiln feed) is fed into the upper end and calcined at about 1,100° C (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 3 to 4 meters (9 to 14 feet) and a height of 15 to 21 meters (50 to 70 feet). They are the most widely employed type in the world, especially in Europe. A vertical kiln is divided into four distinct zones where specific parts of the manufacturing process take place. They are, from top to bottom: (1) stone storage zone, (2) preheating zone, (3) calcining zone, and (4) cooling and discharge zone.

Examples of other kiln designs are the rotary hearth kiln and the fluosolids kiln. The rotary hearth design consists of a preheater, circular hearth, and cooler, all refractory lined. Stone is placed on the hearth and rotated through a heating chamber. In the fluosolids kiln, fine-sized stone is densely suspended by air and hot gases in the preheating and calcining zone of a vertical heated chamber. It can be operated at lower temperatures because of the fine stone size. The quicklime product is the most highly reactive of any commercial lime.

Byproducts and Coproducts

Most lime companies mine their own limestone or dolomite for kiln feed. Some companies also produce as a separate coproduct crushed and pulverized stone. If practical and if markets exist, byproduct fines from the kiln feed preparation process and fugitive lime dust from different stages of the lime production process also may be marketed. Precipitated calcium carbonate (PCC) is produced as a coproduct at three commercial lime plants by combining quicklime with byproduct carbon dioxide recovered from the kiln. Byproduct carbon dioxide is recovered for use in the carbonation step of sugar refining.

Substitutes

Limestone is a low-cost substitute for lime for many uses such as agriculture, fluxing, and flue gas desulfurization (FGD). Limestone contains less reactive material, is slower to react, and may have other disadvantages compared to lime, depending on the use. Calcined gypsum is an alternative material in industrial plasters and mortars. Cement, lime kiln dust, and fly ash are potential resources as substitutes for some construction uses of lime. Alkalis such as caustic soda, soda ash, sodium bicarbonate, sodium sulfate, and magnesium hydroxide are substitutes used in the neutralization stage of water treatment.

Economic Factors

Prices.—Traditionally, lime has been a low-priced commodity. Its average value, as reported to the USBM on an f.o.b. plant basis, ranged from $4 to $15 per short ton from 1910 to 1970. It was only in the 1970's, when energy prices escalated, that lime values showed a progressive and dramatic increase. This steady increase continued into the 1980's, although at a slower pace. In 1987, lime decreased in value for the first time since 1968. When comparing values since 1973, based on constant 1993 dollars, two trends become evident. From 1973 to 1979, values increased every year and were up a total of 49%. From 1979 to 1991, values decreased every year and were down a total of 30%.

Average values for quicklime sold are only available for the past 9 years. During that period the average actual value has been reasonably stable, ranging from $51.10 to $55.48 per ton ($46.36 to $50.33 per short ton). During the past 4 years, the values have been essentially flat.

The average values for hydrated lime sold for the same period have been less stable. The average actual value has ranged from $63.65 to $82.62 per ton ($57.74 to $74.95 per short ton). During the past 5 years, however, the values have been relatively stable. *(See figures 1, 2, 3, and 4.)*

Costs.—Production costs in lime manufacture can be divided, in descending order, into the following categories: energy (mainly fuel costs), kiln feed, dust collection, depreciation, direct labor, and miscellaneous. The ranking may differ from plant to plant, and most of the categories display a great range in costs from one plant to another. The difference in ranking and the range in costs are accounted for by such variables as distance from fuel sources; thermal efficiency of individual kilns; whether kiln feed is quarried, mined underground, or purchased; electrical energy rates; and age of the plant.[3]

Tariffs.—In the Harmonized Tariff Schedule of the United States, quicklime, slaked lime (hydrate), and hydraulic lime are listed under 2522.10, 2522.20, and 2522.30, respectively. Imports are free from countries with most-favored-nation (MFN) status, Mexico, and Canada. Non-MFN countries have tariffs of 0.2¢ per kilogram (about $2.20 per short ton) for quicklime, 0.3¢ per kilogram (about $3.31 per short ton) for slaked lime, and 0.2¢ per kilogram (about $2.20 per short ton) for hydraulic lime.

ANNUAL REVIEW

Legislation and Government Programs

Under authority of the Clean Water Act, as amended, the Environmental Protection Agency (EPA) released its final regulations establishing standards for the use of disposal of sewage sludge. The regulations provide requirements for sewage sludge applied to the land for a beneficial purpose, for sewage sludge disposed of on surface disposal sites, and for sewage sludge when incinerated. In section 503.32 of the Clean Water Act, an acceptable alternative for reduction of pathogens in sewage sludge is to raise the pH of the sewage sludge to above 12 for 72 hours. In appendix B to part 503—Pathogen Treatment Processes, lime stabilization is mentioned under Processes To Significantly Reduce Pathogens, where it states that "Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 after 2 hours of contact."[4]

The EPA finalized all or portions of five core regulations for the Acid Rain Program of title IV of the Clean Air Act, as amended. The regulations addressed General Provisions and Permits, the Allowance System, Continuous Emissions Monitoring, Excess Emissions, and Administrative Appeals. "Title IV of the Act requires EPA to establish an Acid Rain Program and a national emissions cap of 8.11 million metric tons (8.95 million short tons) per year on electric utility SO_2 emissions to be implemented in two phases. Phase I (beginning in 1995) requires the 110 highest-emitting utility plants to meet an intermediate SO_2 emissions limitation. By the year 2000 (in which Phase II begins) virtually all other utility units with output capacity greater than 25 megawatts and all new utility units will be required to meet emissions limitations as well. Total annual SO_2 emissions will be reduced by 9.1 million metric tons (10 million tons) below 1980 levels beginning in the year 2000, a reduction of total SO_2 emissions of approximately 40%."[5]

Phase I requirements have already translated into increased lime demand for flue gas desulfurization. In 1993, lime consumption for this use increased by 16% when compared with 1992 levels and 18% when compared with 1990 levels. The large increase in 1993 is probably explained by the lag time between passage of the Clean Air Act and installation of new SO_2 scrubbers at utility powerplants seeking to comply with Phase I.

Production

The term "lime," as used throughout this chapter, refers primarily to six chemicals produced by the calcination of high-purity calcitic or dolomitic limestone followed by hydration where necessary. They are (1) quicklime, calcium oxide (CaO); (2) hydrated lime, calcium hydroxide [$Ca(OH)_2$]; (3) dolomitic quicklime ($CaO \cdot MgO$); two types of dolomitic hydrate, (4) type N [$Ca(OH)_2 \cdot MgO$] and (5) type S [$Ca(OH)_2 \cdot Mg(OH)_2$]; and (6) dead-burned dolomite. Nondolomitic quicklime and hydrated lime may be called high-calcium lime. Lime can be produced from a variety of calcareous materials such as aragonite, chalk, coral, marble, and shell. Lime also is regenerated; that is, produced as a byproduct, by paper mills, carbide plants, and water-treatment plants; however, regenerated lime is beyond the scope of this report.

Total U.S. lime production from limestone, including that of Puerto Rico, increased by 4.5% compared to that of 1992. Commercial lime sold by producers increased by 5.5%, and captive lime used by producers decreased by 3.3%.

In 1993, 69 companies produced lime. Leading producing companies, in descending order, were Dravo Lime Co., with two plants in Kentucky and one plant in Alabama; Mississippi Lime Co. in Missouri; Marblehead Lime Co., with two plants in Illinois and one each in Indiana and Michigan; Chemstar Inc., with two plants each in Arizona, California, and Nevada and one each in Idaho and Utah; Continental Lime Inc., with one plant each in Montana, Nevada, Utah, and Washington; Allied Lime Co., with two plants in Alabama; Martin Marietta Magnesia Specialties in Ohio; APG Lime Co., with one plant each in Texas and Virginia; Texas Lime Co., with two plants in Texas; and Chemical Lime Inc., with two plants in Texas. These 10 companies operated 28 plants and accounted for 58% of total lime production. *(See tables 2 and 3.)*

Continued changes in the industry were

reflected by announcements of restructuring, name changes, sales, closures, plant openings, construction plans, and large utility FGD contracts. Mississippi Lime Co. restructured itself and formed North American Lime Co., which includes Mississippi Co. (Ste. Genevieve, MO), Bluff City Minerals Co. LP (Alton, IL), Eastern Ridge Lime Co. LP (Ripplemead, VA), and Prairie du Rocher Lime Co. LP (Prairie du Rocher, IL).[6] Prairie du Rocher Lime Co. LP is a new lime plant under construction in Illinois about 13 kilometers (8 miles) north of Mississippi Lime's Ste. Genevieve operations. Effective October 1, 1993, Ohio Lime Co. changed its name to Redland Ohio Inc. to reflect the acquisition of its parent Steetley PLC by Redland PLC in 1992.[7] Tenn Luttrell Co., Luttrell, TN, was sold by Penn Virginia Corp. to Global Stone Corp., Vancouver, British Columbia, Canada, for a reported $24.15 million. Subsequent to the sale, Tenn Luttrell announced plans to install two 300-ton-per-day (330-short-ton) Cimprogetti vertical kilns, one due on-stream in mid-1995 and the second in mid-1997.[8] Warner Co., a long-established producer of dolomitic lime products in southeastern Pennsylvania, closed and was put up for sale by its parent company Chemical Waste Management.[9] Early in the year, Wyoming Lime Producers started up its lime plant at Frannie, WY, and began producing from its 363-ton-per-day (400 short tons) Kennedy Van Saun preheater rotary. Wyoming Lime Producers is a part of Dakota Coal Co., which is in turn a subsidiary of Basin Electric Power Cooperative.[10] Western Lime & Cement Co. completed installation of a second preheater rotary kiln at its lime plant in Green Bay, WI. The new kiln went on-line in early summer 1993.[11] Dravo Lime Co. was awarded the contract to supply lime for FGD to the General James M. Gavin power station in southeastern Ohio. The 15-year contract will require about 408,000 tons per year (450,000 short tons) of magnesium-enhanced lime beginning in 1995. To meet the demand, Dravo plans to expand production capacity at its Maysville and Black River Divisions in Kentucky.[12] *(See table 4.)*

Consumption and Uses

Lime was consumed in every State. The breakdown of consumption by major end uses was as follows: 64% for chemical and industrial uses, 25% for environmental uses, 10% for construction uses, and 2% for refractory dolomite. Captive lime was used mainly in sugar refining and in the production of steel in basic oxygen furnaces.

In steel refining, quicklime was used as a flux to remove impurities such as phosphorus, silica, and sulfur. Dolomitic lime was substituted for a fraction of the high-calcium lime to extend refractory life. Dead-burned dolomite, also called refractory lime, was used as a component in tar-bonded refractory brick used in basic oxygen furnaces. Lime consumption by the steel industry increased by nearly 3% to 5.1 million tons (5.6 million short tons) and accounted for about 30% of all lime consumed in the United States.

In nonferrous metallurgy, lime was used in the beneficiation of copper ores to neutralize the acidic effects of pyrite and other iron sulfides and maintain the proper pH in the flotation process. It was used to process alumina and magnesia, to extract uranium from gold slimes, and in the recovery of nickel by precipitation. It was used in gold and silver recovery operations to control the pH of the sodium cyanide solution used to leach the gold and silver from the ore. Such leaching processes are called dump leaching when large pieces of ore are involved, heap leaching when small pieces of ore are involved, and carbon-in-pulp cyanidation when the ore is leached in agitated tanks. Dump and heap leaching involve crushing the ore, mixing it with lime for pH control and agglomeration, and stacking the ore in heaps for treatment with cyanide solution. Lime is used to maintain the pH of the cyanide solution at a pH level between 10 and 11 to maximize precious-metals recovery and to prevent the creation of dangerous hydrogen cyanide gas.

In the environmental sector, lime was used in the softening and clarification of municipal potable water. In sewage treatment, lime was used to control pH in the sludge digester, which removes dissolved and suspended solids that contain phosphates and nitrogen compounds. It also aided clarification and killing of bacteria. Lime was used to neutralize acid mine and industrial discharges. In FGD systems serving utility and industrial plants, lime was used to react with sulfur oxides in the flue gas. Lime was used to stabilize sludge from desulfurization plants before disposal.

The paper industry used lime as a coagulant aid in the clarification of plant process water. It was used, generally in conjunction with soda ash, for softening plant process water. This is a precipitation process to remove bivalent soluble calcium and magnesium cations (and to a lesser extent manganese, ferrous iron, zinc, and strontium), which contribute to the hardness of water. This process also reduces carbonate alkalinity and dissolved solids content.

In the basic Kraft pulping process, wood chips and an aqueous solution (called liquor) of sodium hydroxide and sodium sulfide are heated in a digester. The cooked wood chips (pulp) are discharged under pressure along with the spent liquor. The pulp is screened, washed, and sent directly to the paper machine or for bleaching. Lime is sometimes used to produce calcium hypochlorite bleach for bleaching the paper pulp. The spent liquor is processed through a recovery furnace where dissolved organics are burned to recover waste heat and where sodium sulfide and sodium carbonate are recovered. The recovered sodium sulfide and sodium carbonate are diluted with water and then treated with slaked lime to recausticize the sodium carbonate into sodium hydroxide (caustic soda) for reuse.

Lime was used to make precipitated calcium carbonate (PCC), a specialty pigment used in premium-quality coated and uncoated papers. The most common PCC production process used in the United States is the carbonation process.

Carbon dioxide is bubbled through milk-of-lime to form a precipitate of calcium carbonate and water. The reaction conditions determine the size and shape of the resulting PCC crystals.

The chemical industry used lime in the manufacture of alkalies. Quicklime was combined with coke to produce calcium carbide, which was used to make acetylene and calcium cyanide. Lime was used to make calcium hypochlorite, citric acid, petrochemicals, and other chemicals.

In sugar refining, milk-of-lime, a suspension of hydrated lime in water, was used to raise the pH of the product stream, precipitating colloidal impurities. The lime itself was then removed by reaction with carbon dioxide to precipitate calcium carbonate. The carbon dioxide was obtained as a byproduct of lime production.

Dolomitic quicklime was used as a flux in the manufacture of glass. Quicklime was used to make calcium silicate building products such as sand-lime brick; hydrated lime was used to produce silica refractory brick.

In construction, lime was used for soil stabilization to upgrade clay soils into satisfactory base and subbase materials. Common applications included the construction of roads, airfields, building foundations, earthen dams, and parking areas. Hydrated lime was used with fly ash to make a base material, in asphalt mixes to act as an antistripping agent, and in plaster, stucco, and mortar to improve durability.

Begun in 1992, a tour demonstrating the manufacture and use of autoclaved cellular concrete (ACC) blocks continued in 1993. ACC or autoclaved aerated concrete is a common concrete building material in Europe and other parts of the world. The tour planned to visit eight utility companies to demonstrate the production of ACC blocks using fly ash and to show how the blocks can be used. The demonstrations were aimed at builders, architects, building inspector, masons, developers, and others. The raw material mix in this ACC product contained 20% lime, although other autoclaved aerated concretes may utilize portland cement instead.

Specific patented manufacturing processes differ, but the process involved in the demonstration tour used sand or fly ash, lime, portland cement, aluminum powder, and water. These raw materials were mixed together and the resulting slurry poured into molds. This slurry expands and hardens, at which point it is cut into blocks or panels and then autoclaved for 12 hours. The resulting materials are lightweight, fire resistant, provide good thermal and sound insulation, and have good structural properties.[13] *(See table 5.)*

Prices

The average value of lime sold or used by producers, as reported to the USBM on an f.o.b. plant basis, decreased in 1993 to $57.83 per ton ($52.46 per short ton). Average values per ton were $56.11 ($50.90 per short ton) for chemical and industrial lime, $58.15 ($52.75 per short ton) for environmental lime, $63.34 ($57.46 per short ton) for construction lime, $73.42 ($66.61 per short ton) for agricultural lime, and $83.17 ($75.45 per short ton) for refractory dolomite.

The average value of quicklime sold decreased to $55.02 per ton ($49.91 per short ton). Average values per ton were $54.32 ($49.28 per short ton) for chemical and industrial lime, $55.54 ($50.39) for environmental lime, $54.74 ($49.66 per short ton) for construction lime, $111.40 ($101.06 per short ton) for agricultural lime, and $81.18 ($73.65 per short ton) for refractory dead-burned dolomite.

The average value of hydrated lime sold decreased to $67.84 per ton ($61.54 per short ton). Average values per ton were $64.28 ($58.31 per short ton) for chemical lime, $70.63 ($64.07 per short ton) for environmental lime, $67.52 ($61.25 per short ton) for construction lime, and $72.55 ($65.82 per short ton) for agricultural lime.

Transportation

The following is a clarification of the Department of Transportation regulations covering the transportation of hazardous materials (HRM-181), 49 CFR 171-180. The regulations refer only to lime (calcium oxide) shipped by air. The listing "UN 1910, Quicklime, Calcium Oxide" is to be used only on air shipments. For standard truck, rail, or barge shipments, the term "Quicklime, Calcium Oxide" is proper.[14]

Foreign Trade

According to the Bureau of the Census, exports of lime increased by 18% to 69,045 tons (76,109 short tons). Imports of lime increased by 4% to 200,587 tons (221,109 short tons). Most U.S. trade was with Canada and Mexico, which together accounted for nearly 100% of the U.S. exports and imports of lime. Canada was the major trading partner, receiving 74% of U.S. exports and shipping 95% of U.S. imports. *(See tables 6 and 7.)*

World Review

Canada.—Preliminary figures for 1993 put Canada's production at 2.45 million tons (2.70 million short tons) at a value of $201 million. This consisted of 2.26 million tons (2.49 million short tons) of quicklime valued at $181 million and 0.186 million tons (0.205 million short tons) of hydrated lime valued at $19.3 million.

European Union.[15]—The overall economy has depressed lime demand in most traditional markets, such as steel and construction. There was some variation in individual country markets. Eastern Germany's construction boom has increased demand for lime, mainly for production of sand-lime brick and aerated concrete products. Road and rail construction projects in France and Germany have increased demand for lime for soil stabilization. Lime demand for PCC production has grown in Scandinavia.

As environmental regulations have grown more stringent, the demand for lime has increased for various environmental uses. Lime usage has encountered difficulties in water treatment owing to sludge disposal restrictions that increase total treatment costs. The utility FGD market has grown some, but most FGD systems are limestone based. In addition, nuclear power and natural gas play a more significant role in Europe's current and future power generation plans. Some growth potential is seen in FGD treatment of incinerator gases.

Germany.—German consumption has been increasing in recent years but production has remained relatively flat. The increased demand has been met primarily by imports from the Czech Republic, Slovak Republic, and the former U.S.S.R.[16]

In 1993, Rheinisch-Westfälische Kalkwerke AG (RWK) transferred its business operations to a newly formed company called RWK Kalk AG. RWK Kalk AG was merged with Belgium's Lhoist Group's French and Czech operations to form Chaufourneries de Hergenrath SA. The new company will operate six plants in Germany, five in France, and one in the Czech Republic.[17]

United Kingdom.[18]—The lime industry continued to be impacted by the European recession, with both capacity utilization and profits at low levels. Buxton Lime Industries Ltd. is the largest producer, operating lime plants at Hindlow and Tundstead. Other United Kingdom producers included Singleton Birch Ltd., Tilcon Ltd., and British Steel PLC. Totternhoe Lime & Stone Co. Ltd. discontinued quicklime production in early 1993 and now purchases quicklime and hydrates it for regional customers. Owing to poor market conditions, the joint venture between Tilcon Ltd. and the Calcitherm-Carmeuse Group of Belgium has been put on hold. The two companies had announced in 1991 plans to construct lime production facilities and to market quicklime and hydrated lime in the United Kingdom. *(See table 8.)*

Current Research

Research by a group at the University of Western Australia has demonstrated a process for destroying polychlorinated biphenyls (PCB's) and other toxic organic compounds utilizing a conventional ball mill and quicklime. The organic compound is fed along with quicklime into a mill containing 12-millimeter-diameter (0.5-inch-diameter) steel balls. The milling process converts almost all of the organic material into carbon, calcium chloride, and calcium hydroxide. In laboratory tests, a pure sample of PCB mixed with quicklime was milled for 12 hours and produced a mixture containing only 5 parts per million of PCB. The codeveloper, Australian mining company CRA Ltd., will commercialize the process.[19]

In Germany, Solvay Umweltchemie GmbH has run pilot plant tests on a process to dispose of asbestos fibers by dissolving ground asbestos in a 40% solution of hydrofluoric acid. When the reaction is complete, the solution is neutralized by adding 20% hydrated lime. The estimated disposal costs in a commercial plant are expected to be competitive with current techniques that require cement fixing before final disposal.[20]

In Canada, research funded by the Ministère de l'Environment du Quebéc, Environment Canada-St. Lawrence Centre, and Groupe Olymel, was conducted on the use of lime to treat slaughterhouse sludge wastes for land application. The slaughterhouses produce a sludge waste generated by the use of a dissolved air flotation process for pretreatment of their wastewater. This sludge contains pathogens (bacteria, viruses, protozoa, and parasitic worms), heavy metals, and other contaminants. In a bench experiment, lime was applied to samples of the sludge at various concentrations, with the best results coming from the application of 150 kilograms (331 pounds) of calcium oxide equivalent per ton dry weight of sludge. This allows the maintenance of a pH of 12 or greater for several weeks. The experiment resulted in a major reduction of pathogens, heavy-metal content, and offensive odors. The resulting product was deemed suitable for application to agricultural land.[21]

OUTLOOK

Lime has dozens of end uses in the chemical, industrial, and construction industries. Steelmaking is still the largest single end use for lime, accounting for 30% of consumption. The steel industry's consumption of lime increased by nearly 3% when compared with 1992 levels. Steel output increased by more than 5% in 1993 and should continue to increase modestly in the short term as economic growth continues. Integrated steel mills operated at 96% of capacity in 1993 and are forecast to operate at 97% of capacity in 1994 and 98% of capacity in 1995. Consumption of lime by the steel industry has been relatively flat in the recent past, but the growing economy should translate into increased lime consumption for the next few years.

Construction markets, primarily for the soil stabilization, grew by about 25% in 1993. Barring long periods of bad weather, the construction markets should continue a strong showing. Soil stabilization and asphalt paving should be the driving forces in the construction markets.

The FGD market showed a dramatic increase in 1993 and is expected to show even greater growth in next few years. The deadline for Phase I compliance with the Clean Air Act Amendments is January 1, 1995, which means utility companies will have to have their compliance strategies in place by the end of 1994. Three midwestern powerplants have announced their plans to use lime in newly installed scrubbers beginning in 1995. These plants alone will consume about 725,000 to 815,000 tons (800,000 to 900,000 short tons) per year. This will mean an increase of 40% to 45% above current FGD consumption levels. Additional growth is expected from the utility industry, and longer term increases could materialize from the use of lime in dry scrubbers used with small nonutility boilers. Consumption of lime for FGD will likely top 3 million tons (3.3 million short tons) in the next 3 to 5 years, and increase even more when Phase II of the Clean Air Act Amendments goes into effect.

Other environmental markets as a whole were up nearly 4%, spurred by acid-water neutralization's surprising 35% increase. The sewage treatment market grew by nearly 6%, which probably reflects the expected growth in the sewage sludge stabilization market. The only significant environmental market that exhibited a drop was the water purification market, which decreased by 3%. Despite occasional variations in yearly consumption patterns, the individual environmental markets should remain strong, with the greatest potential for growth in sewage sludge stabilization.

Both the traditional pulp and paper market and precipitated calcium carbonate increased in 1993. In pulp mills, lime is used for water treatment and to causticize waste sodium carbonate solution to regenerate sodium hydroxide (caustic soda). Paper industry analysts project a 2.7% increase in paper production and a 3.2% increase in paperboard production in 1994. Demand for paper depends on the health of the economy and the strength of the U.S. dollar against foreign currencies. The weakening of the U.S. dollar against foreign currencies may slow imports and increase exports of paper products, increasing production even more. Increased consumption of paper products, driven by a stronger U.S. economy, should translate into greater consumption of lime for precipitated calcium carbonate production.

Lime consumption by the gold industry decreased significantly in 1993. Gold production is forecasted to remain flat over the next 2 to 3 years and then increase by about 5%. The gold boom may be over owing to the changed political climate and growing antimining sentiments, but current mining and mines in development should continue to provide a solid regional market.

The three chemical caustic soda plants constructed in recent years have been shut down owing to low prices. When operating, one plant purchases 100% of required lime and the other two regenerate lime, needing only to purchase makeup lime. Some forecasts now call for caustic soda supplies to tighten and for prices to climb back to the $250 to $300 level. As a result, the chemical caustic plants may reopen in late 1994 or in 1995. In addition to the three companies with idle plants, other companies have been considering building chemical caustic plants. The chemical caustic industry could still develop into a regional market for lime, but it will depend entirely on the price of caustic.

A couple of years ago, a major manufacturer of propylene oxide had proposed replacing caustic soda with hydrated lime in the dehydrochlorination stage of the production process. The company shelved the proposal with the precipitous drop in caustic soda prices. With the expected rise in caustic soda prices, the proposal may be dusted off and reconsidered. If the company proceeded with the substitution, it would require about 450,000 tons (500,000 short tons) of hydrated lime per year.

A small boost to the Mississippi River region market is expected by the end of 1994 when Vicksburg Chemical Co. begins production of potassium carbonate (K_2CO_3) at its new plant at Vicksburg, MS. The plant will utilize a patented ion-exchange process where potassium chloride, quicklime, and carbon dioxide will be used to produce K_2CO_3 and calcium chloride. The plant will require about 10,000 tons (11,000 short tons) of lime per year.

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TABLE 1
SALIENT LIME STATISTICS

(Thousand metric tons unless otherwise specified)[1]

		1989	1990	1991	1992	1993
United States:[2]						
Number of plants		115	113	112	112	112
Sold or used by producers:						
Quicklime		13,154	13,392	13,191	[r]13,665	14,266
Hydrated lime		2,040	2,098	2,168	[r]2,232	2,353
Dead-burned dolomite		365	342	308	302	315
Total[3]		15,560	15,832	15,667	[r]16,199	16,932
Total	thousand short tons	17,152	17,452	17,270	[r]17,856	18,664
Value[4]	thousands	$852,113	$901,549	$890,482	$949,674	$977,079
Average value per ton		$54.76	$56.94	$56.84	$58.63	$57.71
Lime sold		13,622	14,014	13,848	[r]14,306	15,101
Lime used		1,937	1,818	1,819	1,893	1,831
Exports[5]		29	49	47	59	69
Imports for consumption[5]		[r]197	157	158	193	201
Consumption, apparent[6]		15,530	15,940	15,778	[r]16,333	17,064
World: Production		[r]139,946	[r]135,592	[r]131,598	[r]125,955	[e]124,395

[e] Estimated. [r] Revised.

[1] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.

[2] Excludes regenerated lime. Excludes Puerto Rico.

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

[4] Selling value, f.o.b. plant, excluding cost of containers.

[5] Bureau of the Census.

[6] Calculated by sold or used plus imports minus exports.

TABLE 2
LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1992					1993				
	Plants	Hydrated[2] (thousand metric tons)	Quicklime[2] (thousand metric tons)	Total[2 3] (thousand metric tons)	Value (thousands)	Plants	Hydrated[2] (thousand metric tons)	Quicklime[2] (thousand metric tons)	Total[2 3] (thousand metric tons)	Value (thousands)
Alabama	4	156	1,298	1,454	$82,619	4	178	1,447	1,625	$89,457
Arizona, Nevada, Utah	9	168	[r]1,350	[r]1,518	88,889	8	199	1,410	1,610	72,354
California	10	[r]47	[r]207	254	18,072	9	22	171	193	14,751
Colorado, Montana, Wyoming	9	—	363	363	21,709	10	—	369	369	24,168
Idaho, Oregon, Washington	8	[r]63	[r]422	[r]486	35,672	8	17	547	565	40,915
Illinois, Indiana, Missouri	8	490	[r]2,675	[r]3,165	[r]174,458	8	455	2,734	3,189	175,165
Iowa, Nebraska, South Dakota	5	W	W	250	15,222	5	W	W	235	14,428
Kentucky, Tennessee, West Virginia	5	109	1,689	1,797	100,963	5	129	1,725	1,854	104,929
Michigan	8	27	[r]549	577	31,253	8	25	572	596	30,926
North Dakota	3	—	[r]100	[r]100	4,288	3	—	101	101	4,512
Ohio	9	W	W	1,670	96,739	9	W	W	1,699	100,721
Pennsylvania	9	256	1,250	1,506	94,543	9	286	1,248	1,535	95,377
Puerto Rico	1	27	—	27	3,717	1	27	—	27	3,653
Texas	7	495	842	1,337	83,359	8	627	978	1,604	103,274
Virginia	5	124	[r]639	764	40,271	5	117	639	756	40,039
Wisconsin	4	110	363	[r]472	26,579	4	116	395	511	30,880
Other[3]	9	[r]187	[r]2,220	[r]488	[r]35,042	9	181	2,244	489	35,183
Total[2]	113	[r]2,259	13,967	[r]16,226	953,391	113	2,380	14,581	16,959	980,732
Total thousand short tons	XX	[r]2,490	15,396	[r]17,886	XX	XX	2,624	16,073	18,694	XX

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

[1] Excludes regenerated lime. Includes Puerto Rico.

[2] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.

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

[4] Includes Arkansas, Louisiana, Massachusetts, Minnesota, Oklahoma, and data indicated by the symbol W.

TABLE 3
LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY RANGE OF PRODUCTION

Range of production	1992			1993		
	Plants	Quantity[2] (thousand metric tons)	Percent of total	Plants	Quantity[2] (thousand metric tons)	Percent of total
Less than 10,000 tons	11	[r]74	(3)	10	70	(3)
10,000 to 25,000 tons	21	351	2	20	330	2
25,000 to 50,000 tons	14	[r]490	3	11	340	2
50,000 to 100,000 tons	14	910	6	22	1,623	10
100,000 to 200,000 tons	23	2,892	18	17	2,138	13
200,000 to 400,000 tons	21	5,423	33	22	5,489	32
More than 400,000 tons	9	6,086	38	11	6,970	41
Total[4]	113	[r]16,226	100	113	16,959	100
Total thousand short tons	XX	[r]17,886	XX	XX	18,694	XX

[r] Revised. XX Not applicable.

[1] Excludes regenerated lime. Includes Puerto Rico.

[2] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.

[3] Less than 1/2 unit.

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

TABLE 4
DESTINATION OF SHIPMENTS OF LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

(Thousand metric tons)[2]

State	1992			1993		
	Quicklime	Hydrated lime	Total[3]	Quicklime	Hydrated lime	Total[3]
Alabama	580	22	601	661	47	708
Alaska	—	2	2	5	1	6
Arizona	302	41	343	321	47	368
Akransas	110	23	133	124	25	149
California	333	88	421	343	67	410
Colorado	141	28	169	156	32	189
Connecticut	19	4	23	22	2	24
Delaware	8	2	10	17	2	19
District of Columbia	19	23	42	8	8	16
Florida	387	20	407	400	22	422
Georgia	219	72	291	216	86	302
Hawaii	(4)	(4)	(4)	—	(4)	(4)
Idaho	[r]113	40	[r]153	162	2	163
Illinois	496	165	660	504	161	664
Indiana	1,320	31	1,350	1,404	31	1,435
Iowa	59	26	85	56	25	81
Kansas	73	28	101	89	21	110
Kentucky	355	38	393	374	39	414
Louisiana	230	98	328	228	86	313
Maine	(4)	(4)	(4)	4	(4)	4
Maryland	107	13	121	124	17	141
Massachusetts	159	13	172	143	12	155
Michigan	868	35	903	879	32	911
Minnesota	293	17	310	284	17	300
Mississippi	173	13	186	187	16	204
Missouri	140	62	203	166	58	223
Montana	159	13	172	122	9	131
Nebraska	57	12	69	54	10	65
Nevada	[r]321	25	[r]345	415	36	451
New Hampshire	—	(4)	(4)	2	(4)	2
New Jersey	123	17	139	115	20	135
New Mexico	130	29	159	130	52	182
New York	78	24	102	87	26	113
North Carolina	181	42	222	202	43	245
North Dakota	230	7	237	250	3	253
Ohio	1,664	119	1,783	1,743	139	1,882
Oklahoma	113	10	124	120	9	129
Oregon	141	22	163	130	18	148
Pennsylvania	1,525	206	1,731	1,537	203	1,740
Rhode Island	6	1	7	8	1	9
South Carolina	185	23	209	191	48	239
South Dakota	21	1	22	19	1	20
Tennessee	192	56	247	193	48	241
Texas	844	505	1,349	925	613	1,538
Utah	[r]279	18	[r]297	263	21	284

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 metric tons)[2]

State	1992			1993		
	Quicklime	Hydrated lime	Total[3]	Quicklime	Hydrated lime	Total[3]
Virginia	172	41	213	205	56	261
Washington	215	17	232	231	12	243
West Virginia	467	60	527	421	52	473
Wisconsin	135	44	179	136	43	179
Wyoming	[r]148	18	[r]167	124	15	140
Total[3]	13,888	[r]2,216	[r]16,104	14,500	2,335	16,835
Puerto Rico	(4)	22	22	—	21	21
Canada	49	14	63	55	16	71
Other[5]	30	7	37	25	8	32
Total[3]	80	43	122	80	45	124
Grand total[3]	[r]13,967	[r]2,259	[r]16,226	14,581	2,380	16,959
Grand total thousand short tons	[r]15,396	[r]2,490	[r]17,886	16,073	2,624	18,694

[r] Revised.

[1] Excludes regenerated lime.

[2] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.

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

[4] Less than 1/2 unit.

[5] Includes other countries and U.S. possessions.

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

(Thousand metric tons and thousand dollars)[2]

Use	1992				1993			
	Sold	Used	Total[3]	Value	Sold	Used	Total[3]	Value
Agriculture	26	—	26	1,867	19	—	19	1,429
Chemical and industrial:								
Alkalies	W	W	155	8,249	W	W	129	6,201
Aluminum and bauxite	157	—	157	9,314	157	—	157	9,095
Copper ore concentration	W	W	W	23,086	W	W	W	20,198
Food products, animal or human	20	—	20	1,516	25	—	25	1,943
Glass	108	—	108	5,639	109	—	109	6,646
Oil well drilling	12	—	12	737	17	—	17	1,064
Oil and grease	35	—	35	3,107	46	—	46	4,616
Ore concentration, other	367	—	367	20,341	293	—	293	16,902
Paper and pulp	W	W	1,022	57,706	W	W	1,185	69,275
Petrochemicals	56	—	56	4,366	60	—	60	4,870
Precipitated calcium carbonate	W	W	386	21,253	473	9	481	25,937
Steel:								
Basic oxygen furnaces	W	W	3,833	206,648	W	W	3,527	191,431
Electric arc furnaces	805	—	805	47,001	1,207	—	1,207	61,611
Argon oxygen decarburization	88	—	88	4,827	96	—	96	5,236
Ladle desulfurization, iron or steel	95	—	95	[r]5,371	116	—	116	6,379
Other	[r]178	—	[r]178	[r]9,169	193	—	193	11,001
Total steel:	1,166	W	4,999	273,016	1,612	W	5,139	275,658
Sugar refining	27	610	637	37,408	33	669	701	44,595
Tanning	[r]19	—	[r]19	1,279	21	—	21	1,476
Other[4]	[r]7,012	1,128	[r]2,743	[r]145,381	6,321	956	2,438	117,492
Total[3]	8,979	1,737	10,717	612,336	9,167	1,634	10,801	605,968
Construction:								
Asphalt paving	98	—	98	5,661	117	—	117	6,844
Finishing lime	51	—	51	3,901	46	—	46	3,459
Mason's lime	(5)	(5)	136	10,018	(5)	(5)	164	11,237
Soil stabilization	856	—	856	53,280	1,111	—	1,111	68,852
Other	[r]175	—	[r]175	18,726	193	—	193	12,923
Total[3]	(5)	(5)	[r]1,317	[r]91,587	(5)	(5)	1,631	103,315
Environmental:								
Acid water, mine or plant	279	2	281	17,027	377	2	378	23,283
Flue gas sulfur removal	1,545	—	1,545	[r]86,771	1,787	—	1,787	100,163
Industrial solid waste treatment	41	—	41	2,399	34	—	34	1,964
Industrial wastewater treatment	51	—	51	3,047	39	—	39	2,318
Scrubber sludge solidification	54	—	54	3,031	53	—	53	2,985
Sewage treatment	467	1	468	29,548	491	2	494	30,682
Water purification	1,060	—	1,060	60,995	1,028	—	1,028	61,281
Other	[r]365	—	[r]365	19,554	361	17	378	21,126
Total[3]	3,863	3	3,866	222,371	4,171	(5)	4,191	243,802
Refractory lime (dead-burned dolomite)	(5)	(5)	302	25,230	(5)	(5)	315	26,218
Grand total[3]	[r]14,333	1,893	[r]16,226	953,391	15,128	1,831	16,959	980,732
Grand total thousand short tons	[r]15,799	2,087	[r]17,886	XX	16,676	2,018	18,694	XX

[r]Revised. W Withheld to avoid disclosing company proprietary data. XX Not applicable.

[1] Excludes regenerated lime. Includes Puerto Rico.

[2] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.

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

[4] Includes briquetting, brokers, calcium carbide, chrome, citric acid, commercial hydrators, desiccants, ferroalloys, fiberglass, glue, insecticides, magnesia from seawater or brine, magnesium metal, metallurgy, pelletizing, pharmaceuticals, rubber, silica brick, soap, and uses indicated by symbol W in "Chemical and industrial" lime only.

[5] Withheld to avoid disclosing company proprietary data; included in "Grand total."

TABLE 6

U.S. EXPORTS OF LIME

	Quantity[1] (metric tons)	Value[2] (thousands)
1989	29,249	$3,893
1990	48,842	6,145
1991	46,891	6,058
1992	58,513	7,540
1993	69,045	7,825

[1] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.
[2] F.a.s. value.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF LIME

	Quicklime		Hydrated lime		Total[1]	
	Quantity[2] (metric tons)	Value[3] (thousands)	Quantity[2] (metric tons)	Value[3] (thousands)	Quantity[2] (metric tons)	Value[3] (thousands)
1989	136,825	$7,841	60,629	$4,127	197,454	$11,968
1990	98,725	6,222	58,396	4,171	157,122	10,392
1991	110,384	7,227	47,399	3,841	157,784	11,068
1992	151,918	11,322	40,877	3,661	192,795	14,983
1993	155,119	9,998	45,468	3,301	200,587	13,299

[1] Data may not add to totals shown because of independent rounding.
[2] To convert metric tons to short tons multiply metric tons by 1.10231 or divide metric tons by 0.907185.
[3] Customs value.

Source: Bureau of the Census.

TABLE 8
QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Algeria (hydraulic)	27	32	61	[r] [e]62	62
Australia[e]	1,500	1,500	1,500	1,500	1,500
Austria	1,622	1,637	[e]1,600	[r]1,716	1,700
Belgium	1,968	2,076	2,021	[r]1,871	1,750
Belize[e]	[3]1	1	1	1	1
Bosnia-Herzegovina[e]	—	—	—	[r]50	50
Botswana	—	([4])	([4])	[e]([4])	([4])
Brazil[e]	[e]5,730	5,700	[r]5,700	[r]5,700	5,700
Bulgaria	[r]1,538	[r]1,557	[r]1,034	[r] [e]1,000	1,000
Burundi	([4])	([4])	([4])	[r]([4])	([4])
Canada	2,552	[r]2,341	[r]2,375	[r]1,456	1,495
Chile (hydraulic)[e]	1,300	1,300	1,200	1,300	1,300
China[e]	15,966	17,000	18,500	19,000	19,500
Colombia[e]	1,300	1,300	1,300	[r] [e]671	700
Congo	([4])	([4])	([4])	[r]([4])	([4])
Costa Rica[e]	10	[r]13	[3]9	9	10
Croatia[e]	—	—	—	[r]200	200
Cuba[e]	180	180	180	160	180
Cyprus (hydrated)	7	7	7	[r]6	6
Czech Republic[5]	—	—	—	—	2,500
Czechoslovakia[6]	3,346	3,120	3,230	[e]3,000	—
Denmark (sales)	[r]131	[r]134	[r]156	[r]163	160
Dominican Republic[e]	18	4	—	—	—
Egypt[e]	95	68	[3]749	749	749
Ethiopia	([4])	([4])	([4])	[e]([4])	([4])
Fiji	[e]2	—	—	—	—
Finland (sales)	224	225	225	[r]241	250
France[e]	[3]3,084	3,000	3,000	3,000	3,000
Germany:					
Eastern states	3,407	[e]3,000	—	—	—
Western states	7,033	6,893	—	—	—
Total	10,440	[e]9,893	7,532	[r]7,542	7,500
Guadeloupe[e]	5	5	5	5	5
Guatemala[e]	[3]79	75	[r]72	70	70
Hungary	878	831	[r]571	[r]446	300
India[e]	790	800	[r]820	850	860
Iran[e]	650	650	650	650	650
Ireland	111	112	110	[r]110	100
Israel	[e]180	230	208	[e]208	208
Italy[e] [7]	3,900	3,850	[r]3,800	3,600	3,600
Jamaica[e]	90	90	95	[r] [3]179	200
Japan (quicklime only)	8,486	8,983	[r]9,045	[r]8,049	8,000
Jordan	3	5	5	[r]7	7
Kenya	32	14	[r]12	[r] [e]12	12
Korea, Republic of [e]	230	230	240	240	250
Kuwait	65	50	5	[r] [e]5	35
Lebanon[e]	10	10	10	15	15
Libya[e]	260	260	260	260	260
Macedonia[e]	—	—	—	[r]20	20

See footnotes at end of table.

TABLE 8—Continued

QUICKLIME AND HYDRATED LIME, INCLUDING DEAD-BURNED DOLOMITE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Malawi	3	4	[e]4	[e]4	4
Martinique[e]	5	5	5	5	5
Mauritius[e]	7	7	7	7	7
Mexico[e]	6,000	6,000	6,500	6,500	6,500
Mongolia[e]	95	103	[r]76	[r]50	55
New Zealand[e]	100	100	90	100	100
Nicaragua	[e]4	[r]1	2	[r]2	2
Norway[e]	100	100	100	100	100
Panama[e]	[3]2	3	[3]1	2	2
Paraguay[e]	[3]103	100	100	100	100
Peru[e]	13	13	14	14	14
Philippines	[e]4	12	7	[e]10	10
Poland	4,421	[r]3,200	[r]2,413	[r]2,526	2,500
Portugal[e]	200	200	200	200	200
Romania	[r]3,983	[r]3,028	[e]3,000	[r] [e]3,000	3,000
Saudi Arabia[e]	12	12	12	12	12
Serbia and Montenegro	—	—	—	[r]565	500
Slovakia[5]	—	—	—	—	1,070
Slovenia[e]	—	—	—	[r]250	250
South Africa, Republic of (sales)	1,939	1,830	1,765	[r]1,738	[3]1,599
Spain[e]	[r]1,200	1,200	1,200	1,200	1,200
Sweden	[r]656	[r]603	[r]506	[r] [e]500	500
Switzerland	30	26	[e]40	[r] [e]30	40
Taiwan	615	554	614	[r]670	650
Tanzania (calcined and hydrated)	3	1	[e]1	[r]2	1
Tunisia[e]	650	650	650	600	600
Turkey[e] [8]	[r]1,432	[r]1,407	[r]1,581	[r]1,582	1,700
Uganda[e]	1	2	2	[r] [3]2	[3]2
U.S.S.R.[9]	30,378	[e]28,000	[e]26,000	[e] [10]23,000	[10]20,000
United Arab Emirates[e]	45	45	45	45	45
United Kingdom[e]	2,800	[r]2,800	[r]2,800	2,500	2,500
United States, including Puerto Rico (sold or used by producers)	15,584	15,859	15,694	16,227	[3]16,959
Uruguay[e]	[3]12	12	12	12	12
Venezuela[e]	2	2	2	2	3
Yugoslavia[11]	2,407	2,123	1,600	—	—
Zaire	100	92	83	65	50
Zambia	[r]230	[r]214	184	[r]212	200
Total metric tons[12]	[r]139,946	[r]135,592	[r]131,598	[r]125,955	124,395
Total short tons	[r]154,264	[r]149,464	[r]145,062	[r]138,841	137,122

[e]Estimated. [r]Revised.

[1] Table includes data available through July 12, 1994.

[2] Lime is produced in many other countries besides those listed. Argentina, Iraq, Pakistan, and Syria are among the more important countries for which official data are not available.

[3] Reported figure.

[4] Less than 1/2 unit.

[5] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[6] Dissolved Dec. 31, 1992.

[7] Includes hydraulic lime.

[8] Data are lime produced for steel production and do not include the widespread artisanal production of lime for whitewash and sanitation purposes.

[9] Dissolved in Dec. 1991.

[10] Total production of the former U.S.S.R. Production data for the 15 new countries are not yet reported separately.

[11] Dissolved in Apr. 1992.

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

FIGURE 1

TIME-VALUE RELATIONSHIPS FOR QUICKLIME SOLD

(Metric tons)

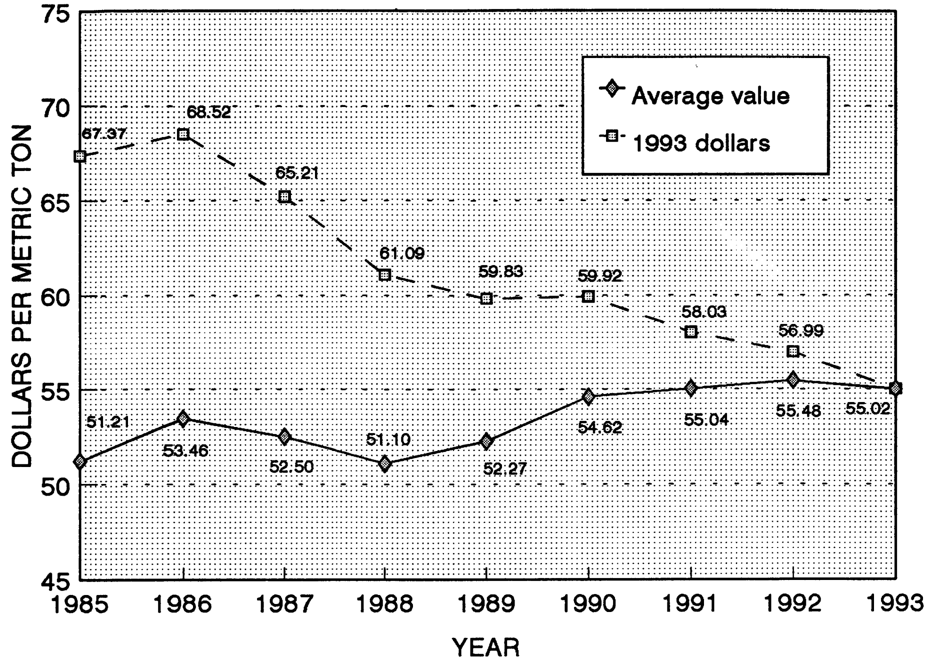


FIGURE 2

TIME-VALUE RELATIONSHIPS FOR HYDRATED LIME SOLD

(Metric tons)

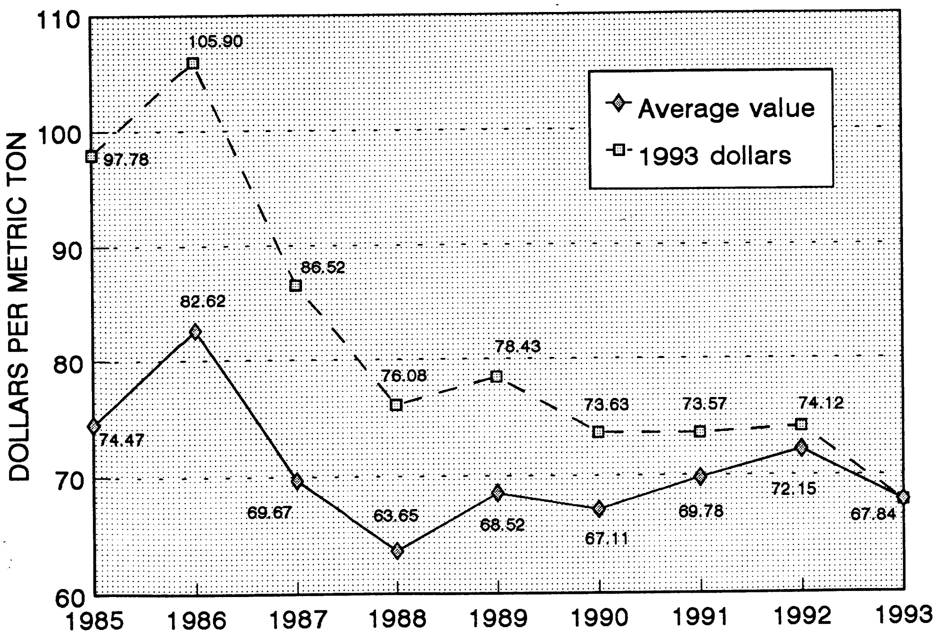


FIGURE 3
TIME-VALUE RELATIONSHIPS FOR QUICKLIME SOLD

(Short tons)

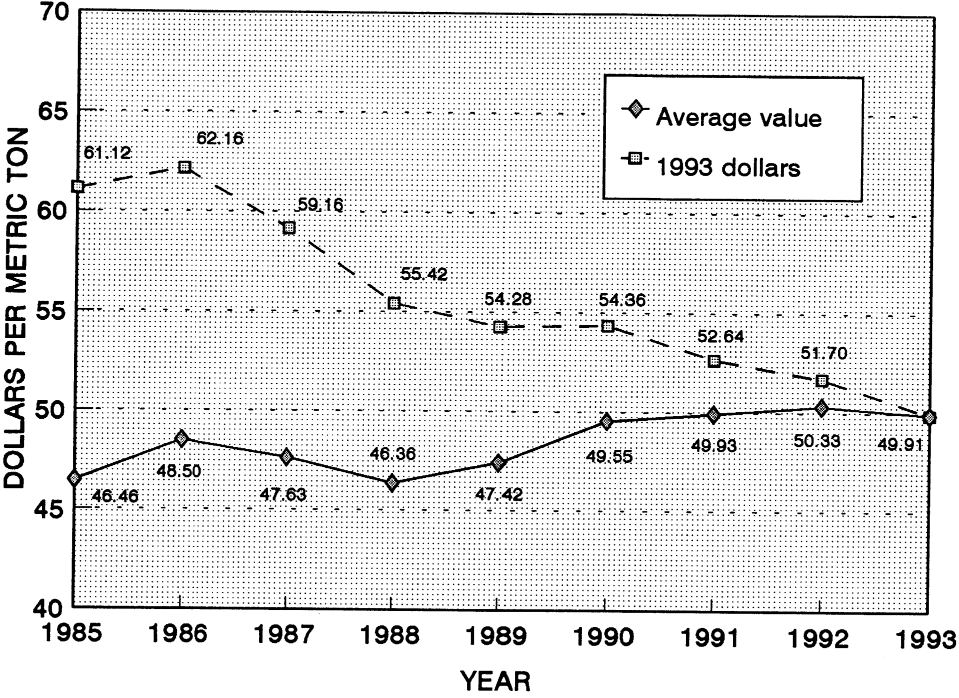
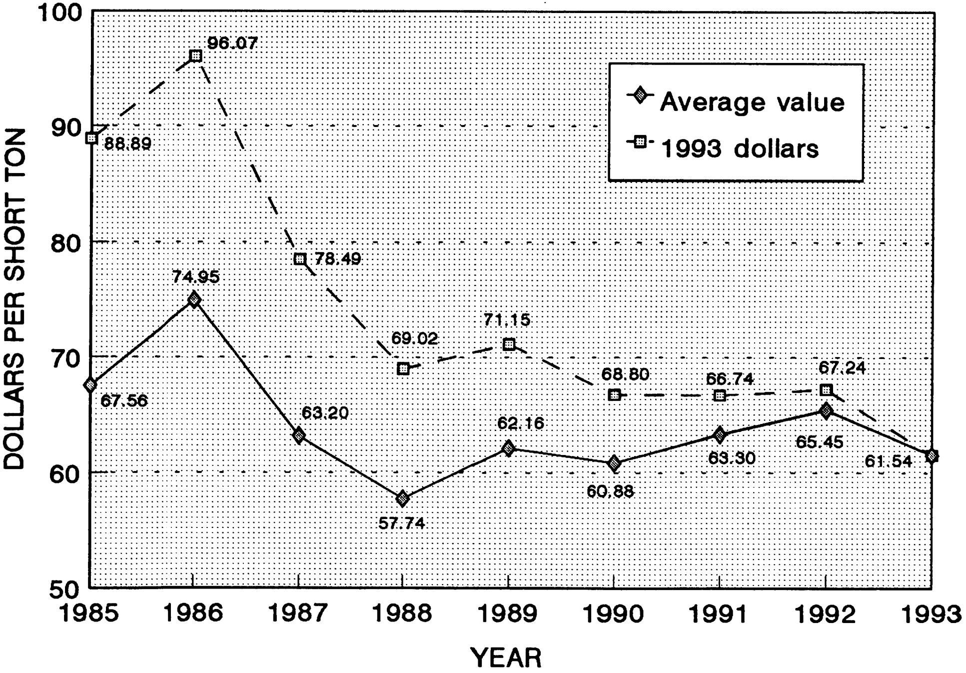


FIGURE 4
TIME-VALUE RELATIONSHIPS FOR HYDRATED LIME SOLD

(Short tons)



LITHIUM

By Joyce A. Ober

Mrs. Ober, a physical scientist with 16 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for lithium since 1986. Domestic survey data were prepared by Pamela G. Shorter, statistical assistant; and the world table was prepared by Amy Durham, international data coordinator.

The United States has been the largest producer and consumer of lithium, and the two U.S. companies that produced lithium have been leading lithium carbonate producers in the world for many years. One U.S. company, with operations in the United States and Chile, merged with another major U.S. mineral producer. The other U.S. company was exploring the possibility of developing a brine deposit in South America. Chile has become an increasingly important player in the lithium industry, and with the expected development of a second lithium operation in that country, it may become the world lithium leader by the end of this century.

Because lithium is electrochemically reactive and has other unique properties, there are many commercial lithium products. Producers sold lithium as mineral concentrate, brine, compound, or metal depending on the end use. Most lithium compounds were consumed in the production of ceramics, glass, and primary aluminum.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines collects domestic production data for lithium from a voluntary survey of U.S. operations. The two U.S. companies responded to the survey, representing 100% of total production. Production and stock data were withheld from publication to avoid disclosing company proprietary data. *(See table 1.)*

ANNUAL REVIEW

Legislation and Government Programs

During 1993, the Department of Energy (DOE) offered for sale approximately 14 million kilograms of its 36-million-kilogram stock of lithium hydroxide monohydrate. Bids ranging from $1.32 to $1.54 per kilogram were accepted for the sale of about 13,600 kilograms of the material; bids for about 1 million kilograms were rejected because the prices offered were unacceptably low. DOE was pursuing the possibility of negotiating future sales because sales resulting from the first offering were less than had been desired.

DOE had planned to offer the lithium hydroxide in 1989, but delayed the disposal until an environmental impact study was complete. The stocks were excess from a weapons program that used the lithium to make tritium, a compound necessary for nuclear fission reactions. The stockpile originally contained about 42,000 metric tons of material, from which about 75% of the lithium 6 isotope had been removed. This material possibly contained 8 to 9 parts per million of mercury, which could present an environmental hazard.

Production

The two companies that produced lithium in the United States in 1993 did so from two different types of deposits. Both firms mined spodumene (a lithium-aluminum-silicate mineral) from large hard-rock deposits in North Carolina using open pit methods. Lithium was recovered from geothermal brine deposits in Nevada. Spodumene is the most common form of lithium ore, but petalite and lepidolite are other types of lithium ores that are mined in different parts of the world. These three types of ore are beneficiated to produce lithium ore concentrates that can be consumed directly in certain applications. Spodumene and brines are converted to lithium carbonate and then other compounds for consumption in other end uses.

Lithium carbonate is the most important lithium compound produced from brine and ore deposits. Spodumene was a major raw material for the production of lithium carbonate in North Carolina, and small amounts of spodumene concentrate were produced for sale. Extracting lithium from spodumene entails an energy-intensive chemical recovery process.

After mining, spodumene is crushed and undergoes a flotation beneficiation process to produce concentrate. Concentrate is heated to 1,075° C to 1,100° C, changing the molecular structure of the mineral, making it more reactive to sulfuric acid. A mixture of finely ground converted spodumene and sulfuric acid is heated to 250° C, forming lithium sulfate. Water is added to the mixture to dissolve the lithium sulfate. Insoluble portions of ore are then removed by filtration. The purified lithium sulfate solution is treated with soda ash, forming insoluble lithium carbonate that precipitates from solution. The carbonate is separated and dried for sale or use by the producer as feedstock in the production of other lithium compounds.

Production of lithium carbonate from

brine in Nevada is much less energy intensive than production from the spodumene. Brines enriched in lithium chloride—averaging about 300 parts per million when operation began in 1966—are pumped from the ground and progress through a series of evaporation ponds. Over the course of a year to 18 months, concentration of the brine increases to 6,000 parts per million of lithium through solar evaporation. When the lithium chloride reaches optimum concentration, the liquid is pumped to a recovery plant and treated with soda ash, precipitating lithium carbonate. The carbonate is then removed through filtration, dried, and shipped.

Cyprus Foote Mineral Co., a subsidiary of Cyprus Minerals Co., produced lithium carbonate from its brine deposit in Silver Peak, NV, and spodumene concentrate at its mine in Kings Mountain, NC. Cyprus Foote operated processing facilities for downstream lithium products and metal in Kings Mountain; Sunbright, VA; and New Johnsonville, TN. The company continued to maintain its lithium carbonate plant at Kings Mountain on a care-and-maintenance status as it had since mid-1986. In 1993, Cyprus Minerals merged with Amax Inc. to form Cyprus Amax Minerals Co. The merger had little impact on the lithium operations during the year.

FMC Corp., Lithium Div., formerly Lithium Corp. of America (Lithco), mined spodumene from pegmatite dikes near Bessemer City, NC. The company produced lithium carbonate and a full range of downstream compounds, including lithium metal and some organic lithium compounds, at a chemical plant near the mine. The company also operated a butyllithium plant in Bayport, TX.

Consumption and Uses

Ceramics and glass production and aluminum smelters were the largest consumers of lithium carbonate and lithium concentrates in the United States, comprising an estimated 20% and 18% of the lithium market, respectively. Other consuming industries were synthetic rubber and pharmaceuticals, 13%; chemical manufacturing, 13%; miscellaneous chemicals, 12%; lubricants, 11%; batteries, 7%; and air treatment, 4%.[1] Estimated domestic consumption was unchanged from that of 1992.

Lithium carbonate and mineral concentrate additions in ceramics and glass manufacturing processes lower process melting points, reduce the coefficient of thermal expansion and the viscosity, and eliminate the use of more toxic chemicals. The manufacture of thermal-shock-resistant cookware (pyroceramics) consumed the majority of lithium used in the ceramics and glass industry domestically. The manufacture of black and white television picture tubes consumed significant amounts of lithium concentrates overseas. Low-iron spodumene and petalite were a source of lithium used to improve the physical properties of container and bottle glass and as a source of alumina, another important component of the glass. Glass manufacturers used lithium in container and bottle glass, enabling them to produce lighter weight, thinner walled products.

Aluminum producers added lithium carbonate to cryolite baths in aluminum potlines. The chemistry of the potline converts it to lithium fluoride, lowering the melting point of the bath, allowing a lower operating temperature for the potline, and increasing the electrical conductivity of the bath. Operators used these factors to increase production or reduce power consumption.

The third largest end use for lithium compounds is as catalysts in the production of synthetic rubbers and plastics and pharmaceuticals. N-butyllithium initiates the reactions between styrene and butadiene that form abrasion-resistant synthetic rubber and thermoplastic rubbers that require no vulcanization. Other organic lithium compounds are important in the production of polyolefins such as polyethylene, a low-cost, high-strength plastic. Lithium metal and compounds also are used by drug manufacturers in the production of a number of drugs, including Vitamin A, some steroids, an anticholesterol drug, an analgesic, antihistamines, tranquilizers, sleep inducers, and contraceptives. Pharmaceutical-grade lithium carbonate is approved directly for the treatment for manic-depressive psychosis. This is the only treatment approved by the U.S. Food and Drug Administration in which lithium is consumed by the patient.

The multipurpose grease industry was another of the important end uses for lithium in 1991. Lithium hydroxide monohydrate was the compound used for the production of lithium lubricants. Lithium-base greases are favored for their retention of lubricating properties over a wide temperature range; good resistance to water, oxidation, and hardening; and formation of a stable grease on cooling after melting. These greases continued to be utilized in military, industrial, automotive, aircraft, and marine applications.

Almost all major battery manufacturers marketed some type of lithium batteries, and research and development continued for further substitution in applications that implement more conventional alkaline batteries. These batteries represent a growth area for lithium consumption, and new battery configurations continue to be developed. Continued interest in electrically powered vehicles spurred additional interest in battery research. New, more efficient types of rechargeable (secondary) lithium batteries have been developed and improved to meet the needs for this market and for electronic equipment, such as portable telephones and video cameras. Work continued on lithium polymer and lithium ion batteries. These batteries are of particular interest because they take advantage of large power capacity available from lithium batteries without the safety problems encountered when these batteries contain lithium metal, a very reactive and volatile material when exposed to air and moisture.

Nonrechargeable (primary) lithium batteries offer improved performance over alkaline batteries at a slightly higher cost and have been commercially available for more than 10 years. They were used in watches, microcomputers, and cameras, and, more recently, in small appliances, electronic games, and toys. The military purchased large and small lithium batteries for a variety of applications. The *Galileo* spacecraft, launched in October 1989 for its 6-year trip to explore the atmosphere of Jupiter, contained lithium sulfur dioxide batteries to power its scientific instruments when it reaches its destination. Recent modifications to the lithium sulfur dioxide battery have extended the life of the batteries to at least 10 years with little or no reduction of performance.

Aircraft manufacturers in several countries have designed new aircraft using aluminum-lithium alloys for wing and fuselage skin or structural members. Use of aluminum-lithium alloys can reduce the weight of the aircraft by more than 10%, allowing significant fuel savings during the life of the aircraft. The alloys, which are 2% to 3% lithium by weight, are attractive to the aircraft and aerospace industry because of their reduced density and superior corrosion resistance compared to those of conventional aluminum alloys. These alloys face direct competition, however, from composite materials consisting of boron, graphite, or aramid fibers imbedded in polymers.

Small quantities of other lithium compounds were important to many industries. Lithium chloride and lithium bromide were used in industrial air-conditioning systems, commercial dehumidification systems, and in the production of sophisticated textiles. Sanitizers for swimming pools, commercial glassware, and public restrooms contained lithium hypochlorite, as did dry bleach for commercial laundries. Lithium metal was used as a scavenger to remove impurities from copper and bronze, and anhydrous lithium chloride was used as a component in fluxes for hard-to-weld metals, such as steel alloys and aluminum.

Prices

The price for lithium carbonate, the largest volume lithium compound, decreased 2.6% in 1993. Lithium chloride and lithium hydroxide monohydrate increased 3%, and standard-grade lithium metal increased 3.5%. Prices for other lithium products were unchanged from those of 1992. *(See table 2.)*

Foreign Trade

Total U.S. exports of lithium compounds were about 16% lower in 1993 than they were in 1992. The majority of U.S. exports of lithium compounds were to Germany, Japan, and the United Kingdom. Data reported by the Bureau of the Census indicated that exports of U.S. pharmacopoeia (U.S.P.-grade) lithium carbonate in 1993 were less than 1% of the exports reported in 1992; however, calculations of unit value for this category of exports indicate that the majority of this material in previous years was probably technical-grade material that was mistakenly reported as U.S.P.-grade. Technical-grade is much lower in value than U.S.P.-grade lithium carbonate, and the unit value for both grades were very similar in 1992. Unit value for U.S.P.-grade in 1993 was nearly five times that of the technical-grade.

Imports of lithium compounds increased 5%. Cyprus Foote Mineral Co. owns a lithium brine operation in Chile; 97% of all lithium carbonate imports was from this source. Lithium ore concentrates from Australia, Canada, and Zimbabwe were consumed in the United States, but no import statistics were available. *(See tables 3 and 4.)*

World Review

A small number of countries throughout the world produced lithium ore and brine. The United States and Chile were the leading producers of lithium carbonate; significant quantities of lithium compounds and ore concentrates also were produced in Australia, Canada, Chile, China, Portugal, Russia, and Zimbabwe. Argentina, Brazil, and Namibia produced smaller quantities; production primarily consisted of concentrates. Rwanda, the Republic of South Africa, and Zaire are past producers of concentrates. Pegmatites containing lithium minerals have been identified in Austria, France, India, Ireland, Mozambique, Spain, and Sweden, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface brines in Argentina, Bolivia, China, and Israel. Companies in France, Germany, Japan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Capacity.—The data in table 5 are rated capacity for mines and refineries as of December 31, 1993. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Any restrictions to capacity utilization related to legal, political, or environmental restraints have been footnoted.

Lithium presented special problems during compilation of production capacities for different operations. Ore concentrate products are not comparable to lithium carbonate. Lithium carbonate was the primary compound produced at lithium chemical plants and the compound from which all other lithium chemicals were produced. Because even high-grade ore products usually contained less than 4% lithium and lithium carbonate contains almost 20% lithium, production capacities reported in tons per year represent large differences in the actual lithium content of the product. For that reason, capacities were reported based on the lithium content of the products. *(See* *table 5.)*

Argentina.—FMC began construction of two evaporation ponds to test evaporation rates prior to full-scale development of the Salar de Hombre Muerto. Testing evaporation rates at Hombre Muerto is essential because its altitude of 4,000 meters may impede evaporation, making development of the deposit less attractive. FMC signed an agreement with the Argentine Government in 1986 to explore this salar in Catamarca Province but intensified its test program in 1990. The Argentine brines may become more attractive for development since the Argentine Government began considering revisions of its mining laws to attract more foreign investment.[2] Estimates of geologic resources have been reported at 130,000 tons of lithium contained in brine ranging from 0.22 to 1.08 grams per liter. The Salar del Rincon also was identified as a lithium resource in the Salta Province. Lithium pegmatites are mined in Argentina. Small annual production occurred from pegmatite deposits in the Catamarca and San Luis Provinces. Spodumene reserves are estimated at 140,000 tons of 0.7% lithium.[3]

Australia.—Gwalia Consolidated mined high-grade, low-iron spodumene at its mine in Greenbushes, Western Australia. Gwalia produced two spodumene concentrate products through a flotation process for sale to the ceramics and glass industry. The majority of the company's spodumene concentrate was used in the manufacture of black and white television picture tube glass and pyroceramics in the Pacific rim countries and Europe. Glass-grade concentrate with lower lithium content was marketed in the same countries for consumption in container glass.

During the year, Gwalia announced an agreement with the China National Nonferrous Metals Import and Export Corp. to supply 60,000 tons of spodumene concentrates to China during the next 3 years. The company was considering entrance into the lithium carbonate market also. Technical problems that discouraged construction of a lithium carbonate plant several years ago have been solved, and Gwalia was studying the possibility once again.[4]

Bolivia.—A lithium brine deposit identified in Bolivia may be the world's largest salt flat. Preliminary studies of the Salar de Uyuni, which is more than 3,600 meters above sea level, indicated resources of 5.5 million tons of lithium, 110 million tons of potassium, and 3.2 million tons of boron.[5]

FMC had been negotiating for 4 years with the Government of Bolivia for the rights to develop a joint-venture operation in the Salar de Uyuni, a lithium brine deposit considered to be a national asset. FMC's plans included an exploration program and a plant for the recovery of lithium carbonate from the evaporated brines. Extreme political pressures in 1990 delayed the ratification of the contract that defined FMC's development of the project to produce 10,000 tons per year of lithium carbonate over 40 years at an investment of at least $92 million.[6] After FMC signed the contract, the Bolivian Congress changed four major conditions of the contract, including raising the value added tax rate. FMC informed the Government of Bolivia that the company could not accept the changes to the contract and canceled the contract in January 1993.[7]

Development of Uyuni is still a possibility, but not in the near future. Representatives from Cyprus Foote visited Bolivia after the FMC deal fell through to explore the possibility of their company developing the deposit if and when the lithium market improves.[8]

Brazil.—Brazil has produced small quantities of lithium minerals for almost 30 years. Companhia Brasileira de Litio built a plant in Aquas Verhelhas, Minas Gerais, to produce 1,000 tons of lithium hydroxide and 200 tons of lithium carbonate.

Canada.—During the year, Cabot Corp. became 100% owner of Tantalum Mining Corp. of Canada (Tanco), the sole producer of lithium minerals in Canada, acquiring the 62.5% of Tanco owned by Hudson Bay Mining and Smelting Co. Ltd. and Manitoba Mineral Resources Ltd.[9] Since production of spodumene concentrate began at its mine near Bernic Lake in southeastern Manitoba in 1984, Tanco has grown to become the largest supplier of lithium concentrates to the U.S. ceramics and glass industry. The Canadian spodumene was similar to the material mined in Australia (high-grade spodumene with very low iron content), making the concentrates ideal for direct application in the ceramics and glass industry.

A number of other lithium deposits have been identified throughout Canada. A pegmatite deposit was operated in Quebec for about 10 years starting in 1955, but there has been no production since then. The largest demonstrated resources occur in the Yellowknife deposits in the Northwest Territories.[10] Although large, the location is too remote for production to be feasible in the foreseeable future.

Chile.—Cyprus Foote Mineral Co. is the sole owner of its lithium brine operation at the Salar de Atacama, Sociedad Chilena de Litio Ltd., having bought the remaining interest from the Chilean Government in 1989. Cyprus Foote produced lithium carbonate from the brines at this Salar, which has been worked since 1984. The project originated as a joint venture between Cyprus Foote and Corporación de Fomento de la Producción (CORFO), a Chilean Government agency. Production capacity for lithium carbonate increased steadily from a 6,300-ton-per-year capacity to reach the current level of almost 12,000 tons per year.

The possibility of a second lithium operation at the Salar de Atacama has been under investigation. Minera Salar de Atacama Ltda. (MINSAL), the consortium formed by AMAX Exploration Inc. (United States), CORFO, and Molibdenos y Metales S.A. (Chile), completed studying the feasibility of developing another lithium operation on the Salar in 1988. Evaluations of the results were analyzed, and AMAX announced its decision to sell its portion of the project in 1990.[11]

Sociedad Quimica y Minera de Chile (SQM) bought AMAX's interest in the project in the second half of 1992. SQM is a Chilean fertilizer producer and its interest in the MINSAL project is for the potash that would be produced as a raw material for its potassium nitrate plant. Production of lithium carbonate is important to the economics of the project. Production of 9,000 tons per year of lithium carbonate, the second stage of the project, should begin by the end of the century.[12] SQM had been negotiating with FMC to develop the lithium portion of the project, but FMC withdrew from discussions.[13]

China.—Lithium pegmatite and brine deposits are worked in China, but specific information about any of the deposits is not available. Lithium carbonate and hydroxide from China has been marketed in Germany, Japan, and the Netherlands.

France.—Lithium metal is produced by Metaux Speciaux SA in Plombieres St. Marcel, Savoie. The plant has the capacity to produce 25 tons per year of very high-purity metal for use in aluminum-lithium alloys. The company is a subsidiary of Pechiney.[14]

Germany.—Germany has been a major producer of lithium compounds, although no lithium ore is mined there. Chemetall GmbH, a member of the Metallgesellschaft Group AG, produced downstream lithium compounds and metal from lithium carbonate imported from the United States and other countries. The company's lithium operations are in Langelsheim.

Japan.—Japan is a major consumer of lithium compounds, some of which it produces from imported lithium carbonate. FMC and the Honjo Chemical Co. have a joint venture, Asia Lithium Corp., to market FMC's lithium products in Japan. Asia Lithium operated a 100-ton-per-year battery-grade lithium metal operation in Kagawa to meet the demands of the large lithium battery industry in Japan. Yahagi Iron Co. also produced lithium metal in Nagoya.

Namibia.—Southwest Africa (SWA) Lithium Mines produced petalite concentrate at its Rubicon Mine near Karibib. Low-grade ores were beneficiated through a flotation process, while high-grade ores were hand picked. Small amounts of two other lithium minerals, lepidolite (lithia mica) and amblygonite (lithia alumina phosphate), were other products. The Federal Republic of Germany imported most of these concentrates. High-grade lepidolite was hand picked at the company's Helicon Mine for export to Western Europe and Japan.[15]

Portugal.—Lithium has been produced inconsistently in Portugal. Recent reports indicate that production has gone up significantly in recent years, but details on the operations and markets are not available. Past lithium production had been lepidolite.

United Kingdom.—Lithium Corp. of Europe operates a facility in Bromborough, Mersyside, for the production of lithium metal and butyllithium. Lithium carbonate and lithium chloride are imported from its parent company, FMC.

Former U.S.S.R.—Lithium ores, compounds, and metal were produced in the former U.S.S.R., but no details were available. The majority of lithium production is believed to be from the Kola Peninsula in Russia.

Zimbabwe.—Bikita Minerals Ltd. mined petalite, another lithium mineral, near Masvingos. Although the ore reserves were becoming depleted, installation of a dense-media separator made it possible to recover lithium in the form of petalite averaging about 4.4% lithium oxide from a stockpile of previously rejected material. This extended the estimated mine life 30 years. Hand sorting, the method used since the mining began in 1916, amassed a stockpile of more than 1 million tons that could be recovered with a significant savings in mining costs after installation of the new device. Hand sorting continued to be used only for special small orders of minerals other than petalite.[16] *(See table 6.)*

OUTLOOK

The health of the lithium industry is closely tied to the performance of the primary aluminum industry. Reduced consumption of lithium in the aluminum industry has once again had a negative effect on lithium consumption. Demand for lithium compounds and minerals in the ceramics and glass industry continues to grow modestly. Similar increases are expected for the near future.

Demand for butyllithium is expected to continue to increase, and both domestic producers have increased production capacity to meet that demand. Demand for lithium metal for batteries and to some extent for alloys should increase, but total consumption of metal will remain small in comparison to the demand lithium compounds for the short term. The fate of the lithium battery market will be largely dependent on the success of electric vehicles and whether the best type of battery for powering them finally is determined to be some form of lithium battery.

Other markets should remain relatively stable with slight growth. Lithium demand could increase dramatically if any of the new technology areas such as nuclear fusion were perfected. This is not expected to occur within the remainder of this century and probably not within the next 25 years.

The United States should remain the largest producer of lithium carbonate until production of lithium carbonate from SQM project in Chile. At that time, Chile should become the leading producer of lithium compounds in the world.

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TABLE 1

SALIENT LITHIUM STATISTICS

(Metric tons of contained lithium)

	1989	1990	1991	1992	1993
United States:					
Production[1]	W	W	W	W	W
Producers' stock changes[1]	W	W	W	W	W
Imports[2]	630	790	590	770	810
Exports[3]	2,600	2,600	2,400	2,100	1,700
Consumption:					
Apparent	W	W	W	W	W
Estimated	2,700	2,700	2,600	2,300	2,300
Rest of world: Production[1]	5,400	[r]5,300	[r]5,000	[r]5,700	[e]5,500

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

[1] Mineral concentrate and carbonate.

[2] Compounds, concentrate, ores, and metal.

[3] Compounds.

TABLE 2

DOMESTIC YEAREND PRODUCERS' AVERAGE PRICES OF LITHIUM AND LITHIUM COMPOUNDS

	1992		1993	
	Dollars per pound	Dollars per kilogram	Dollars per pound	Dollars per kilogram
Lithium bromide, 54% brine: Truckload lots, delivered in drums	5.47	12.06	5.47	12.06
Lithium carbonate, technical: Truckload lots, delivered	1.96	4.32	1.91	4.21
Lithium chloride, anhydrous, technical: Truckload lots, delivered	4.67	10.30	4.83	10.65
Lithium fluoride	6.87	15.15	6.87	15.14
Lithium hydroxide monohydrate: Truckload lots, delivered	2.51	5.53	2.59	5.71
Lithium metal ingot, standard-grade: 1,000-pound lots, f.o.b	32.45	71.54	33.60	74.05
Lithium sulfate, anhydrous	4.16	9.17	4.16	9.17
N-butyllithium in n-hexane (15%): Truckload lots, delivered	19.34	42.64	19.34	42.64

Source: U.S. lithium producers and Chemical Marketing Report, v. 245, No. 1, Jan. 3, 1994, p. 28.

TABLE 3

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1992		1993	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium carbonate:				
Argentina	30,000	$122,430	28,959	$118,613
Australia	38,901	194,364	37,600	174,382
Bahamas, The	—	—	136	5,325
Belgium	3,556	33,866	462	9,420
Brazil	9	6,110	24,290	119,711
Canada	591,758	2,228,129	892,232	3,490,726
Germany	1,678,751	5,256,754	1,438,398	4,607,793
India	51,594	229,176	42,350	182,697
Japan	1,263,792	4,415,657	1,651,767	6,573,872
Korea, Republic of	75,962	285,503	114,744	387,229
Mexico	123,426	486,590	119,780	478,719
Netherlands	436,975	1,444,464	788,583	2,671,880
Nigeria	—	—	184	20,972
Russia	—	—	5,471	67,640
Singapore	16,000	57,553	28,773	101,888
South Africa, Republic of	—	—	1,600	7,616
Taiwan	66,258	243,776	72,511	267,367
United Kingdom	1,704,699	4,612,190	999,887	2,816,188
Venezuela	696,847	2,420,900	—	—
Total[1]	6,778,526	22,037,462	6,247,727	22,102,038
Lithium carbonate U.S.P.[2]				
Australia	49,381	149,432	—	—
Germany	500	10,407	1,313	34,370
Ghana	—	—	321	4,098
Guatemala	—	—	136	2,691
India	16,928	87,249	98	11,966
Italy	363	4,800	—	—
Japan	357,831	1,161,580	—	—
Korea, Republic of	174,283	587,652	—	—
Malaysia	—	—	1,000	15,310
Mexico	—	—	998	4,058
New Zealand	1,383	23,086	1,699	28,151
Panama	—	—	150	13,783
South Africa, Republic of	—	—	—	—
Taiwan	46,764	159,329	—	—
United Kingdom	—	—	2,500	21,041
Venezuela	799,998	2,786,616	—	—
Total	1,447,431	4,970,151	8,215	135,468
Lithium hydroxide:				
Argentina	135,649	580,933	96,971	361,072
Australia	61,506	258,358	61,531	274,652
Bahamas, The	157	6,039	—	—
Belgium	8,613	16,142	1,207	5,688
Brazil	212,057	908,391	15	10,192
Canada	41,830	202,272	65,388	309,527

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY

Compound and country	1992		1993	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Lithium hydroxide—Continued:				
Chile	33,177	$160,020	29,300	$140,359
Colombia	36,379	162,452	23,000	107,654
Dominican Republic	998	7,400	—	—
Ecuador	5,000	19,000	6,598	31,537
Egypt	5,000	24,120	20,316	107,021
Germany	360,548	1,642,567	447,114	1,838,585
Haiti	—	—	9,891	33,798
Honduras	1,850	8,717	1,000	5,553
India	63,034	270,639	349,767	1,265,920
Indonesia	36,651	229,179	—	—
Israel	33,867	149,399	19,185	95,505
Italy	—	—	31	6,232
Japan	739,862	3,831,787	776,806	3,698,943
Korea, Republic of	280,032	1,163,886	161,404	629,047
Malaysia	1,000	4,639	—	—
Mexico	180,462	751,109	228,458	1,051,742
Morocco	14,968	67,735	—	—
Netherlands	74,000	338,451	72,161	338,106
New Zealand	4,500	23,270	500	2,765
Pakistan	27,051	122,236	16,000	67,580
Peru	648	2,970	9,707	41,945
Philippines	45,888	195,680	36,795	165,044
Poland	451	26,110	1,406	51,932
Saudia Arabia	15,000	65,851	69,196	308,956
Singapore	64,721	339,141	91,019	406,508
South Africa, Republic of	20,973	126,520	2,790	14,256
Sweden	—	—	278	85,412
Taiwan	24,944	111,352	3,990	19,020
Thailand	78,000	353,331	110,675	504,723
United Arab Emirates	—	—	15,000	64,103
United Kingdom	275,275	889,475	300,691	942,317
Venezuela	27,027	124,209	30,611	190,499
Total[1]	2,911,116	13,183,380	3,058,801	13,176,193

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

[2] Pharmaceutical-grade lithium carbonate.

Source: Bureau of the Census.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF LITHIUM CHEMICALS

	Compounds			
	1992		1993	
	Quantity (kilograms)	Value[1]	Quantity (kilograms)	Value[1]
Lithium carbonate:				
Canada	60	$8,454	113	$11,190
Chile	4,051,286	10,561,787	4,162,365	11,653,469
China	—	—	71,450	250,405
France	—	—	1,000	4,545
Germany	100	3,001	258	8,750
Hong Kong	—	—	52,475	188,470
Japan	602	43,564	—	—
Russia	—	—	900	3,651
Total	4,052,048	10,616,806	4,288,561	12,120,481
Lithium hydroxide:				
Canada	125	7,847	158	10,262
China	17,000	64,600	2,000	17,600
Germany	771	18,086	324	10,292
Japan	16,862	170,752	21,311	198,394
Netherlands	200	23,521	—	—
Russia	—	—	1	1,292
Switzerland	2	1,539	—	—
United Kingdom	1,470	7,215	—	—
Total	36,430	293,560	23,794	237,840

[1] Customs value.

Source: Bureau of the Census.

TABLE 5
WORLD LITHIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993

(Metric tons of contained lithium)

Country	Capacity
North America:	
United States	4,100
Canada	500
Total	4,600
South America:	
Argentina[e]	10
Brazil[e]	290
Chile	2,200
Total[e]	2,500
Europe:[e]	
U.S.S.R.[1,2]	1,100
Portugal	18
Total	[3]1,100
Africa:	
Namibia[e]	30
Zimbabwe	730
Total	760
Asia: China[e,2]	730
Oceania: Australia	1,300
World total	10,990

[e] Estimated.

[1] Dissolved in Dec. 1991.

[2] These estimates denote only an estimated order of magnitude; no basis for more exact estimates is available. Output from China and the former U.S.S.R. has never been reported.

[3] Rounded.

TABLE 6
LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Argentina, spodumene and amblygonite	[r]84	[r]67	[r]305	[r]126	130
Australia, spodumene	[e]40,000	[e]40,000	[3]40,376	[3]42,516	40,000
Brazil, concentrates	[r]1,471	[r]475	[r]1,560	[r] [e]1,600	1,600
Canada, spodumene[e] [4]	14,000	12,000	12,000	18,500	18,500
Chile, carbonate from subsurface brine	7,508	9,082	8,575	[r]10,823	10,800
China (minerals not specified)[e] [5]	15,000	15,000	15,500	15,500	15,500
Namibia:					
Amblygonite	131	54	20	[r]5	10
Lepidolite	41	80	33	[r]93	80
Petalite	1,226	1,134	1,139	[r]1,064	1,100
Portugal, lepidolite	18,264	[r]7,614	[r] [e]10,000	[r] [e]9,000	10,000
Russia (minerals not specified)[5] [6]	—	—	—	[e]45,000	40,000
U.S.S.R.[e] [7]	55,000	55,000	50,000	—	—
United States, spodumene and subsurface brine	W	W	W	W	W
Zimbabwe (minerals not specified)	20,647	19,053	9,186	[r]12,837	15,000

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

[1] Table includes data available through Apr. 13, 1994.

[2] In addition to the countries listed, other nations may produce small quantities of lithium minerals, but output is not reported and no valid basis is available for estimating production levels.

[3] Data are for year ending June 30 of that stated.

[4] Based on all of Canada's spodumene concentrates (Tantalum Mining Corp. of Canada Ltd.'s Tanco property).

[5] These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available.

[6] All production in the U.S.S.R. from 1989 through 1991 came from Russia.

[7] Dissolved in Dec. 1991.

MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

Ms. Kramer is a physical scientist with the Branch of Industrial Minerals. She has covered magnesium and magnesium compounds for 10 years. Domestic survey data were prepared by Wannette Davis, statistical assistant; and international data tables were prepared by Amy Durham and Dave Mann, international data coordinators.

U.S. primary magnesium metal production declined slightly in 1993 and imports, primarily from Russia and Ukraine, provided an increased percentage of domestic demand. In addition, inventories of magnesium increased significantly from the low level at the end of 1992. These increases in inventories and imports prompted two of the three U.S. producers to announce cutbacks in production rates near the end of 1993. This oversupply situation was reflected in free market prices for primary magnesium during the year. Prices dropped steadily through the first three quarters of 1993 before rebounding slightly during the last 3 months.

In the past few years, automobile manufacturers have begun designing magnesium alloy diecastings into future car models. Many of these new components have been introduced in the 1994 model year and as a result, consumption of primary magnesium for diecastings has increased significantly. This is expected to increase as magnesium continues to be specified by designers for more components.

In Europe, a producers' association filed an antidumping complaint alleging dumping of magnesium on the European market by the former U.S.S.R. Other countries, including Japan and India, also have suggested that magnesium exports from the former U.S.S.R. have adversely affected their magnesium production. Several magnesium production facilities in Japan and Europe were either shut down completely or closed for a short period during 1993. At the same time, construction of new facilities in Australia and Israel was proceeding on schedule.

U.S. production of magnesium compounds from all sources (magnesite, dolomite, seawater, brines, and olivine) continued to decline as it has each year since 1988. Domestic demand, however, increased by nearly 8%. The increase in demand was met primarily by increased imports, particularly caustic-calcined and dead-burned magnesia from China. U.S. producers were concentrating on increasing production of magnesium compounds for use in environmental applications such as acid neutralization.

DOMESTIC DATA COVERAGE

Data for magnesium metal are collected from two voluntary surveys of U.S. operations. Of the 113 companies canvassed for magnesium consumption data, 73% responded, representing 46% of the primary magnesium consumption shown in tables 4 and 6. Data for the 30 nonrespondents were estimated based on prior-year consumption levels and other factors.

Data for magnesium compounds were collected from one voluntary survey of U.S. operations. Of the 19 operations canvassed, 84% responded, representing 75% of the magnesium compounds shipped and used shown in table 13. Data for the three nonrespondents were estimated based on prior-year consumption levels and other factors.

BACKGROUND

Definitions, Grades, and Specifications

Primary magnesium metal contains a minimum of 99.8% magnesium. Magnesium-base alloys are named by the composition of the two chief alloying elements, each designated by a letter, and the approximate percentage of each alloying element. For example, AZ91 contains about 9% aluminum (A) and 1% zinc (Z), and HK31 contains about 3% thorium (H) and 1% zirconium (K). Other letters used in specifying magnesium alloys are E for rare-earth metals and M for manganese.

Magnesite, or magnesium carbonate ($MgCO_3$), has a theoretical magnesium content of 47.6%. Dolomite is a calcium carbonate-magnesium carbonate mineral ($CaCO_3 \bullet MgCO_3$) that has a theoretical magnesium content of 22%. Brucite, magnesium hydroxide [$Mg(OH)_2$], contains up to 69% magnesium, and olivine ($Mg_2Fe_2SiO_4$) contains up to 19% magnesium. Of these minerals, magnesite and dolomite are the largest sources of magnesium and magnesium compounds.

Seawater, brines, and bitterns represent vast sources of magnesium and magnesium compounds. In the United States, more than 60% of the magnesium compounds produced annually is recovered from seawater and brines, and 80% of the magnesium metal production capacity uses seawater or brines as a raw material.

Various magnesia products are made by calcining magnesium carbonate or magnesium hydroxide at different temperatures. Caustic-calcined magnesia, which is readily reactive with water, is calcined at temperatures up to 890° C. Dead-burned magnesia, also called refractory or sintered magnesia, is calcined at temperatures up to 1,450° C and is unreactive with water. Fused magnesia is produced at temperatures greater than 3,000° C. Magnesia produced from magnesite is generally called natural magnesia, and magnesia produced from seawater or brines is called synthetic magnesia.

Standards for magnesia, including chemical composition, bulk density, and particle size, generally are set by the consumer for a specific application. Refractory magnesia composition depends on the area of the furnace in which the material is to be used. Magnesia produced from magnesite can contain between 88% and 98% magnesia, with varying quantities of alumina, calcium, iron, and silica impurities. Synthetic magnesia normally is purer than natural magnesia, containing between 92% and 99.5% magnesia, with smaller quantities of the same impurities found in natural magnesia. Most fused magnesia contains greater than 94% magnesia.

Products for Trade and Industry

The principal use for magnesium metal, averaging greater than 50% of U.S. consumption annually, is as an alloying addition to aluminum. Magnesium improves the hardness and corrosion resistance of pure aluminum. Aluminum-magnesium alloys are used in a variety of applications, including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys.

Magnesium and its alloys are used as structural components on automobiles, trucks, aircraft, computers, and power tools. Many of these applications use magnesium because of its light weight and ease of machinability. Magnesium is used in the iron and steel industry for external hot-metal desulfurization and in the production of nodular iron. Production of the nonferrous metals, beryllium, hafnium, titanium, uranium, and zirconium, involves the use of magnesium as a reducing agent. Anodes of magnesium are used for cathodic protection of underground pipe and water tanks. Small quantities of magnesium are used as a catalyst in producing organic compounds, as photoengraving plates, and in alloys other than aluminum.

Refractory magnesia represents the largest use of magnesium in compounds. Refractory magnesia is manufactured into bricks and other shapes, principally for linings in furnaces and auxiliary equipment used to produce iron and steel. Magnesia-base refractories also are used in furnaces in the cement, glass, and nonferrous metals industries.

Caustic-calcined magnesia is used in a variety of applications in the agricultural, chemical, construction, and manufacturing industries. Caustic-calcined magnesia is an important component of animal feed and fertilizer, providing essential nutrients for livestock and plant growth. In construction, caustic-calcined magnesia is used in special cements for industrial flooring and in lightweight insulating wallboard. In the chemical industry, it is used as a starting point for the manufacture of other magnesium salts. Special grades of caustic-calcined magnesia are used for pharmaceuticals, including antacids, toothpaste, milk of magnesia, and cosmetics. Magnesia is used to remove sulfur from flue gases and boiler fuels and is used for acid neutralization in process wastewater and in lubricating oils. Caustic-calcined magnesia is also important in manufacturing paper, rayon, and rubber.[1]

Other magnesium compounds are used in place of, or in addition to, caustic-calcined magnesia in many of the above applications. Magnesium hydroxide is used in the pulp and paper industry; magnesium sulfate is used for pharmaceuticals, animal feed, and fertilizers; and magnesium carbonate is used in the chemical, pharmaceutical, and rubber industries. Fused magnesia is used primarily for electrical insulation.

The principal use for olivine is as a foundry sand used in casting iron and steel components and some nonferrous metals. Olivine is used in smaller quantities for refractories, slag control in blast furnaces, and abrasives.[2]

Industry Structure

U.S. producers of magnesium and magnesium compounds are shown in tables 1 and 2. Two companies in the United States produce olivine—Applied Industrial Materials Corp. (AIMCOR) and Olivine Corp. AIMCOR operates two mines in North Carolina and Washington, and processing plants in Indiana, North Carolina, and Washington; Olivine operates one mine and one processing plant in Washington.

Electrolytic plants in Canada, Kazakhstan, Norway, Russia, Ukraine, and the United States represent 67% of the world magnesium metal production capacity (excluding the capacity in Kazakhstan, Russia, and Ukraine that is used exclusively for titanium metal production). Smaller thermal plants are in Brazil, Canada, China, France, India, Italy, Japan, Serbia and Montenegro, and the United States.

The largest magnesite production facilities in the world are in China, North Korea, and Russia. Together, these three countries account for 60% of the world magnesite production capacity. Japan and the United States account for 61% of the world's magnesium compounds production capacity from seawater or brines. Fused magnesia is produced in Australia, Canada, France, Israel, Japan, Mexico, the United Kingdom, and the United States.

Norway is the world's principal producer of olivine, and in addition to supplying its domestic needs, Norway is a major world supplier of olivine. Countries with smaller output include Austria, Italy, Japan, Mexico, Spain, Sweden, and the United States. *(See tables 1 and 2.)*

Geology

Magnesium is the eighth most abundant element and constitutes about

2% of the Earth's crust. It is the third most plentiful element dissolved in seawater, with a concentration averaging 0.13%. Although many minerals contain magnesium, magnesite, dolomite, brucite, and olivine are the only minerals from which magnesium compounds are recovered commercially.

Dolomite is a sedimentary rock commonly interbedded with limestone, which extends over large areas of the United States and is widespread throughout the rest of the world. Most dolomite occurrences are likely the result of replacement of calcium by magnesium in preexisting limestone beds. Magnesite primarily is found in four types of deposits—sedimentary beds, alterations of serpentine, vein fillings, and replacements of limestone and dolomite. Brucite is found in crystalline limestone and as a decomposition product of magnesium silicates associated with serpentine, dolomite, magnesite, and chromite. Olivine generally occurs as granular masses or disseminated grains or crystals and is a common constituent of basic igneous rocks such as basalt and gabbro. Dunite is an olivine-rich rock.[3]

Technology

***Processing.*—Metal.**—Two thermal processes currently are in use to recover magnesium metal from dolomite—the Pidgeon process and the Magnetherm process. Both use the same basic chemistry, but the Pidgeon process uses an external heat source, and the Magnetherm process uses heat generated by the electrical resistance of the reactants. In the Pidgeon process, dolomite and ferrosilicon are formed into briquettes and heated in a retort under a vacuum. Magnesium oxide in the dolomite reacts with the ferrosilicon to produce magnesium vapor, which is cooled and condensed in a separate section of the retort. Plants in Canada, Italy, and Japan use this process to recover magnesium.

In the Magnetherm process, calcined dolomite, ferrosilicon, and alumina are heated under a vacuum. Alumina reduces the melting point of the slag produced by the dolomite-ferrosilicon reaction to make resistance heating practical. Magnesium vapor is cooled and condensed in a condensing chamber. The Magnetherm process is used in plants in Brazil, France, Japan, Serbia and Montenegro, and the United States.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that normally is prepared from seawater or brines. Two types of magnesium chloride can be made—hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow Chemical Co., magnesium hydroxide is precipitated from seawater by the addition of dolomitic limestone. Adding hydrochloric acid to the magnesium hydroxide produces a neutralized magnesium chloride solution. This solution is dehydrated until it contains about 25% water and then is fed directly to electrolytic cells.

Magnesium Corp. of America (MagCorp) and Norsk Hydro A/S of Norway use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulfate impurities and removing boron by solvent extraction, the brine is concentrated further and dehydrated in a spray dryer. The resulting powder is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.[4] Norsk Hydro starts with concentrated magnesium chloride brine. The brine is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.

Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions usually is not disclosed. Essentially, magnesium chloride fed to an electrolytic cell is broken down into magnesium metal and chlorine gas by direct current at 700° C. Magnesium is removed from the cell and cast into ingots, and the chlorine gas is recycled or sold.

Magnesium International Corp. developed a one-step process for producing anhydrous magnesium chloride that was demonstrated at Magnesium Co. of Canada Ltd.'s (MagCan) plant, which opened in 1990 and closed in 1991. Reacting magnesite with chlorine gas in the presence of carbon monoxide in a packed-bed reactor at 900° C produces magnesium chloride and carbon dioxide. Liquid magnesium chloride collects at the bottom of the reactor and is tapped periodically for transfer to electrolytic cells.[5] This process was not proven on a commercial scale.

Nonmetal.—Preparing either caustic-calcined or dead-burned magnesia from magnesite involves crushing the magnesite to various sizes, depending on the type of material to be produced. After crushing, magnesite is beneficiated; the degree of beneficiation depends on the quality of the ore and its ultimate end use. Lower quality ore often requires heavy-media separation, magnetic separation, and flotation to remove impurities. High-quality ore may require only screening and hand sorting to produce a material of acceptable quality. Caustic-calcined magnesia is produced in shaft kilns, multiple-hearth furnaces, or rotary kilns. Dead-burned magnesia is produced in rotary or shaft kilns.

In producing synthetic magnesia, seawater or brines are treated either with a small quantity of lime or sulfuric acid to remove dissolved carbon dioxide. Then calcium hydroxide, in the form of lime or dolime, is added to precipitate the dissolved magnesium as magnesium hydroxide. The resulting slurry is thickened and vacuum-filtered to yield a filter cake containing about 50% magnesium hydroxide. The filter cake can be directly calcined to produce caustic-calcined or dead-burned magnesia, or it can be calcined and pelletized before dead-burning to give specific size and density characteristics.

Fused magnesia is produced by fusion of high-grade magnesite or caustic-calcined synthetic magnesia in an electric arc furnace. After fusion, the material is crushed, inspected to remove any unfused magnesia, and crushed further in a ball mill.

Recycling.—Magnesium scrap is in forms similar to those of other nonferrous metals. New scrap comes in forms such as castings, drippings, drosses, gates, runners, and turnings. Old scrap primarily comes from old aircraft parts and discarded consumer products, such as lawnmower decks, chainsaw housings, and hand tools. The diecasting industry traditionally is the largest source of scrap magnesium.

Sorted scrap is charged into a steel crucible, which is heated to 675° C. As the scrap at the bottom begins to melt, more scrap is added. The liquid magnesium on the bottom is covered with a flux to inhibit surface burning. After any alloying elements are added and melting is complete, molten magnesium is transferred to ingot molds by either hand ladling, pumping, or tilt pouring.[6]

Economic Factors

Costs to produce magnesium metal vary greatly, depending upon the feed material and the process used. Operating costs for magnesium production range from $309 to $2,283 per ton, with energy costs as the largest component of the total operating cost. A weighted average operating cost was estimated to be $1,122 per ton. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending upon source material and processing techniques. Operating costs range from $24 to $425 per ton for magnesium compound production, with seawater as the most costly source. The weighted average operating cost for magnesium compounds production from all sources was $288 per ton. Energy costs also represent the largest component of total operating costs.[7]

Analysts at Commodities Research Unit (CRU) evaluated the direct operating costs of magnesium plants that operated during 1991. The operating cost curve showed that about one-half of the producers had direct operating costs less than $1.00 per pound of magnesium, and about 20% of the production was at direct operating costs above $1.25 per pound. In their cost estimates, CRU evaluated capital and operating costs for a 60,000-ton-per-year greenfield magnesium plant constructed in Australia. Capital costs were estimated at $470 million, with a 20% rate of return on investment over a 10-year life of the loan. In addition, operating costs were estimated to be $1.76 per pound in constant 1990 dollars, with most of the costs being capital charges resulting from the rate of return on investment and loan life. If the rate of return was lowered to 10% and the life of the loan was extended to 20 years, capital change would drop by one-half.[8]

Tariffs for magnesium and magnesium compounds are shown in table 3. Depletion allowance for magnesium chloride from domestic or foreign sources is 5%. Magnesium carbonate and dolomite have depletion allowances of 14% from domestic and foreign ores. Depletion allowances for other ores are brucite, 10% (domestic and foreign), and olivine, 22% domestic and 14% foreign. *(See table 3.)*

ANNUAL REVIEW

Magnesium

Legislation and Government Programs.—On August 16, the United States-Canada Binational Secretariat upheld findings by the Department of Commerce that Norsk Hydro Canada Inc. was dumping magnesium on the U.S. market. The panel, established by the United States-Canada Free Trade Agreement, also affirmed the countervailing duty determinations, except on two issues. The panel was unclear on why Commerce conducted a disproportionality analysis on an enterprise-by-enterprise basis rather than on an industry-by-industry basis. The panel also stated that Commerce's appropriate allocation period for grants to Norsk Hydro for pollution control equipment must be explained to be consistent with preceding binational panel cases. Commerce explanations of the two issues were due within 30 days of the findings.[9] After remanding the final antidumping duty determination to Commerce on August 16, the United States-Canada Binational Secretariat affirmed Commerce's redetermination on October 6. As a result, the antidumping duty on pure magnesium from Canada was reduced from 31.33% ad valorem to 21% ad valorem. This reduction makes the total antidumping and countervailing duties on pure magnesium 28.65%.[10]

Because of responses received in response to a request for administrative review, the Department of Commerce was initiating administrative reviews of antidumping and countervailing duty determinations made against Norsk Hydro Canada Inc. For antidumping duties assessed on pure magnesium, the review will cover the period from November 20, 1991, through July 31, 1993. For countervailing duties, the review period for pure and alloy magnesium is from December 6, 1991, to December 31, 1992. Commerce intended to issue the final results of these reviews by August 31, 1994.[11]

On October 16, Russia was added to the list of countries that can export their goods into the United States under the Generalized System of Preferences (GSP). Counties that are designated GSP countries can export goods either free of tariffs or at substantially reduced rates. For magnesium, Russia's exports into the United States became duty free with GSP status.

Production.—U.S. primary magnesium production in 1993 declined by 4% from the 1992 level. In contrast, producer stocks of magnesium metal increased significantly from the low level at yearend 1992 as imports supplied a greater share of domestic demand.

In September, Northwest Alloys Inc. announced that it would idle two of its primary magnesium furnaces at its plant in Addy, WA, for retrofitting. The furnaces were expected to be down for about 3 months, and according to industry estimates, production will be reduced by about 2,700 to 2,800 tons. Northwest Alloys reportedly has built up inventories and can satisfy existing contracts.[12] At the beginning of October, Dow Magnesium announced a magnesium production cutback of about 30%. The cutback was expected to take place in two phases; the first would occur before the end of 1993, and the second would occur in January 1994. Fourth quarter 1993 production losses were estimated to be about 3,000 to 4,000 tons. Approximately 20% of the company's work force will be affected by the closure. Dow cited the entrance of countries from the former U.S.S.R. into the world market as the principal reason for the closure.[13] *(See table 4.)*

Consumption and Uses.—Dow Magnesium announced that its direct-chill continuous magnesium caster came on-stream in November and that it was supplying T-bars to large aluminum customers on a trial basis. Although the caster was not intended to increase Dow's production levels, it was expected to eliminate some production bottlenecks. Dow initially will offer the T-bars in three sizes—250-pound, 500-pound, and 1,000-pound, and the company plans eventually to offer 500-pound and 750-pound round billets. A second caster was expected to be operational in January 1994. Dow is the only U.S. producer of the direct-chill-cast T-bars, which the company claims have a smoother surface and a lower likelihood of pockets than conventionally cast magnesium ingots.[14]

The automotive industry continued to be a main target area for increasing magnesium usage resulting in announcements of new magnesium alloy components and increases in diecasting capacity to meet the growing demand. Port City Diecasting in Muskegon, MI, planned to complete construction on a 1,200-square-meter magnesium diecasting facility in the summer. The company, which has been casting aluminum and zinc, is installing two 600-ton cold-chamber diecasting machines dedicated to magnesium. About one-half of Port City's current customers are with the automotive industry, and the company expects to have the same product mix with magnesium.[15]

Magnesium Products of America Inc., a subsidiary of Canada's Meridian Technologies Inc., plans to install three 3,000-ton magnesium diecasting machines in its new facility in Eaton Rapids, MI; the total number of high-pressure casting machines was scheduled to be 12 or 13, ranging in size from 800 tons to 3,000 tons. This new plant was expected to be in operation in September.[16]

Because of increased demand for large die-cast magnesium components, Lunt Manufacturing planned to begin construction of a second 6,000-square-meter magnesium casting facility near Chicago, IL, in 1993. The company currently operates an 8,000-square-meter facility with 12 diecasting machines.

Borg-Warner Corp. plans to increase its production of magnesium alloy four-wheel-drive transfer cases by more than 100%, to a level of more than 500,000 units annually, within 3 years. Production of the additional cases will require nearly 3,000 tons of magnesium annually. The transfer cases are among the largest automotive parts made of magnesium, and Borg-Warner expected to shift to a production ratio of 90% magnesium-10% aluminum within 3 years.[17]

Chrysler Corp. announced that it would incorporate magnesium steering wheel armatures on its new economy car models, which were scheduled to be introduced early in 1994. It is estimated that this application will consume about 200 to 250 tons of magnesium annually. Chrysler's components will be manufactured by Gibbs Die Casting Corp., Henderson, KY, the same company that manufactures steering wheel diecastings for Ford Motor Co.[18] Ford also is investigating the potential for magnesium steering wheels for the 1996 models of another of its product lines. Ford currently uses magnesium steering wheels on several platforms. This application was estimated to represent 800 to 900 tons of magnesium alloy consumption per year.

Chrysler also reportedly finalized plans to use magnesium steering columns and mounting brackets in its minivans beginning in 1996. Total annual magnesium requirements for these parts were estimated to be about 1,000 tons annually. Suppliers for the die-cast parts were Magnesium Products Ltd. in Canada and U.S. manufacturer Diemakers Inc.[19]

Ford and General Motors Corp. (GM) were investigating the use of magnesium alloy seat risers in place of conventional steel units in two truck lines for the 1996 model year. These applications could consume more than 3,000 tons of magnesium alloy annually. Replacement of the steel part with magnesium alloy diecasting is projected to reduce the part weight from 3.6 to 4.5 kilograms to 0.9 to 1.1 kilograms.[20]

GM reportedly was completing plans for instrument panel support beam applications that could require about 5,000 tons of magnesium per year. The new components, which were scheduled to be introduced over a 2-year period beginning in late 1995, were expected to replace steel stampings in three vehicle lines. With a weight of 15 kilograms, the magnesium components were estimated to replace more than 17,000 tons of steel in GM's midsize and standard-size vans and C-body luxury cars.[21]

U.S.-based Rossborough Manufacturing was finalizing a joint venture with the East Slovak Steel Co. to construct a blending plant to produce magnesium-base desulfurization powders in Slovakia. Rossborough planned to expand the plant as demand for desulfurization increases in Eastern Europe.[22]

Dynacast Inc. reportedly acquired the assets of Lone Star Die Casting Corp., New Braunfels, TX, a major supplier of aluminum and magnesium diecastings for garden tools.[23]

IBM Corp. announced that it was producing a small pen-base notebook computer with magnesium cases. Because of magnesium's light weight, the material was chosen to reduce the case mass and make the computer easier to carry.[24]

A review of structural magnesium applications highlighted changes in the past 30 years. In 1966, more than 50 applications for magnesium were cited in 13 areas; by 1988, only 23 applications in 7 areas were cited. Reductions in the number of applications occurred in aerospace and nonindustrial machinery in particular. However, automotive and sporting good applications have increased.[25] *(See tables 5 and 6.)*

Stocks.—Producers' stocks of primary magnesium at yearend 1993 increased to 17,827 tons, more than three times the level at yearend 1992 of 5,863 tons. Stocks of magnesium metal and alloy held by consumers increased to 7,772 tons at yearend 1993 from 7,274 tons at yearend 1992. Consumer stocks of secondary magnesium also increased to 388 tons at yearend 1993 from 356 tons at yearend 1992.

Markets and Prices.—Magnesium prices quoted in trade journals generally decreased steadily through the first three quarters of 1993 before beginning to rise again. The Metals Week U.S. transaction price quotation declined from a range of $1.46 to $1.53 per pound at the beginning of the year to $1.36 to $1.46 by the end of the second quarter. Beginning in July, Metals Week began publishing two primary magnesium prices—the U.S. spot Western price and the U.S. spot dealer import price. The spot Western price would only reflect North American producer-consumer transactions, while the spot dealer import would reflect the price of imported magnesium, delivered, duty paid. These two quotations would replace the U.S. transaction price, which was a weighted average of all transactions.

The Metals Week U.S. spot dealer import price range was quoted at $1.22 to $1.48 per pound at the beginning of the third quarter, and this range dropped steadily to a low of $1.13 to $1.18 per pound by mid-September. By yearend, this price range had increased slightly to $1.17 to $1.21 per pound.

The Metals Week U.S. spot Western price was estimated at $1.45 to $1.46 from the beginning of July through mid-November. From that point, the range widened to $1.43 to $1.46 and remained at that level until yearend.

At the beginning of 1993, Metals Week's quoted European free market price range was $2,400 to $2,500 per ton. The range declined to reach a low for the year of $1,975 to $2,050 by the beginning of September and rose to $2,250 to $2,325 per ton by the end of the year.

Metal Bulletin's free market price quotation also trended downward through the first three quarters of 1993. At the beginning of 1993, the price range was quoted at $2,500 to $2,550 per ton. By mid-September, the quoted range had decreased to $1,950 to $2,050 per ton. This range rose to reach $2,220 to $2,300 per ton by the end of the year.

Foreign Trade.—Exports of magnesium in 1993 declined by 25% from the 1992 level. Canada, Japan, and the Netherlands were the principal destinations. Imports of magnesium increased significantly, with imports from Canada, Russia, and Ukraine making up the bulk of the total. *(See tables 7 and 8.)*

World Review.—In early September, Euroalliages, a European producer association, filed an antidumping suit against magnesium imports from the former U.S.S.R. The European Commission accepted the complaint in October, which alleged that magnesium from the Commonwealth of Independent States was dumped at a margin of 123%. Russian producers stated that the low prices of the magnesium appearing on the European market were from illegal exports and did not correspond to producer prices. Other countries, including Japan and India, also claimed that exports from the former U.S.S.R. were having an adverse effect on their magnesium production.[26]

According to the International Magnesium Association (IMA), world magnesium inventories at the end of 1993 were 42,400 tons, a 44% increase from the yearend 1992 level of 29,500 tons. *(See tables 9, 10, and 11.)*

Australia.—The Australian Federal and Queensland State Governments were jointly funding a feasibility study to construct a magnesium diecasting facility in Gladstone, near Queensland Metals Corp.'s (QMC) proposed magnesium plant. The study represented a strategy for adding value to QMC's magnesite deposit.

Canada.—Meridian Technologies, a Canadian-based magnesium diecaster, reportedly completed two agreements to expand its market into Europe. The company announced an agreement in principle with Stahlschmidt & Maiworm Technics GmbH to develop, produce, and sell magnesium wheels in Germany. Meridian Technologies also signed a Heads of Agreement with Italy's Teksid, with the objective of setting up a European diecasting operation. Teksid, which produces iron and aluminum castings, would provide European contacts and market knowledge to Meridian Technologies.[27]

Magnesium Products installed two 800-ton cold-chamber diecasting machines at its Strathroy, Ontario, facility and began operating a 2,200-ton caster to bring the total casting capacity at the plant to 7,000 tons per year. The company also completed construction at its Eaton Rapids, MI, plant and was planning a June 1994 startup.[28]

France.—Because of high inventory levels, Pechiney announced that it would close two-thirds of its 17,000-ton-per-year primary magnesium production capacity in November 1993, earlier than the company's normal winter closure. Pechiney originally was scheduled to shut down production completely between Christmas and the beginning of March. With the high inventory levels, the company could supply its customers' needs despite the closure. Closure of the plant during the winter, which was initiated last year and occurred during January and February only, was originally intended to reduce electric power costs.[29]

Israel.—At the end of June, Israel's Dead Sea Works (DSW), a subsidiary of Israel Chemicals Ltd. (ICL), announced that it had signed a $9 million contract with a consortium of companies and research institutes in the Commonwealth of Independent States to purchase electrolytic cell technology using carnallite as a feed material. In March, ICL's board of directors had approved a $366 million investment for the plant and a new 110-megawatt power station. The new plant will be at the southern tip of the Dead Sea in the town of Sdom. By mid-July, two Israeli engineering firms had begun work on the engineering, construction, procurement, and management for the planned 25,000-ton-per-year magnesium plant, scheduled to be completed in 1995. If expansion is warranted, construction of a second 25,000-ton-per-year phase is scheduled for 1998. A foundation stone-laying ceremony was held on October 19.[30]

Japan.—Japanese magnesium producer Ube Industries Ltd. reportedly signed a formal agreement with an unidentified partner in China to take dolomite feedstock under a long-term agreement. Previously, Ube Industries had long-term agreements with suppliers in the Republic of Korea and Taiwan and made spot purchases from China. Ube Industries was estimated to require between 80,000 and 100,000 tons of dolomite per year.[31]

Japan Metal & Chemicals (JMC) reportedly liquidated its 5,000-ton-per-year primary magnesium plant in December, after it had been idle for more than 1 year. The plant was originally opened in 1987 and has been closed since mid-1992. Furnace problems were cited as the original reason for closure, but because of increased imports from China and the former U.S.S.R. and appreciation of the yen, the plant has remained closed. JMC announced that it would continue to market magnesium through remelting ingot consigned from Northwest Alloys Inc.[32]

Kawasaki Steel Corp. in Japan announced that it is testing a desulfurization process using magnesium; this company would be the first Japanese steel producer to use magnesium. This could increase the world magnesium desulfurization market significantly.[33]

Japan's Kobe Steel finished installing production equipment at its new aluminum and magnesium alloy casting plant in Daian. The casting shop was expected to be completely operational by December.[34]

Norway.—Hydro Magnesium reportedly was conducting a preliminary study to build a magnesium recycling plant near Herøya, Norway. The proposed plant would have a capacity of 10,000 tons per year and would be the first magnesium recycling plant in Norway. To encourage European automakers to use magnesium, the plant would melt scrap returned from diecasters and return it in ingot form. Completion of the study was scheduled for the second or third quarter of 1993.[35]

Saudi Arabia.—A feasibility study conducted for the Gulf Organization for Industrial Consultancy, an offshoot of the Gulf Corporation Council (GCC), suggested constructing a 10,000-ton-per-year primary magnesium plant in the Persian Gulf area. (The six Arab nations that form the GCC are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.) The study said that Saudi Arabia would be a likely location for the new plant, but both Oman and Qatar could be possible locations. Annual magnesium demand in the six nations was estimated to be 3,000 tons, but was expected to increase to 10,000 tons by 2000. Cost for building the new magnesium plant was calculated to be $85 million, and because of inexpensive fuel costs in the area, the consultancy estimated that the cost of producing 1 ton of magnesium would be $2,880.[36]

Ukraine.—In Ukraine, the Government introduced export duties on a variety of metals and raw materials. Included in these materials is magnesium, which has an export duty of 30% of the sale price, effective June 1, 1993. Previously, the country had no export duty on magnesium.[37] In May, Alusuisse-Lonza Trading Group reportedly signed an agreement with Kemo Komplex in Ukraine to market its Kalusch 99.9% magnesium in most areas of the world. Kemo Komplex was expected to continue to market magnesium in Europe, and its agreement with Alusuisse-Lonza would improve its marketing, transportation, and storage arrangements.[38]

Current Research.—Researchers at the U.S. Bureau of Mines have developed a process to vacuum distill magnesium and zinc from aluminum alloys as an alternative to chlorination. Distillation is considered more environmentally benign than chlorination, and the metals are produced as byproducts that can be recycled. Bench-scale tests have shown lower than expected distillation rates at 850° C, but commercial operations could use induction heating at higher temperatures to improve distillation rates.[39]

The International Magnesium Association's annual magnesium conference highlighted developments in several areas of magnesium and magnesium alloy technology. Topics covered in papers presented at the 1993 conference included advancements in magnesium alloy diecasting technology, alloy development and improvements, desulfurization advances, and magnesium alloy recycling.[40]

Researchers at the Universidad Nacional Autonoma de Mexico studied the effects of microstructure and alloying elements on the efficiency of sacrificial magnesium anodes. From the results of their investigations, the researchers found that by controlling the quantity of second-phase, iron-rich particles at grain boundaries, anode efficiency was improved.[41]

As part of a broad research program aimed at the characterization and development of magnesium and magnesium alloy composites, researchers at Laval University investigated different methods of producing magnesium and magnesium alloy composites reinforced with silicon carbide. Two methods of powder metallurgy processing and one method of ingot metallurgy processing were investigated. In the first powder metallurgy method, mechanical alloying using a low-energy ball mill to form composite particles is followed by hot pressing and hot extrusion. The second powder metallurgy method used simple dry mixing of the particles, followed by hot pressing and hot extrusion. In ingot metallurgy, a fluxless melting technology is used. The researchers found that the best combination of properties, including crack initiation and propagation behavior, was achieved with the low-energy mechanical alloying.[42]

Magnesium Compounds

Production.—Because of decreases in the demand for domestically produced refractory magnesia, production of dead-burned magnesia and magnesium hydroxide declined in 1993. Other magnesium compound production increased slightly.

Dow announced that it had expanded the magnesium hydroxide production capacity at its Ludington, MI, plant to 125,000 tons per year, an increase of 30,000 tons from the prior capacity level. This increase in capacity was driven by anticipated growth in acid neutralization applications for magnesium hydroxide.[43] Martin Marietta Magnesia Specialties reportedly completed a new facility at its Manistee, MI, location for producing FlowMag® slurry products use in wastewater neutralization applications. The company also received a patent on its FlowMag granular product, used to remove heavy metals from industrial-process effluent. To reduce costs and to broaden its product line, Martin Marietta began importing magnesite from China in 1993.[44] *(See table 12.)*

AIMCOR announced that it planned to sell its Metals/Minerals Group, including its olivine operations. The company has hired investment bankers Bowles Hollowell Connor & Co. to find a buyer for the group as a whole or separate buyers for the minerals division and the metals division.[45]

Consumption and Uses.—Dead-burned magnesia refractories for use in metal, cement, and glass production furnaces continued to be the primary application for magnesium compounds in the United States, representing about 66% of the total U.S. demand for magnesium compounds.

In 1993, agricultural applications (animal feed and fertilizer) were the dominant use for caustic-calcined magnesia, accounting for 35% of U.S. shipments. Chemical processing was the next largest segment, with 18% of total shipments. The following categories, with the individual components in parentheses in declining order, were the other end-use sectors for caustic-calcined magnesia: metallurgical (refractories, water treatment, electrical, and stack-gas scrubbing), 16%; manufacturing (rayon, rubber, fuel additives, and pulp and paper), 13%; construction (oxychloride and oxysulfate cements and general construction), 5%; pharmaceuticals and nutrition (medicinal and pharmaceutical, sugar, and candy), 4%; and unspecified uses, 9%.

Magnesium carbonate was used principally as a chemical intermediate and in medicines and pharmaceuticals. Magnesium hydroxide was used mainly in the chemical industries, water treatment, and pulp and paper. Magnesium sulfate was used mostly in pharmaceuticals and animal feed.

Magnesium chloride was used mainly in oxychloride cements. Magnesium chloride brines were used principally for road dust and ice control.

Foundry uses were the largest application for olivine in the United States, accounting for 60% of consumption of domestically produced material. Refractory applications consumed 26% of U.S. olivine shipments, sand blasting and other abrasive applications accounted for 7%, and slag control accounted for the remaining 7% of U.S. olivine consumption. *(See table 13.)*

Markets and Prices.—Most quoted magnesium compound prices at yearend 1993 were significantly higher than prices at the end of 1992. Magnesium hydroxide prices in particular increased almost 25%, which was mainly a result of the increased interest in the material in environmental applications.

U.S. olivine prices, quoted in Industrial Minerals, were $62 to $109 per ton for foundry grade and $50 to $79 per ton for aggregate material. All prices were quoted f.o.b. mine or plant. *(See table 14.)*

Foreign Trade.—Trade data for olivine are not reported separately by the Bureau of the Census. Some data on olivine are available from a computer service, the Port Import/Export Reporting Service (PIERS). PIERS reports data on materials that are transported by ship. According to this source, the United States imported 136,478 tons of olivine from Norway in 1993. Exports of olivine from the United States totaled 1,859 tons. Peru, with 43% and Chile, with 33% of the total, were the principal recipients. Australia, Italy, the Republic of Korea, New Zealand, and Taiwan were the other destinations. *(See tables 15, 16, 17, and 18.)*

World Review.—In Europe, the refractory magnesia market has undergone significant changes in the past few years. Western Europe has been a large producer and significant exporter of dead-burned magnesia, but recently imports have supplied up to 35% of the area's needs. For first-grade refractory magnesia, domestic sources in Greece, Ireland, Italy, the Netherlands, and the United Kingdom traditionally supplied most of western Europe's requirements, but closures in Greece, Italy, and the United Kingdom changed this. With the opening of the Qmag plant in Australia, this country is emerging as a major supplier to western Europe.[46]

Australia.—Queensland Metals Corp. (QMC) and ICI Australia Ltd. reportedly signed an agreement that formally establishes the Enviromag joint venture in May. The 50-50 joint venture was incorporated as Enviromag (Marketing) Pty. Ltd. The company planned to market magnesium hydroxide for environmental markets throughout the world.[47] QMC also reached an agreement in principle with a European group to join the 50-50 Flamemag joint venture, for which the primary objective is to identify to lowest cost process capable of producing a wide range of magnesium hydroxides from magnesite. QMC planned to construct a large pilot plant in Europe, to be operational by the second half of 1994.

China.—At the Liaoning Magnesite Refractory Co., a two-stage froth flotation process was developed to eliminate talc and other minerals from magnesite. By using this process, the magnesite concentrate may be upgraded to contain less than 1.5% silica. A two-stage calcining process also was developed to produce high-purity dead-burned magnesite. By using the high-purity raw material, the company has produced magnesia-carbon, magdol-carbon, direct-bonded magnesite-chrome, and magnesite-alumina refractory bricks. With the process improvements, these refractories have shown improved service performance in several iron and steel- and cement-making applications.[48]

Greece.—To improve the quality of both caustic-calcined and dead-burned magnesite, Grecian Magnesite S.A. commissioned a new petroleum coke facility and a new research and development laboratory. The company also was involved with several outside partners in developing new dead-burned refractory materials. The other magnesite producer, Magnomin Gemco S.A., switched from producing only caustic-calcined magnesite to a 50-50 mix of caustic-calcined and dead-burned magnesite over the past few years. Magnomin was involved in improving product quality through its research and development program, which involved evaluation of the effects of particle size of dead-burned magnesite and assessing the advantages of vertical shaft kilns.[49]

To make itself more attractive to potential buyers, Fimisco reportedly restarted magnesia refractories production in late 1993 from stockpiles of raw materials that the company had on hand. The company was put under Alpha Finance A.E. and was being privatized during 1993, although there were no offers for Fimisco during the first round of privatization. Mining, Trading & Manufacturing Ltd. (MTM), a Greek magnesite producer whose operations have been closed since 1988, also was undergoing privatization under the auspices of Alpha Finance. MTM's operations consisted of an open pit and underground mine, prebeneficiation and beneficiation facilities, and two shaft kilns.[50]

India.—India Rayon announced that it was beginning a project to produce 50,000 tons per year of high-purity refractory magnesia from seawater. This plant will be India's first seawater magnesia plant. Commercial production was expected to begin in early 1995. Refractories Consulting and Engineering, an Austrian firm, was providing technology for the project, and India Rayon was planning to import a part of the plant and equipment required for the project.[51]

In June, Dalmia Magnesite Corp. announced that it was closing its mines in Tamil Nadu for at least 2 months. Before the closure, the company had been working at reduced levels because of poor market conditions. Because of reduced import duties for magnesite, implemented in February, less costly imports from Australia, Brazil, China, North Korea, and Turkey have increased to supply a greater share of the country's demand.[52]

Khaitan Hostombe Spinels reportedly was constructing a $100 million plant in Salem, Tamil Nadu, to produce sintered magnesia and magnesia-chrome clinker. The new 34,000-ton-per-year plant, scheduled to be completed by the third quarter of 1994, will supply domestic consumers, substituting for material that previously was imported.[53]

Israel.—In October, the new 13,000-ton-per-year fused magnesia plant at Mishor Rotem was inaugurated. This $23 million plant is operated by Tateho Dead Sea Fused Magnesia Co., a joint venture between Japan's Tateho Chemical Industries Co. Ltd. and Israel's Dead Sea Periclase Ltd. Preliminary product specifications indicated that the fused magnesia contained 99.5% MgO and 0.5% CaO, with a specific gravity greater that 3.5 grams per cubic centimeter. Initial plant operations will focus on fine tuning process parameters and determining if more than one grade of fused magnesia will be produced.[54]

Jordan.—The Arab Potash Co. Ltd. (APC) planned to build a 3.6-ton-per-day pilot magnesia plant at Safi, the company's existing site. Refractories Consulting & Engineering will supply the equipment and technology for the $1 million plant, which was scheduled to be completed by the beginning of 1994. Magnesium chloride for the plant will be extracted from the brines that APC already uses as a source of potassium chloride. Depending on the results of the pilot tests, APC may decide to construct a 100,000-ton-per-year plant at the same site.[55]

Netherlands.—Billiton Refractories BV was put up for sale by its parent company Royal Dutch/Shell Group after negotiations between Gencor Ltd. and the Shell Group fell through because Billiton did not fit into Gencor's activities. Although many companies were rumored as possible buyers for Billiton, negotiations were not expected to be completed by yearend. Billiton Refractories operates a 100,000-ton-per-year dead-burned magnesia plant in Veendam.[56]

Turkey.—To reform its large state-owned enterprises, Turkey targeted some of its operations for closure and some for privatization. Two of the country's largest magnesite operations—Kümas Kütahya Manyezit and Konya Krom Manyezit—were scheduled for privatization. Kümas was separated from its parent, Çitosan, in 1992, was offered for sale in March 1993, and the bidding was closed in May. One of Turkey's private-sector magnesite companies, Magnesit AS, was one of two companies that bid on Kümas. Konya remained under the umbrella of Çitosan, but was undergoing a major modernization and automation program scheduled to be finished by the end of 1994.[57]

Magnesit began recovering crude magnesite from waste dumps at its mines in June after extensive design studies and testing. The recovery was initiated in 1992 and uses magnetic separation rather than heavy-media separation to recover the magnesite. Original estimates of output were 85,000 tons of crude magnesite per year.[58]

United Kingdom.—U.S.-based J. E. Baker Co. announced an agreement with Redland PLC to acquire the manufacturing plants of Steetly Refractories Ltd. in January. Steetly has two facilities in Worksop and Dudley. The acquisition of the magnesia refractories operations will complement J. E. Baker's dolomite refractories operations in the United States and will enhance the company's international position. *(See tables 19, 20, and 21.)*

Current Research.—Science Ventures Inc. announced that it had developed a leaching process to remove unwanted magnesium from dolomitic phosphate ores as marketable magnesium oxide. In the process, called the P^3 process, sulfuric acid is added to the ore to maintain a pH range of 4.0 to 4.4 and carbon dioxide is continuously removed by boiling the solution. In a second step, lime is added to the solution to precipitate magnesium hydroxide. The process was developed because the magnesium content of dolomitic phosphate ores increases solution viscosity and precipitates on equipment used in the manufacture of phosphoric acid.[59]

OUTLOOK

Magnesium producers throughout the world, but especially in the United States, have targeted the automotive industry as a potential growth market for magnesium. Within the past 15 years, through the introduction of high-purity diecasting alloys, the average magnesium content of a North American automobile has increased from 0.5 kilogram to 2.3 kilograms. As a result, production of magnesium diecasting has increased significantly. Steady growth in this area is likely, as automobile manufacturers continue to announce new applications for magnesium diecastings in future car, truck, and van models.

Other large applications for magnesium, aluminum alloying and iron and steel desulfurization, are likely to be areas of slow growth for magnesium consumption. These markets are fairly mature in the United States. In aluminum alloying, most of the magnesium is used for beverage cans, which generally grow only with increases in population. Although iron and steel desulfurization has had a large growth rate in the past decade, most of the U.S. market already has been captured from calcium carbide. Growth in the desulfurization market only will come as additional metal requires desulfurization, not as a result of substitution done in the past.

The most important influence on world supply of magnesium has been exports from Kazakhstan, Russia, and Ukraine appearing on the world market. In 1993, Russia and Ukraine were responsible for a 470% increase in U.S. primary magnesium imports from the 1992 figure. The IMA also reported that there was a significant increase in imports from the former U.S.S.R. to Europe and Japan. Most of this material was used for aluminum alloying and desulfurization. The European producers already have filed an antidumping suit against these magnesium imports, and press reports indicated that antidumping suits may be filed in the United States and Japan. U.S. producers have cited these increased imports as reasons for closing parts of their plants. World inventories also have shown a significant increase from 1992 levels. The outcome of the European antidumping suit and resolution of potential antidumping actions in the rest of the world will have a significant impact on the world supply of magnesium.

Production and demand for magnesium compounds in the United States were expected to remain relatively stable over the new few years, but the proportion of magnesia used as refractories was expected to continue to decrease. Technological changes in steel production have had a deleterious effect on the consumption of specific refractories. Open-hearth furnaces have been replaced by electric arc furnaces and basic-oxygen steelmaking. Although the trend to electric arc furnaces has reduced the overall demand for refractories, high-quality basic refractories (including magnesia-base refractories) are needed for the body of the furnace. At the same time, improvements in refractories technology resulted in increased longevity. There will still be a demand for magnesia refractories, but producers will continue to work to produce higher quality material that is needed by their customers.

Although refractories are the principal use for magnesia, environmental applications, such as flue gas desulfurization and water treatment, are being investigated as growth areas for magnesia and other magnesium compounds. Any increase in demand for other magnesium compounds is expected to be offset by the decline in refractories demand, leading to a stagnant demand for magnesium compounds in the United States.

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TABLE 1

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY, IN 1993

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

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TABLE 2
U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY, IN 1993

Raw material source and producing company	Location	Capacity (metric tons of MgO equivalent)	Products
Magnesite: Premier Services Inc.	Gabbs, NV	100,000	Caustic-calcined and dead-burned magnesia.
Lake brines:			
Great Salt Lake Minerals Corp.	Ogden, UT	90,000	Magnesium chloride and magnesium chloride brines.
Reilly Industries Inc.	Wendover, UT	45,000	Magnesium chloride brines.
Well brines:			
The Dow Chemical Co.	Ludington, MI	214,000	Magnesium hydroxide.
Martin Marietta Magnesia Specialties Inc.	Manistee, MI	275,000	Caustic-calcined and dead-burned magnesia.
Morton International	do.	10,000	Magnesium carbonate, magnesium hydroxide, and caustic-calcined magnesia.
Seawater:			
Barcroft Co.	Lewes, DE	5,000	Magnesium hydroxide.
The Dow Chemical Co.	Freeport, TX	20,000	Magnesium chloride.
Marine Magnesium Co.	South San Francisco, CA	15,000	Magnesium carbonate, magnesium hydroxide, and caustic-calcined magnesia.
National Refractories & Minerals Corp.	Moss Landing, CA	165,000	Magnesium hydroxide and caustic-calcined and dead-burned magnesia.
Premier Services Inc.	Port St. Joe, FL	50,000	Caustic-calcined and dead-burned magnesia.
Total		989,000	

TABLE 3
U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1993	Jan. 1, 1993
Magnesium:			
Unwrought magnesium	8104.11.0000	8.0% ad valorem	100% ad valorem.
Unwrought magnesium alloys	8104.19.0000	6.5% ad valorem	60.5% ad valorem.
Magnesium waste and scrap	8104.20.0000	Free	Free.
Wrought magnesium	8104.90.0000	14.8 cents per kilograms on Mg content + 3.5% ad valorem	88 cents per kilogram on Mg content + 20.0% ad valorem.
Magnesium compounds:			
Crude magnesite	2519.10.0000	Free	$10.33 per ton.
Dead-burned and fused magnesia	2519.90.1000	0.4 cent per kilogram	1.7 cents per kilogram.
Caustic-calcined magnesia	2519.90.2000	$2.07 per ton	$20.70 per ton.
Other magnesia	2519.90.5000	Free	15.4 cents per kilogram.
Calcined dolomite	2518.20.0000	6% ad valorem	30% ad valorem.
Kieserite, natural	2530.20.1000	Free	Free.
Epsom salts, natural	2530.20.2000	3.7% ad valorem	20% ad valorem.
Magnesium hydroxide and peroxide	2816.10.0000	3.1% ad valorem	25% ad valorem.
Magnesium chloride	2827.31.0000	1.5% ad valorem	5% ad valorem.
Magnesium sulfate	2833.21.0000	3.7% ad valorem	20% ad valorem.

Source: U.S. International Trade Commission.

TABLE 4

SALIENT MAGNESIUM STATISTICS

(Metric tons unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Production:					
Primary magnesium	152,066	139,333	131,288	136,947	132,144
Secondary magnesium	51,200	54,808	50,543	57,045	58,890
Exports	56,631	51,834	55,160	[r]51,951	38,815
Imports for consumption	12,289	26,755	31,863	[r]11,844	37,248
Consumption, primary	105,226	96,108	91,872	93,827	100,571
Price per pound	$1.63	$1.43-$1.63	$1.43	$1.46-$1.53	[1]$1.43-$1.46
World: Primary production	[r]344,447	[r]355,237	[r]341,000	[r]306,381	[e]283,944

[e]Estimated. [r]Revised.

[1]Yearend Platt's Metals Week U.S. spot western price.

TABLE 5

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1989	1990	1991	1992	1993
KIND OF SCRAP					
New scrap:					
Magnesium-base	3,951	3,992	4,867	4,539	3,221
Aluminum-base	19,278	19,432	18,192	21,652	25,092
Total	23,229	23,424	23,059	26,191	28,313
Old scrap:					
Magnesium-base	4,269	4,277	4,443	4,220	4,323
Aluminum-base	23,702	27,107	23,041	26,634	26,254
Total	27,971	31,384	27,484	30,854	30,577
Grand total	51,200	54,808	50,543	57,045	58,890
FORM OF RECOVERY					
Magnesium alloy ingot[1]	4,494	4,290	4,604	W	W
Magnesium alloy castings	795	857	1,043	923	1,091
Magnesium alloy shapes	635	301	158	329	413
Aluminum alloys	43,125	46,807	41,606	48,619	51,587
Zinc and other alloys	W	W	3	3	2
Other[2]	2,151	2,553	3,129	7,171	5,797
Total	51,200	54,808	50,543	57,045	58,890

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

[1]Includes secondary magnesium content of both secondary and primary alloy ingot.

[2]Includes chemical and other dissipative uses and cathodic protection, as well as data indicated by symbol "W."

TABLE 6

U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1989	1990	1991	1992	1993
For structural products:					
Castings:					
Die	5,627	7,479	7,532	8,920	10,949
Permanent mold	811	875	750	853	746
Sand	1,017	724	575	450	397
Wrought products:					
Extrusions	6,712	7,848	6,387	6,435	7,433
Other[1]	2,941	3,096	2,415	2,408	2,438
Total	17,108	20,022	17,659	19,066	21,963
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	53,821	45,060	45,809	41,003	46,498
Other	9	8	9	10	10
Cathodic protection (anodes)	5,474	5,421	4,976	4,852	4,723
Chemicals	594	800	695	739	653
Iron and steel desulfurization	10,463	9,853	10,895	13,611	12,525
Nodular iron	1,635	1,424	1,074	W	W
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	10,798	8,989	6,071	8,209	9,092
Other[2]	5,324	4,531	4,684	6,337	5,107
Total	88,118	76,086	74,213	74,761	78,608
Grand total	105,226	96,108	91,872	93,827	100,571

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

[1] Includes sheet and plate and forgings.

[2] Includes scavenger, deoxidizer, and powder.

TABLE 7
U.S. EXPORTS OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Argentina	—	—	384	$906	—	—	70	$420
Australia	7	$15	2,975	5,447	—	—	117	517
Belgium	—	—	7	96	15	$88	86	541
Brazil	—	—	338	718	—	—	41	104
Canada	2,097	[r]4,798	4,041	9,967	1,035	2,766	819	4,067
Ghana	—	—	138	360	—	—	—	—
India	—	—	124	335	—	—	45	388
Iran	—	—	450	1,496	—	—	—	—
Japan	11	22	10,996	26,690	59	289	1,174	4,928
Korea, Republic of	—	—	444	1,084	103	715	6,749	2,049
Mexico	295	668	354	949	58	212	201	741
Netherlands	76	240	13,940	41,108	43	129	1,907	5,591
Taiwan	—	—	349	758	10	33	42	570
United Kingdom	10	164	91	592	28	295	139	563
Venezuela	—	—	481	913	1	7	2	5
Other	(1)	(1)	[r]712	[r]4,802	[r]121	[r]831	[r]766	[r]3,883
Total	2,496	5,907	35,824	96,221	1,473	5,365	12,158	24,367
1993:								
Argentina	—	—	119	311	1	9	50	273
Australia	—	—	2,990	5,661	22	42	163	708
Belgium	—	—	1,664	5,498	85	276	419	1,308
Brazil	3	22	190	442	(2)	15	36	112
Canada	1,956	4,484	5,514	15,417	1,140	3,528	726	3,337
Ghana	—	—	100	313	—	—	—	—
India	—	—	110	330	—	—	3	26
Iran	—	—	10	32	—	—	—	—
Japan	—	—	7,451	19,250	188	1,120	331	2,407
Korea, Republic of	16	24	177	519	158	1,119	4,941	1,596
Mexico	24	55	325	923	220	917	370	1,281
Netherlands	—	—	7,488	19,815	12	37	595	1,797
Taiwan	6	32	—	—	7	42	2	25
United Kingdom	2	19	19	306	6	97	210	766
Venezuela	—	—	25	75	3	38	—	—
Other	—	—	336	2,960	111	979	491	5,136
Total	2,007	4,636	26,518	71,852	1,953	8,219	8,337	18,772

[r] Revised.
[1] Revised to zero.
[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM, BY COUNTRY

Country	Waste and scrap		Metal		Alloys (magnesium content)		Powder, sheets, tubing, ribbons, wire, other forms (magnesium content)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Brazil	—	—	40	$110	—	—	—	—
Canada	1,049	$722	548	1,514	3,144	$11,312	344	$913
China	—	—	370	930	57	248	—	—
France	—	—	111	291	1	58	(1)	3
Germany	83	86	—	—	(1)	11	(1)	35
Kazakhstan	—	—	—	—	209	486	—	—
Mexico	87	63	97	289	—	—	988	3,247
Netherlands	137	120	—	—	—	—	(2)	—
Norway	—	—	—	—	(1)	2	1	2
Russia	561	1,179	1,930	5,122	77	209	—	—
Taiwan	31	31	—	—	—	—	—	—
Ukraine	—	—	692	1,871	—	—	—	—
United Kingdom	274	442	(1)	4	324	1,787	3	70
Other	[r]203	[r]178	[r]456	[r]899	27	432	(1)	11
Total	2,425	2,821	4,244	11,030	3,839	14,545	1,336	4,281
1993:								
Brazil	—	—	1,075	2,694	—	—	—	—
Canada	517	742	802	2,391	5,459	18,964	102	458
China	1	3	1,148	2,748	919	2,393	—	—
France	—	—	60	192	6	189	—	—
Germany	162	137	38	87	6	16	1	20
Kazakhstan	—	—	—	—	323	865	—	—
Mexico	1,076	1,376	—	—	—	—	1,328	3,937
Netherlands	451	510	50	103	(1)	3	(1)	5
Norway	—	—	—	—	269	861	36	116
Russia	272	463	16,639	35,831	773	1,638	1	6
Taiwan	140	132	—	—	38	98	—	—
Ukraine	—	—	4,223	8,577	17	40	—	—
United Kingdom	300	422	132	295	252	1,933	1	78
Other	540	737	69	182	22	544	(1)	2
Total	3,459	4,522	24,236	53,100	8,084	27,544	1,469	4,622

[r] Revised.
[1] Less than 1/2 unit.
[2] Revised to zero.

Source: Bureau of the Census.

TABLE 9
WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1993, BY CONTINENT AND COUNTRY

(Metric tons)

Continent and country	Capacity
North America:	
Canada	49,000
United States	160,000
Total	209,000
South America: Brazil	10,600
Europe:	
France	17,000
Italy	[2]10,000
Kazakhstan	[3]65,000
Norway	41,000
Russia	[3]95,000
Serbia and Montenegro	[2]7,000
Ukraine	[3]54,000
Total	289,000
Asia:	
China	10,000
India	1,500
Japan	8,300
Total	19,800
World total	528,400

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

[2] Standby capacity only.

[3] Includes magnesium production capacity that is used exclusively for titanium production as follows: Kazakhstan, 40,000 metric tons; Russia, 35,000 metric tons; and Ukraine, 15,000 metric tons.

TABLE 10

MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Brazil[e]	6,200	[r]8,700	7,800	7,300	9,700
Canada	[r] [e]7,000	26,726	35,512	[e]25,700	23,300
China[e]	[r]3,500	[r]5,900	[r]8,600	[r]10,000	12,000
France	14,600	[r] [e]14,000	[e]14,000	[r]13,700	13,000
Italy	[r]5,768	5,725	[r]3,919	[r]1,211	—
Japan	8,381	12,843	11,559	[r]7,119	7,500
Kazakhstan[e]	—	—	—	20,000	20,000
Norway	49,827	48,222	44,322	30,404	27,300
Russia[e] [2]	—	—	—	40,000	30,000
Serbia and Montenegro[3]	—	—	—	[e]4,000	—
Ukraine[e]	—	—	—	10,000	9,000
U.S.S.R.[e] [4]	91,000	88,000	80,000	—	—
United States	152,066	139,333	131,288	136,947	[5]132,144
Yugoslavia[3] [6]	6,105	5,788	[e]4,000	—	—
Total	[r]344,447	[r]355,237	[r]341,000	[r]306,381	283,944

[e] Estimated. [r] Revised.

[1] Table includes data available through July 14, 1994.

[2] Includes secondary.

[3] All production in Yugoslavia 1989-91 came from Serbia and Montenegro.

[4] Dissolved in Dec. 1991.

[5] Reported figure.

[6] Dissolved in Apr. 1992.

TABLE 11

MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Brazil[e]	1,500	1,600	1,600	1,600	1,600
Japan	20,270	23,308	17,158	12,978	[2]13,215
U.S.S.R.[e] [3]	8,000	7,500	7,000	6,500	6,000
United Kingdom[e] [4]	1,000	[r]900	[r]800	800	500
United States	51,200	[r]54,808	50,543	57,045	[2]58,890
Total	81,970	[r]88,116	[r]77,101	78,923	80,205

[e] Estimated. [r] Revised.

[1] Table includes data available through July 14, 1994.

[2] Reported figure.

[3] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

[4] Includes alloys.

TABLE 12
SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	135	135	154	130	131
Value	$39,529	$37,850	$48,074	[r]$36,781	$39,476
Exports, value[3]	$2,263	$1,406	$2,289	$2,404	$2,459
Imports for consumption, value[3]	$13,657	$13,957	$15,891	$12,309	$15,709
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	348	335	296	291	268
Value	$97,673	$94,962	$85,292	$80,756	$77,716
Exports, value	$10,685	$19,709	$25,038	$22,257	$21,807
Imports for consumption, value	$38,555	$32,858	$30,209	$37,928	$48,673
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	365	342	308	[r]302	315
Value	$28,294	$26,988	$25,736	$25,230	$26,218
World production (magnesite)	[r]11,953	[r]10,481	[r]9,813	[r]10,501	[e]10,136

[e] Estimated. [r] Revised.

[1] Excludes caustic-calcined magnesia used in the production of refractory magnesia.

[2] Includes magnesia used by producers.

[3] Caustic-calcined magnesia only.

TABLE 13
U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	130,118	[r]$36,781	131,207	$39,476
Magnesium hydroxide [100% $Mg(OH)_2$][1]	267,087	[r]64,445	252,471	61,585
Magnesium sulfate (anhydrous and hydrous)	37,889	13,919	42,687	13,974
Precipitated magnesium carbonate[1]	2,162	547	3,005	672
Refractory magnesia	290,558	80,756	268,275	77,716

[r] Revised.

[1] Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

TABLE 14
YEAREND MAGNESIUM COMPOUND PRICES

Material		Price
Magnesia, natural, technical, heavy, 85%, f.o.b. Nevada	per short ton	$232- $265
Magnesia, natural, technical, heavy, 90%, f.o.b. Nevada	do.	265
Magnesia, dead-burned	do.	330
Magnesia, synthetic technical	do.	366
Magnesium chloride, hydrous, 99%, flake	do.	290
Magnesium carbonate, light, technical (freight equalized)	per pound	$0.73- 0.78
Magnesium hydroxide, National Formulary, powder (freight equalized)	do.	.95- 1.05
Magnesium sulfate, technical (epsom salts)	do.	.16

Source: Chemical Marketing Reporter.

TABLE 15
U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Material and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	—	—	142	$47
Colombia	255	$98	355	136
Germany	546	353	495	404
Mexico	359	103	543	243
Netherlands	1,482	801	865	573
United Kingdom	81	131	62	103
Venezuela	2,135	694	1,666	477
Other	[r]404	[r]224	325	476
Total	5,262	2,404	4,453	2,459
Dead-burned and fused magnesia:				
Brazil	685	764	288	292
Canada	38,605	14,595	40,696	14,262
France	1,887	508	67	23
Germany	2	525	2,162	689
Israel	1,457	756	906	524
Japan	532	101	37	7
Korea, Republic of	286	138	756	442
Mexico	1,251	459	1,300	546
Netherlands	150	56	461	170
Switzerland	1,000	368	—	—
Taiwan	307	136	119	82
Thailand	4,257	1,594	2,051	615
Venezuela	5,956	2,011	10,318	3,772
Other	[r]383	[r]246	686	383
Total	56,758	22,257	59,847	21,807
Other magnesia:				
Australia	296	369	491	551
Canada	5,545	2,687	6,508	2,568
Colombia	204	354	213	380
France	86	115	2,664	710
Germany	138	140	109	129
Italy	52	64	136	188
Korea, Republic of	191	174	165	144
Mexico	9,684	5,326	7,380	3,586
Netherlands	116	54	123	87
Spain	1,753	952	1,511	791
Taiwan	317	122	351	222
United Kingdom	82	105	301	175
Venezuela	227	113	1,349	513
Other	384	965	713	1,104
Total	19,075	11,540	22,014	11,148
Crude magnesite:				
Australia	81	86	72	96
Brazil	169	242	385	244
Canada	726	145	791	245
China	—	—	237	105

See footnotes at end of table.

TABLE 15—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Material and country	1992 Quantity (metric tons)	1992 Value (thousands)	1993 Quantity (metric tons)	1993 Value (thousands)
Crude magnesite—Continued:				
Costa Rica	6	$3	1,998	$361
Germany	795	898	134	181
Italy	450	545	—	—
Korea, Republic of	789	316	819	231
Mexico	884	277	818	321
Netherlands	940	736	993	641
New Zealand	209	249	125	176
Panama	—	—	298	177
Spain	96	74	—	—
Taiwan	317	29	37	4
Other	[r]464	[r]614	683	225
Total	5,926	4,128	7,390	2,911
Calcined dolomite:				
Canada	2,695	529	1,864	403
Colombia	212	39	—	—
Mexico	5,761	1,290	7,155	1,624
Saudi Arabia	1,810	252	37	4
Trinidad and Tobago	3,887	507	4,031	605
Venezuela	5,037	642	513	124
Other	182	55	144	58
Total	19,584	3,314	13,744	2,818

[r] Revised.

Source: Bureau of the Census.

TABLE 16

U.S. EXPORTS OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide: Quantity (metric tons)	Magnesium hydroxide and peroxide: Value (thousands)	Magnesium chloride (anhydrous and other): Quantity (metric tons)	Magnesium chloride (anhydrous and other): Value (thousands)	Magnesium sulfate (natural kieserite and epsom salts): Quantity (metric tons)	Magnesium sulfate (natural kieserite and epsom salts): Value (thousands)	Magnesium sulfate (other): Quantity (metric tons)	Magnesium sulfate (other): Value (thousands)
1991	2,691	$4,190	2,995	$2,134	808	$497	2,419	$1,201
1992	2,280	4,411	3,941	2,348	436	333	2,929	1,161
1993	2,543	3,577	3,141	2,636	69	52	4,139	1,667

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Material and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:				
Canada	48,206	$9,507	42,830	$8,555
China	29,423	1,798	83,094	4,700
Greece	2,747	445	9,883	1,468
Japan	2,595	547	359	586
Slovakia[1]	—	—	4,488	400
Turkey	80	12	—	—
Total	83,051	12,309	140,654	15,709
Dead-burned and fused magnesia:				
Australia	263	136	1,327	583
Austria	10,199	4,127	13,624	6,069
Brazil	3,000	360	3,065	378
Canada	2,976	1,599	5,453	2,234
China	132,500	13,807	196,457	15,940
Czechoslovakia[2]	8,537	789	—	—
France	2,000	404	5	9
Germany	2,145	884	1,180	686
Greece	12,767	1,615	6,435	938
Ireland	—	—	4,334	1,594
Israel	12,168	5,121	16,248	6,882
Italy	2,500	558	—	—
Japan	2,465	2,152	7,934	3,467
Mexico	17,525	6,030	21,563	9,313
Other	[r]1,370	[r]346	1,696	580
Total	210,415	37,928	279,321	48,673
Other magnesia:				
Brazil	122	98	244	191
Canada	280	204	100	33
China	168	938	1,330	238
Israel	526	942	856	1,452
Japan	1,918	3,384	1,828	3,639
Netherlands	55	20	340	209
Tajikistan	107	219	—	—
Other	[r]108	[r]355	421	503
Total	3,284	6,160	5,119	6,265
Crude magnesite:				
China	804	83	109	43
Italy	2,163	230	38	12
Japan	338	249	144	167
Other	102	61	41	29
Total	3,407	623	332	251
Calcined dolomite:				
Austria	220	159	1,973	842

See footnotes at end of table.

TABLE 17—Continued
U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Material and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Calcined dolomite—Continued:				
Canada	23,610	$3,069	33,237	$3,509
Germany	54	12	19	9
Other	20	5	567	70
Total	23,904	[r]3,245	35,796	4,430

[r] Revised.

[1] Formerly part of Czechoslovakia.

[2] Dissolved in Dec. 1992.

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite)		Magnesium sulfate (natural epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991	3,842	$6,355	7,184	$1,691	16,727	$596	107	$14	6,524	$1,265
1992	1,750	2,461	4,594	1,447	16,902	754	36	36	5,193	1,119
1993	1,773	1,826	5,323	1,742	20,157	1,040	138	154	6,652	1,376

Source: Bureau of the Census.

TABLE 19

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1993

(Thousand metric tons, MgO equivalent)

Country	Raw material				Total
	Magnesite		Seawater or brines		
	Caustic-calcined	Dead-burned	Caustic-calcined	Dead-burned	
North America:					
Canada	100	—	—	—	100
Mexico	—	—	10	150	160
United States	NA	NA	NA	NA	[2]989
Total	100	NA	10	150	1,249
South America: Brazil	45	146	—	—	191
Europe:					
Austria	90	565	—	—	655
France	—	—	30	—	30
Greece	100	140	—	—	240
Ireland	—	—	NA	NA	100
Italy	25	—	5	125	155
Netherlands	—	—	—	100	100
Norway	—	—	25	—	25
Poland	—	10	—	—	10
Russia	—	2,200	—	—	2,200
Serbia and Montenegro	40	200	—	—	240
Slovakia	26	700	—	—	726
Spain	135	70	—	—	205
Turkey	50	259	—	—	309
Ukraine	—	—	20	80	100
United Kingdom	—	—	NA	NA	200
Total	466	4,144	80	305	5,295
Africa:					
Kenya	NA	NA	—	—	170
South Africa, Republic of	4	80	—	—	84
Zimbabwe	NA	NA	—	—	2
Total	4	80	—	—	256
Asia:					
China	200	850	—	10	1,060
India	30	204	—	—	234
Israel	—	—	10	60	70
Japan	—	—	590	60	650
Korea, North	NA	NA	—	—	2,100
Korea, Republic of	—	—	—	50	50
Nepal	—	50	—	—	50
Total	230	1,104	600	180	4,214
Oceania: Australia	160	30	—	—	190
Grand total	1,005	5,504	690	635	11,395

NA Not available.

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

[2] Includes capacity for production of magnesium chloride, magnesium chloride brines, magnesium carbonate, magnesium hydroxide, and caustic-calcined and dead-burned magnesia.

TABLE 20
MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Australia[e]	55,000	60,000	100,000	820,000	800,000
Austria	1,204,942	1,179,162	[r]960,589	[r]995,347	1,000,000
Brazil[2] (beneficiated)	259,508	257,159	242,256	[e]250,000	250,000
Canada[e] [3]	150,000	150,000	180,000	180,000	180,000
China[e]	2,600,000	[r]2,170,000	[r]1,650,000	[r]1,510,000	1,500,000
Colombia	20,425	19,300	18,768	[r]18,840	18,900
Czechoslovakia[4] [5]	642,000	561,000	328,000	—	—
Greece	903,593	696,900	590,188	[e]250,000	250,000
India	479,530	544,000	[e]539,000	[e]550,000	500,000
Iran[6]	6,967	1,405	29,291	[r]36,165	40,000
Korea, North[e]	1,500,000	1,500,000	1,600,000	1,600,000	1,600,000
Mexico	[r]4,229	[r]579	[r]—	[r]—	—
Nepal	27,978	[e]25,000	[e]25,000	[e]25,000	25,000
Pakistan	8,750	4,274	5,191	[r]6,484	3,000
Philippines[e]	[7]4,796	700	700	700	700
Poland	24,133	23,300	[r]8,100	[r]12,900	14,000
Russia[8]	—	—	—	1,100,000	800,000
Serbia and Montenegro[9]	—	—	—	[r]185,000	185,000
Slovakia[4] [10]	—	—	—	1,267,000	1,200,000
South Africa, Republic of	75,695	114,182	92,634	[r]60,085	60,000
Spain	[r]430,778	[r]444,350	[r] [e]445,000	[r] [e]400,000	400,000
Turkey (run of mine)	1,343,893	[r]845,124	[r]1,365,287	[r]1,224,900	1,300,000
U.S.S.R.[e] [8] [11]	1,825,000	1,600,000	1,400,000	—	—
United States	W	W	W	W	W
Yugoslavia[9] [12]	[r]352,000	[r]252,000	210,000	—	—
Zimbabwe	33,423	32,639	23,295	[r]8,973	9,000
Total	[r]11,952,640	[r]10,481,074	[r]9,813,299	[r]10,501,394	10,135,600

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

[1] Figures represent crude salable magnesite. In addition to the countries listed, Bulgaria produced magnesite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Table includes data available through June 1, 1994.

[2] Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1989—1,385,565; 1990—1,432,741; 1991—879,477 (revised); 1992—880,000 (estimated); and 1993—880,000 (estimated).

[3] Magnesitic dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

[4] All production in Czechoslovakia from 1989-92 came from Slovakia.

[5] Dissolved on Dec. 31, 1992.

[6] Year beginning Mar. 21 of that stated. Figures for 1989 and 1990 are for magnesite; figures for 1991 and 1992 include 3,336 tons and 220 tons of huntite ($Mg_3Ca(CO_3)_4$), respectively.

[7] Reported figure.

[8] All production in U.S.S.R. from 1989-91 came from Russia.

[9] All production in Yugoslavia from 1989-91 came from Serbia and Montenegro.

[10] Formerly part of Czechoslovakia.

[11] Dissolved in Dec. 1991.

[12] Dissolved in Apr. 1992.

TABLE 21
MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WORLD PRODUCTION											
United States:											
Nonmetal	567	574	420	412	464	573	513	499	442	[r]418	386
Metal	104	144	136	125	124	142	152	139	131	137	132
Total	671	718	556	537	588	715	665	638	573	[r]555	518
Rest of world:											
Nonmetal	4,777	4,676	4,807	5,009	4,905	4,756	[r]4,745	[r]4,321	[r]4,128	[r]4,327	[e]4,222
Metal	156	184	189	196	200	192	192	[r]216	[r]210	[r]169	[e]152
Total	4,933	4,860	4,996	5,205	5,105	4,948	[r]4,937	[r]4,537	[r]4,338	[r]4,496	[e]4,374
World total	5,604	5,578	5,552	5,742	5,693	5,663	[r]5,602	[r]5,175	[r]4,911	[r]5,051	[e]4,892
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	567	574	420	412	464	573	513	499	442	[r]418	386
Primary metal	104	144	136	125	124	142	152	139	131	137	132
Secondary metal (old scrap)	23	24	24	23	23	28	28	31	27	31	31
Imports:											
Nonmetal	61	115	134	160	164	198	171	147	156	179	256
Metal	5	9	8	8	11	14	12	27	32	12	37
Industry stocks, metal, Jan. 1	42	25	32	39	39	28	25	26	26	27	13
Total U.S. supply	802	891	754	767	825	983	901	869	814	[r]804	855
Distribution of U.S. supply:											
Exports:											
Nonmetal	15	27	25	25	20	34	26	59	57	49	52
Metal	43	44	36	40	44	50	57	52	55	52	39
Industry stocks, metal, Dec. 31	25	32	39	39	28	25	26	26	27	13	26
Industrial demand[1]	719	788	654	663	733	874	792	732	675	[r]690	738
U.S. DEMAND PATTERN											
Nonmetal:											
Chemicals	105	131	127	171	155	202	188	174	187	[r]176	200
Refractories	508	531	402	376	453	535	470	413	354	[r]372	390
Total	613	662	529	547	608	737	658	587	541	[r]548	590
Metal:											
Cans and containers	19	23	23	22	39	39	42	45	42	40	38
Chemicals	7	8	5	3	2	1	1	1	1	1	1
Iron and steel desulfurization	NA	10	12	12	13	15	15	16	13	20	19
Iron and steel foundries	3	4	3	3	2	3	2	1	1	2	2
Machinery	34	29	22	27	19	20	17	20	21	25	20
Nonferrous metal production	6	9	12	9	5	11	12	11	7	9	10
Transportation	31	36	38	33	38	38	36	38	37	34	47
Other	6	7	10	7	7	10	9	13	12	11	11
Total	106	126	125	116	125	137	134	145	134	142	148
Total industrial demand	719	788	654	663	733	874	792	732	675	[r]690	738
Total U.S. primary demand[2]	696	764	630	640	710	846	764	701	648	[r]659	707
Total U.S. demand for primary metal[3]	83	102	101	93	102	109	106	114	107	111	117

[e] Estimated. [r] Revised. NA Not available.

[1] Sum of total nonmetal and total metal demands.

[2] Total U.S. demand less U.S. recovery from secondary metal.

[3] U.S. demand for metal less U.S. recovery from secondary metal.

MANGANESE

By Thomas S. Jones

Dr. Jones, a physical scientist with more than 30 years industry and U.S. Bureau of Mines experience, has been the commodity specialist for manganese since 1982. Domestic survey data were prepared by Glenn Wallace, statistical assistant; and the international data tables were prepared under the direction of Ivette Torres, Chief, Section of International Data.

Manganese (Mn) is essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties. Currently, no practical approaches exist for replacing it by other materials or for obtaining the bulk of U.S. requirements from domestic sources. The steel industries and economies of Japan and Western Europe are in much the same position relative to manganese as are those of the United States.

In the United States in 1993, ironmaking and steelmaking continued to account for most domestic manganese demand, in the range of 85% to 90% of the total. The overall level and nature of manganese use in the United States is expected to remain much the same in the near and medium terms. Reported data indicated that the overall rate of usage of manganese in ironmaking and steelmaking decreased in 1993 compared to that in 1992. A slight decline of 3% in overall unit consumption of ferroalloys and metal was again because of a lower usage rate for ferromanganese. In ironmaking, the usage rate of manganese as ore dropped sharply, by about two-thirds.

U.S. imports rose to record levels for silicomanganese and manganese dioxide. Volume was up about one-fourth for silicomanganese, with major increases for receipts from China and Ukraine. The domestic industry petitioned the Government late in the year for tariff protection against imports of silicomanganese from four countries because of alleged sales at less than fair value. Renewed record imports of manganese dioxide signified continuing strong growth in demand for manganese in dry cell batteries. To help meet demand, domestic producers were making significant increases in their dioxide production capacity.

Disposals of manganese materials from Government stockpiles progressed at an increasing rate, including the making of 5-year sales contracts for metallurgical ore. At yearend, the Government inventory of manganese, all forms, was still equivalent to more than 2 years of apparent consumption.

Prices continued to trend downward, particularly for ore. The price decline for metallurgical-grade manganese ore delivered to U.S. customers was assessed at about one-fifth. Decreases in year-average prices for manganese ferroalloys in the U.S. market for high-carbon ferromanganese and silicomanganese were about 5% and 2%, respectively.

World production of manganese ore as listed in table 1 was estimated to have totaled nearly the same as that in 1992, with declines in areas of the former U.S.S.R. being offset by increases in Australia and elsewhere. In keeping with continuing trends, use of the blast furnace for producing ferromanganese was ended in Germany and the United Kingdom, and further international relationships were formed bearing on supply of ore to smelting operations.

DOMESTIC DATA COVERAGE

Data on domestic consumption of manganese ore, exclusive of that consumed within the steel industry, are collected by means of the "Manganese Ore and Products" survey. By means of this survey, approximately 15 firms were canvassed that process ore by such methods as grinding and roasting or consume it in the manufacture of manganese ferroalloys, metal, and chemicals. Their collective consumption is believed to represent that of the United States except for negligible quantities consumed by other firms, if any. In 1993, responses were obtained from all but one firm canvassed. Data for the missing respondent, which were estimated based on information received from them in prior years and data trends of other firms having similar business activities, were assessed as less than 2% of total consumption. The aggregated consumption data so obtained were incorporated into table 4 but only displayed within totals to avoid disclosing proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

Ore.—The U.S. Bureau of Mines has compiled statistics on manganese-bearing ores, concentrates, nodules, and sinter, all referred to simply as "ore," by manganese content as follows: **manganese ore**, 35% or more manganese; **manganiferous ore**, less than 35% but not less than 5% manganese; and within the latter **ferruginous manganese ore**, 10% to 35% manganese; and **manganiferous iron ore**, 5% to 10% manganese.

Manganese ore may be considered as metallurgical, chemical, or battery grade. Metallurgical-grade material has an approximate manganese content range of 38% to 55% and may differ from chemical-grade ore only in physical form. Chemical- and battery-grade ores are often categorized by manganese dioxide

(MnO_2) content, which typically is in the range of 70% to 85% (44% to 54% Mn). The U.S. Government maintains specifications for metallurgical, chemical, and battery grades of ore for stockpile purposes; industry has no corresponding standards.

Ferroalloys and Metal.—Ferromanganese is a manganese-iron-carbon alloy classified according to decreasing carbon content into standard or high-carbon grades, medium-carbon grades, and low-carbon grades. Silicon is also specified in silicomanganese (such as 18%) and ferromanganese-silicon (about 30%). For U.S. tariff purposes, ferroalloys are required to have an iron content of 4% or greater; a manganese material with less iron would be treated as manganese metal. The specifications the U.S. industry generally follows for manganese ferroalloys and metal are those of the American Society for Testing and Materials. Those for metal call for a minimum total manganese content of 99.5%, of which a minimum of 99.9% is metallic.

Products for Trade and Industry

Metallurgical-grade ore is used primarily in making ferroalloys, pig iron, and steel. Such ore is used mostly to make ferroalloys, for which it is particularly desirable that the ore has a relatively high manganese and low phosphorus content.

The sulfur-fixing, deoxidizing, and alloying attributes of manganese, whose atomic weight is 54.94, are obtained mostly through use of intermediate forms such as ferromanganese. Manganese ferroalloys for use in steelmaking are selected on the basis of cost per manganese unit, allowable steel carbon and silicon specifications, and steelmaking practice. For 1993, with the cost of manganese in metallurgical ore taken as 1.0, the corresponding approximate costs per manganese unit were 2.4 for high-carbon ferromanganese, 2.1 for silicomanganese, 4.2 for medium-carbon ferromanganese, and 8.9 for manganese metal. Metallic manganese is used little per se because it is typically brittle and unworkable.

Manganese is added to aluminum principally by use of briquets that typically contain 75% Mn and 25% Al and that are made by compacting manganese and aluminum powders. Electrolytic manganese metal and aluminum-manganese master alloys that typically contain 25% Mn also are used for this purpose.

Various manganese dioxide-types of material, possibly ground, are used for batteries and other applications. These include natural mineral product (NMD) and synthetic dioxide produced either electrolytically (EMD) or chemically (CMD). If pure, these dioxides would contain 63.2% Mn.

Other manganese materials and some of their uses include manganese sulfate ($MnSO_4$) and manganous oxide (MnO) for animal feed and soil conditioners, ground manganese ore for brick coloring, and potassium permanganate ($KMnO_4$) for water treatment.

Industry Structure

Makeup of the world's manganese ore producers has been chiefly as follows: Australia, Groote Eylandt Mining Co. Pty. Ltd. (GEMCO) and, recently, Portman Mining Ltd.; Brazil, Cia. Vale do Rio Doce (CVRD) (including Urucum Mineração S.A.) and Indústria e Comércia de Minérios S.A. (ICOMI), plus a number of relatively small mines; China, apparently small- to moderate-size operations mostly in the southeastern Provinces; Gabon, Compagnie Minière de l'Ogooué S.A. (COMILOG); Georgia, mining of the Chiatura Basin; Ghana, Ghana National Manganese Corp.; India, about 200 mines, with Manganese Ore India Ltd. the most prominent company; Mexico, Cía. Minera Autlán de C.V. (Autlán); Republic of South Africa, The Associated Manganese Mines of South Africa Ltd. (AMMOSAL) and Samancor Ltd.; and Ukraine, mining of the Nikopol' Basin. Most ore produced goes into metallurgical applications.[1] Ore for nonmetallurgical uses generally is supplied by the large-scale producers mentioned and smaller ones elsewhere.[2]

In recent years, the international ore market mainly has been supplied by a group of countries consisting of Australia (GEMCO), Brazil (ICOMI and CVRD), Gabon (COMILOG), and the Republic of South Africa (AMMOSAL and Samancor) acting in the manner of an oligopoly. In addition, Georgia and Ukraine in the former U.S.S.R. together had been supplying more than 1 million metric tons[3] of ore annually to Eastern Europe. However, the total of such exports was not much more than 700,000 tons in 1987 and dropped precipitously to average about 150,000 tons in 1990-91. The radical political changes that have taken place in Eastern Europe and the former U.S.S.R. have made the future pattern and magnitude of manganese ore exports and imports in this region considerably uncertain.

Smelting of ore into manganese ferroalloys is more diversified geographically than ore production, but is becoming more integrated with ore production through international alliances. Leading ferroalloy producers are as follows: Brazil, Cia. Paulista de Ferro-Ligas (Paulista; a number of plants); China, about 10 main plants; France, Société du Ferromanganèse de Paris-Outreau (SFPO); Germany, Thyssen Stahl AG (until late 1993); Japan, Japan Metals & Chemicals Co. Ltd. and Mizushima Ferroalloy Co. Ltd.; Mexico, Autlán; Norway, Elkem A/S; Republic of South Africa, Metalloys Ltd., a subsidiary of Samancor; and Ukraine, Nikopol' Ferroalloy Works. As with ore production, the output of Georgia combined with the much larger production from Ukraine had made the former U.S.S.R. by far the world's largest producer of manganese ferroalloys.

Four market economy countries (MEC's) currently produce metal, all electrolytically, listed in decreasing order of capacity: the Republic of South Africa, the United States, Japan, and, beginning in 1989, Brazil. China, Georgia, and Ukraine produced metal, including that obtained metallothermically in the former U.S.S.R. World productive capacity for metal was given as 76,000 tons annually as of 1985[4] and would be approximately the same in 1993.

Annual world capacity for EMD was assessed as 198,000 tons in 1989, including capacities of 71,000 tons for Japan and 36,000 tons for the United States.[5] The main changes since have been the establishment of a plant in Australia with an annual capacity of about 18,000 tons and increases in U.S. annual capacity projected to total almost 12,000 tons by mid-1994. The principal producer of CMD is Belgium's Sedema S.A., with an annual capacity of about 36,000 tons.

Geology-Resources

The world's major land-based economic resources of manganese are of two principal types: marine chemical sediments and secondary enrichment deposits.[6] Marine chemical deposits represent a majority of known resources. In 1985, the Manganese Centre (name changed in 1989 to International Manganese Institute) estimated that known relatively high-grade deposits (those with a manganese content of at least 44%) contained about 330 million tons of manganese.[7] As given in the World Review section of this chapter, the reserve base for manganese can be considered more than 10 times this size. In a recent study, the world total for manganese in land-based resources was assessed as about 9 billion tons each in actually minable manganese deposits and in potentially minable accumulations.[8] The world's potential supply of manganese also includes extensive marine accumulations, such as oxide nodules on deep ocean floors and oxide crusts on midocean ridges, whose commercial future is indeterminate.

Among the more common minerals occurring in manganese ores are oxides including pyrolusite, a mineral form of manganese dioxide; the oxysilicate braunite; and rhodochrosite, a mineral manganese carbonate.

Technology

Exploration.—Highly selective methods of locating land manganese deposits do not exist, but interpretation of geologic environments can assist prospecting.[9]

Mining.—Most manganese ore is produced by mechanized operations. Standard earth-moving equipment is used in surface mining. Underground mining generally is by room-and-pillar techniques. Selective mining may be practiced in producing battery- and chemical-grade ores from a deposit being worked principally for metallurgical-grade ore.

Beneficiation.—Crushing, screening, washing, jigging, and tabling as well as flotation, heavy-medium, and high-intensity magnetic separation are being or have been used to upgrade raw manganese ore into usable concentrates. Carbonate ore may be calcined. Ore fines are sintered into bulkier shapes at some ferroalloy plants, a practice employed also by certain ore producers.

Processing.—Electrothermy is the predominant method of manufacturing manganese ferroalloys, as by the submerged-arc-furnace process.[10] Blast furnace-type operations are used in decreasingly fewer foreign countries to make still significant 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. Control of minor ore impurities and production technology is especially important in the manufacture of high-quality dioxide.[11] CMD can be prepared by precipitating manganese carbonate from a sulfate solution and decomposing the carbonate to oxide.[12]

Recycling.—Scrap recovery specifically for manganese is insignificant. Considerable manganese reenters processing as a minor component of steel scrap, steel slag, and nonferrous scrap. Such recycling of manganese tends not to lead to a progressive buildup in steelmaking but it does in aluminum processing.

Economic Factors

A study by the Minerals Availability Program (MAP) of the U.S. Bureau of Mines has identified transportation as the most significant cost element in the production of manganese concentrates.[13] In a later MAP assessment of costs for most major mines in MEC's, transportation was found to account for about two-thirds of concentrate cost.[14] Transportation costs were about equally divided between transportation to the port and transportation to the market. Also according to this assessment, the major mines for metallurgical-grade ore of the MEC's are quite competitive as to ore production cost. Of the considerable resources evaluated, more than 80% had estimated production costs within 20% of the lowest cost.

Operating Factors

Manganese is an essential element for people, animals, and plants.[15] For adults, a daily dietary intake in the range of 2 to 5 milligrams of manganese has been recommended, and it seems that normal diets satisfactorily meet human requirements.[16] In excess, manganese can be harmful to the respiratory and nervous systems.[17] Thus, manganese can be an industrial poison, but normally is not a hazard. According to a review published in 1991, no environmental damage was known to be caused by manganese nor did manganese exposure pose a general risk to the environment.[18]

In 1988, the U.S. Environmental Protection Agency (EPA) imposed an annual requirement of reporting releases to the environment of manganese chemical compounds and metal (40 CFR 372). This initially applied to operations classifiable within Standard Industrial Classification codes 20 to 39 that annually manufacture or process at least 75,000 pounds of these materials, subject to a minimum concentration limitation. This threshold decreased to 25,000 pounds for 1989 and beyond. Also, a reporting threshold of 10,000 pounds was established for annual use of these materials other than in their manufacturing and processing.

Environmental concerns associated with dry cell batteries have led to minimization of their content of certain materials, particularly mercury, and development of methods for recycling their constituents.

ANNUAL REVIEW

Legislation and Government Programs

On November 30, EPA announced it had reached agreement with Ethyl Corp. to extend by 180 days the deadline for EPA to take final action on Ethyl's July 12, 1991, request for a waiver to permit use of methylcyclopentadienyl manganese tricarbonyl (MMT, "HiTEC 3000") as an octane-enhancing additive in unleaded gasoline (58 FR 64761). In doing so, EPA stated that Ethyl had satisfactorily demonstrated for purposes of the Clean Air Act that use of MMT at concentrations of up to 1/32d gram of manganese per gallon of gasoline would not cause or contribute to the failure of emissions equipment to achieve compliance with emission standards. The agreement between EPA and Ethyl to extend the deadline until May 29, 1994, was made to give EPA additional time to consider potential public health effects that might result from use of MMT.

Strategic Considerations

Security of Supply.—Manganese, for which there is no economical substitute, is essential to steelmaking. Steel producers in Japan, the United States, and Western Europe have shared a common concern about the lack of economically minable domestic manganese deposits. Also, the ore supply of these countries has come from relatively few sources, chiefly Australia, Brazil, Gabon, India, Mexico, and the Republic of South Africa, and from just one or two major ore mining companies in each of these countries. The United States additionally has been concerned about supply of manganese ferroalloys. The domestic manganese ferroalloy industry has declined well below self-sufficiency. For several years, the only domestic production of manganese ferroalloys has been by Elkem Metals Co. at its Marietta, OH, plant. One of the principal activities of this plant in recent years has been the upgrading for the Government's National Defense Stockpile of metallurgical-grade ore into high-carbon ferromanganese under a 10-year program scheduled to end by December 31, 1994.

Stockpile.—In line with an expanded program for disposing of excess materials from the stockpile, the U.S. Department of Defense's March 22 submission to Congress of its Strategic and Critical Materials Report for fiscal year 1992 reduced to zero the goals for all but two manganese materials, effective 30 legislative days later. The two non-zero goals then remaining were 189,669 tons for the manganese ferroalloy group and 12,857 tons for electrolytic manganese metal. The goal for metal effectively was eliminated November 30 when the President approved the National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160. This act authorized disposal of all 12,857 tons of metal in inventory.

On June 2, the Defense Logistics Agency (DLA) released the Fiscal Year 1994 Annual Materials Plan, which specified maximum amounts of materials available for sale but not necessarily to be offered for sale in fiscal year 1994. For manganese materials, the quantities were, in tons, natural battery-grade ore, 54,431; chemical-grade ore, 45,359; metallurgical-grade ore, 226,796; and high-carbon ferromanganese, 43,359.

DLA's offerings for sale (Solicitation of Offers) of stockpile manganese materials during 1993 included ORES-021 and ORES-031 for ore and ORES-024 for synthetic manganese dioxide. ORES-021 was issued March 15 and originally offered, in tons, 63,485 metallurgical grade, 36,287 chemical grade, and 13,608 natural battery grade, portions of all of which were sold. On October 26, DLA modified and extended ORES-021 until the end of fiscal year 1994. ORES-031 was issued August 6 and offered a minimum of 72,575 tons up to a maximum of 145,150 tons of metallurgical-grade ore during each of the 5 fiscal years 1994 through 1998. The base price for the fiscal year 1994 quantity was set at $2 per short ton unit of manganese, and this was to be adjusted in subsequent quarters of the 5-year period on the basis of the price of high-carbon ferromanganese. Deadline for offers under ORES-031 was September 8. In October, DLA announced that 5-year contracts had been awarded to Elkem Metals, Pittsburgh, PA, and Metals Refining Co., Orem, UT, for which the fiscal year 1994 quantities were 74,769 and 145,046 tons, respectively. DLA received no offers for synthetic manganese dioxide, although as of April 16 the entire stockpile inventory had been made available for sale during fiscal year 1993.

Disposals of manganese materials in 1993 are estimated to have decreased the total stockpile inventory of manganese units by more than twice as much as in 1992; the percentage decline was estimated as more than 7%. Disposals reported by DLA consisted, in tons, 9,072 natural battery ore, 2,903 chemical ore, 270,359 metallurgical ore, 59,760 high-carbon ferromanganese, and 11,757 silicomanganese. Basis of the disposals was cash for the various kinds of ore and payment-in-kind for the ferroalloys. At yearend, the 1.6-million-ton reserve of contained manganese being held by the Government, which is detailed in table 2, was still comfortably more than twice current national apparent consumption. However, almost one-tenth of this reserve was in the form of nonstockpile-grade metallurgical ore.

Issues

The United States has been lacking in reserves and significant production of manganese almost since the start of domestic steel production. Extensive efforts to discover worthwhile ore deposits or effective methods of using low-grade resources, including steel slags, have resulted in little commercial promise. In a 1985 report, the U.S. Congressional Office of Technology Assessment (OTA) concluded that improvements in steel production technology offered the best prospect for reducing U.S. manganese import vulnerability.[19] In so doing, OTA discounted ocean mining for the present, a view also reached in a recent assessment of the prospects for commercialization of deep seabed mining.[20]

The setting up and maintenance of a large stockpile have been the most tangible aspect of Government manganese programs. Management of the makeup, size, and disposition of this stockpile has been a key part of Government policy. Current law limits use of the stockpile to emergency situations, but its mere presence has had economic implications. Political developments during recent years and reappraisal of stockpile needs have led to the view that the size of the stockpile can be considerably reduced. DLA has signaled its intention to dispose of the large majority of the manganese items in the stockpile over a period of possibly a decade or more and has been making offerings and sales or disposals accordingly.

Production

Ore and Concentrate.—Production and shipments continued to consist only of a small amount of manganiferous material for use in coloring brick. This material was mined in Cherokee County, SC, and had a natural manganese content in the range of 5% to 15%. Shipments data were not published to avoid disclosing proprietary data.

Ferroalloys, Metal, and Synthetic Dioxide.—Production statistics for these materials were not published to avoid disclosing proprietary data; plant sites and products are given in table 3. At its Marietta, OH, plant, Elkem Metals, the only domestic producer of manganese ferroalloys, was beginning the transition from conversion of stockpile ore to sales to external markets. During the past decade, Elkem Metals has been converting stockpile manganese ore into ferromanganese for the Government. Emphasis on Government contracts was anticipated to end by the latter part of 1994. The Marietta plant was not included in Elkem Mangan KS, the holding company formed to operate the Norwegian manganese smelters of Elkem Metals' parent company, under the terms of an alliance between Broken Hill Pty. Co. Ltd. (BHP) and Elkem, as discussed more fully under Australia in the world review section of this report.

Domestic annual capacity for EMD was being raised to about 46,000 tons by expansions at New Johnsonville, TN, by Chemetals Inc. and at Henderson, NV, by Kerr-McGee Chemical Corp. Chemetals' expansion in annual capacity of 4,500 tons to more than 16,000 tons was completed on schedule as of July 1993, or approximately 1 year after having been announced. Kerr-McGee's expansion in annual capacity, announced in May 1993, was for a 50% increase, from about 14,500 to 21,800 tons, and similarly was scheduled to be completed about 1 year later.

Consumption, Uses, and Stocks

Metallurgical applications accounted for most manganese consumption, 85% to 90% of which has been for steelmaking. This can be deduced from the data relating to manganese end use that form the basis of tables 4 and 5 plus certain other information. Industry averages are presented in table 6 for kilograms of manganese used in ironmaking and steelmaking (including for castings) per ton of raw steel produced, on the basis of the reported data in tables 4 and 5. Unit consumption of manganese in ironmaking decreased significantly to one-third that in 1992. Overall manganese unit consumption in steelmaking declined further, by 3%, again because of a drop in the rate of usage of ferromanganese. Relatively small quantities of manganese were used for alloying with nonferrous metals, chiefly as manganese-aluminum briquets for alloying with aluminum.

Nonmetallurgical applications for manganese included animal feed, brick coloring, dry cell batteries, manganese chemicals, and plant fertilizers.[21] American Minerals Inc., headquartered at Wayne, PA; Chemetals Inc., headquartered at Baltimore, MD; and Prince Manufacturing Co., headquartered at Quincy, IL, supplied ore that they had ground and/or roasted or otherwise processed for nonmetallurgical uses. In its plant at La Salle, IL, Carus Chemical Co. was the sole domestic producer of potassium permanganate. Chemetals produced a variety of manganese chemicals at its Baltimore, MD, facility. Producers of manganese sulfate formulations included AlliedSignal Chemical Corp. at Pittsburg, KS (plant purchased from Koch Chemical Co. in January 1993); American MicroTrace Corp. at Fairbury, NE; and Frit Industries Inc. at Walnut Ridge, AR.

In the dry cell battery industry, Duracell International Inc. and the Eveready Battery Co. subsidiary of Ralston Purina Co. reported for their fiscal year 1993 operations a growth worldwide in excess of 10% for unit volume of alkaline batteries, which are based on use of synthetic manganese dioxide. Studies of U.S. battery markets have indicated an annual growth rate during 1988-93 of nearly 7% for primary general cells of the alkaline type and have projected that this growth rate will continue through 1996.

In the fall of 1993, a new version of rechargeable alkaline battery was introduced to the U.S. market by the Rayovac Corp., which, with emphasis on the concept of reusability, had begun mass production of popular sizes of such batteries in June. The technology being used by Rayovac was licensed from Battery Technologies Inc. (BTI) of

Ontario, Canada. BTI also had licensed its technology to Phoenix Energy Corp. of Buffalo, NY, as well as to firms elsewhere in the world. Mercury content of cells based on the BTI technology was initially 0.025% with the goal that it be reduced to zero in 1994. Rayovac's initiative was the second for marketing a rechargeable alkaline cell in the United States, as during about 1965-76 Eveready had attempted to commercialize its version of such a battery.

Use of mercury as an ingredient in primary alkaline dry cells, where the mercury content previously had been lowered to the 0.025% level, was ended completely. At least in Japan, manufacturers of alkaline batteries for the consumer market were eliminating lead as well, in this case as a component of the zinc anode, such as by replacing lead with bismuth. Alternative methods for recycling the ingredients of dry cell batteries continued to be developed.

Markets and Prices

Manganese Ore.—The price of metallurgical manganese ore declined for the third successive year. The percentage decrease was roughly twice as great as that in 1992. For the benchmark of high-grade lumpy ore containing 48% manganese, Australia's BHP agreed toward the end of April to an f.o.b. price for deliveries during the Japanese 1993 fiscal year of $2.25 per metric ton unit (mtu), a decrease of 23.7% from the prior year's contract price of $2.95 per mtu. Within a few weeks, South Africa's Samancor also agreed to a 70 cent reduction in f.o.b. price, to $2.15 from $2.85 per mtu for similar ore, a decrease of 24.6%. Shortly after BHP's settlement, Portman Mining in Western Australia had agreed to a price of $2.25 per mtu for its lumpy ore with a nominal manganese content of 45%, a decrease of 55 cents or 18.5% from the 1992 price. BHP attributed the price cut to large inventories of ore and ferroalloys, slow recovery in steel production, and financial problems in Japan's ferroalloy industry.

Metals Week and Metal Bulletin (London) both changed from a c.i.f. to an f.o.b. basis for their price quotes for manganese ore. In May, Metal Bulletin's quote for the price range per mtu for European deliveries went from $2.75-$2.95 c.i.f. to $2.15-$2.25 f.o.b. In late July, Metals Week began publishing a range per long ton unit of $2.48-$2.59 c.i.f. but in late August changed to a range per mtu of $2.15-$2.25 f.o.b.

The prevailing basis for ore purchases by U.S. consumers remained c.i.f. Although, as just noted above, published figures for a U.S. c.i.f. price were not available, an approximate c.i.f. price can be obtained by adding to the published f.o.b. price the differential between these two prices. This differential can be estimated to have been about 40 cents per mtu by averaging data of the Bureau of the Census as to Customs value and c.i.f. value of ore imports. Using this approach, the average price, c.i.f. U.S. ports, for metallurgical ore containing 48% manganese was assessed as $2.60 per mtu, which signifies a decline of 20%. It is to be recognized not only that higher prices pertained during the first quarter of 1993 but also that lower grade ore was sold at lower prices.

Because the metric ton unit is 1% of a metric ton; i.e., 10 kilograms of contained manganese, the price of manganese in ore in 1993 and 1992 can be expressed in cents per kilogram as 26.0 and 32.5, respectively. The price of a metric ton of ore is obtained by multiplying the mtu price by the percentage manganese content of the ore.

The ore market consists of a number of submarkets because of differences between ores according to the various end uses such as ferroalloy production, blast furnace ironmaking, and battery manufacture. The price trend for metallurgical ore during the past two decades is given in table 7, in which constant dollar prices were calculated using Implicit Price Deflators for Gross Domestic Product.

Manganese Ferroalloys.—Overall changes in the price of manganese ferroalloys in the United States, as given by quotations for imports, were generally less than plus or minus 5% except for the price increase during the year for silicomanganese. The year-average price versus that for 1992 declined about 5% for high-carbon ferromanganese and about 2% for silicomanganese. For these two principal manganese ferroalloys, prices at yearend versus those at the beginning of the year were higher by about 2% for high-carbon ferromanganese and 14% for silicomanganese. The larger increase for silicomanganese presumably was linked to an increase in the price of silicon in ferroalloys, which increased by more than 23% during 1993, on the basis of the price for imported 75% ferrosilicon. English units continued to be used for price quotes in the United States as given in sources such as Metals Week.

The price range for high-carbon ferromanganese containing 78% manganese, f.o.b. Pittsburgh or Chicago warehouse, was $485-$490 at the start of 1993 and broadened to $480-$500 later in January. A slight declining trend that led to lows of $475-$485 in April was followed beginning in late June by a slight firming trend that early in November gave a range of $490-$500, which remained to the end of the year.

The pattern of price variation of imported silicomanganese with 2% carbon was similar to that of high-carbon ferromanganese except that the extents of decline and subsequent increase were greater. At the start of the year, the range was 23-23.25 cents per pound of alloy, f.o.b. Pittsburgh or Chicago warehouse. A low of 19.75-20.5 was reached by early April, shortly after which a rising trend developed that produced as of early December the year's highest and also closing level of 26-26.5 cents per pound. Trade journal reports indicated that the increasing presence of Ukrainian ferroalloy in the U.S. silicomanganese market led to two-tiered pricing during part of 1993. Factors differentiating Ukrainian silicomanganese from material from most other sources were, as an advantage, its higher manganese content of 74% versus 66% typically, and, as a disadvantage, its higher phosphorus content of more than 0.3% versus 0.2% or less.

Manganese Metal.—Trade journal listings gave no indication of any price developments for the metal and continued to remain the same throughout the year as those already published effective mid-November 1990: a price range of $1.04-$1.05 per pound according to Metals Week and $1.05 per pound according to American Metal Market. These were for bulk shipments of domestic material, f.o.b. shipping point.

Foreign Trade[22]

For most materials, the volume of exports and imports was greater in 1993 than that in 1992. In terms of estimated total manganese content, the increase in number of manganese units traded was about 14% for exports and 13% for imports. For imports, the ratio of the sum of ferroalloy plus metal to the sum of ore plus dioxide was 3.8, the highest such ratio since 1982.

Among exports, the quantity of ore, although increased, was still unusually low in comparison with quantities exported during at least the past two decades. Ore reexports were 191 tons, all to Canada. Exports of ferromanganese overall increased by more than one-third, principally because of the increase from 4,637 tons to 8,172 tons in exports of material with a carbon content of more than 2%. Exports of silicomanganese, like ferromanganese principally to Canada, rose slightly to set another new record for quantity. Reexports of ferromanganese and silicomanganese, all to Canada but for 15 tons of ferromanganese, consisted of 2,418 tons of ferromanganese and 4,214 tons of silicomanganese. Those of ferromanganese were again about equally divided between higher and lower carbon grades. Reported exports of spiegeleisen were 42 tons, all to Mexico.

For imports, the average manganese content in a 6% lesser volume of ore was 49.9%, the third highest average value of the past decade. Average manganese content for all ferromanganese imports was 78.0%, the least average value since 1989.

Among imports of ferroalloys, those of ferromanganese increased about 14% overall. Imports of low- and medium-carbon ferromanganese each decreased about one-seventh, but this was compensated for by an increase of about one-fourth in imports of the high-carbon grade. Within imports of high-carbon ferromanganese, those from Brazil were the largest yet, those from the Republic of South Africa were up more than 60%, and those from Russia were the first since 1950 from an area of the former U.S.S.R. For imports of silicomanganese, an increase in volume that approached one-fourth easily produced a new record for quantity. Among the larger source countries, imports from Brazil increased to a new record quantity for the third successive year and those from China and Ukraine were 4.5 and 4.7 times as great, respectively, as those in 1992. Reported imports of spiegeleisen remained about the same, 237 tons, mostly from Germany at a high unit value.

The combined volume of imports of the two categories of metal exclusive of waste and scrap was about 8% larger. Growing since 1989 to a total of 2,721 tons, imports from China accounted for nearly one-fifth of the total. Formerly, the Republic of South Africa was practically the only source of imports of unwrought metal.

Among imports of manganese chemicals, those of manganese dioxide continued to resurge and slightly surpassed the previous record for quantity set in 1985. Significantly increased receipts from Australia and Ireland led to an overall advance of about one-eighth. All dioxide imports appeared to be synthetic material. Imports of potassium permanganate, the most since the 1989 record year, were nearly double those in 1992 because of a renewed influx of material from China. Of imports under the classification "Other sulfates," which includes manganese sulfate, those from Mexico decreased about 7% to 11,567 tons at a value of $6.1 million but rose for those from China about 44% to 5,168 tons at a value of $1.3 million.

The schedule of tariffs that applied during 1993 to U.S. imports of selected manganese materials is given in table 10.

The reduction or removal of tariff barriers to the importing of materials from republics of the former U.S.S.R. that began in 1992 continued with the granting of most-favored-nation (MFN) trade status to Kazakhstan and duty-free treatment under the Generalized System of Preferences (GSP) to Russia. MFN status for Kazakhstan was effective February 18 (58 FR 11647) and GSP status for Russia was effective October 16 (58 FR 51561). The GSP program itself was extended in August until September 30, 1994, after technically having been allowed to lapse for about 1 month.

On November 12, Elkem Metals and the Oil, Chemical and Atomic Workers, Local 3-639, Belpre, OH, filed petitions with the International Trade Administration (ITA) of the U.S. Department of Commerce and the U.S. International Trade Commission (ITC) alleging that imports of silicomanganese from Brazil, China, Ukraine, and Venezuela were being sold in the United States at less than fair value and thereby materially injuring or threatening to materially injure a domestic industry. On December 20, the ITC announced its unanimous affirmative determination that a reasonable indication existed that the allegation was true. Consequently, the ITA continued its investigation of the matter with a due date for its preliminary determination of on or about April 21, 1994. The ITA had initially evaluated the alleged dumping margins as 17.6% for Brazil, 150.0% for China, 125.3% for Ukraine, and 37.2% to 55.4% for Venezuela (58 FR 64553).

In December, Congress approved extension of the North American Free Trade Agreement to include Mexico, which had the effect of decreasing tariffs on imports from Mexico beginning January 1, 1994, and eliminating them altogether in most cases by 2003.

World Review[23]

Capacity.—The rated capacity data in table 11 are as of December 31, 1993. The major difference from the listing of the previous year is that the capabilities of the producing areas of the former U.S.S.R. have been disaggregated by respective republic. The data correspond to the manganese contents of ore and/or concentrates capable of being utilized, as in feed to a smelter. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable, long-term operating rate.

Reserves.—Only a few of the world's many manganese concentrations have enough economic significance to be classed as reserves;[24] no domestic deposits qualify.[25] World reserves of manganese, generally on the same basis as capacity, are given in table 12 with no distinction between ore type or application. The data in table 12 are exclusive of perhaps 1% to 2% of total known reserves. These are in nonlisted countries having a similar proportion of world production, as can be seen from table 13. Russia, whose reserve base can be estimated as intermediate between that of Georgia and Kazakhstan, is not listed in table 12 because no manganese ore was produced there for an extended period prior to dissolution of the former U.S.S.R.

Australia.—Manganese ore output rose by nearly two-thirds to the highest level since 1990 at operations of the Groote Eylandt Mine (Northern Territory) of the GEMCO subsidiary of BHP. The total of GEMCO's shipments to foreign and domestic destinations during calendar 1993 were reported to have increased to 1,590,000 tons for an advance comparable to that of mine production.[26]

In September, BHP Minerals and Norway's Elkem announced, following approvals by the Australian and Norwegian Governments, that a strategic business alliance had been made between GEMCO and Elkem's manganese smelting operations. The two parties had signed a letter of intent in July 1992 and a contractual agreement in April 1993. Under the agreement, Groote Eylandt Manganese Sales Pty. Ltd. (GEMS) would supply ore from GEMCO to Elkem's two Norwegian manganese smelters and to the Marietta, OH, plant of Elkem Metals. Ownership of GEMS was 51% by BHP and 49% by Elkem. The two Norwegian smelters, Elkem PEA and Elkem Sauda, were transferred to a new holding company, Elkem Mangan KS, whose ownership became 51% by Elkem and 49% by BHP.

In March, BHP's manganese smelting subsidiary, Tasmanian Electro Metallurgical Co. Pty. Ltd. (TEMCO), completed conversion of its ferrosilicon furnace to production of silicomanganese. BHP stated that this raised annual capacity for manganese ferroalloys of its Bell Bay plant in northern Tasmania to 261,000 tons (ferromanganese equivalent), an increase of 81,000 tons. Part of the increased capability was oriented toward marketing of silicomanganese in Japan, to which BHP traditionally has shipped only ore.

Annual production of manganese ore in Western Australia continued to be at the level of 300,000 tons. Portman Mining began development of the Green Snake deposit at its operations in the Woodie Woodie area of the Pilbara Manganese Province. Production of relatively high-grade ore with low silica and phosphorus contents from this newly discovered deposit was to supplant that from the Cracker deposit.

Brazil.—Shipments of manganese ore by ICOMI from operations at Serra do Navio, Amapá Territory, through Porto de Santana on the Amazon River rose slightly to 502,500 tons. Of this total, 297,200 tons was shipped to European countries and 205,300 tons to South American destinations, including Brazilian consumers.[27] ICOMI's shipments advanced for the third successive year to reach the highest total since 1990.

The Paulista group of companies, which collectively is among the world's largest producers of manganese ferroalloys, expanded its manganese ferroalloy production capabilities but ran into financial difficulties. Two new electric furnaces were brought on-stream late in the year at Eletrosiderúgica Brasileira S.A. (Sibra), which was acquired by Paulista in 1988. This was reported to have raised Sibra's annual capacity for manganese ferroalloys to more than 200,000 tons and that of the Paulista group to more than 400,000 tons. However, in December, both Paulista and Sibra applied to the courts for protection under Brazilian bankruptcy law.

Brazil's production of manganese ferroalloys in 1992 surpassed previous record levels set in 1991 for total quantity and quantity of silicomanganese produced, 479,000 and 300,000 tons, respectively. The corresponding percentage increases were about 9% and 10%. Production of high-carbon ferromanganese was 152,000 tons. At 26,700 tons, production of medium- and low-carbon ferromanganese also set a record slightly above the 1989 production and showed an increase of nearly 40% above the 1991 production. These data were not available when the Manganese Annual Report for 1992 was prepared. They are now included in a new feature that has been added to this annual report, a table of world production of manganese ferroalloys, table 14.

Burkina Faso.—The Tambao Mine was inaugurated in May, following which trial shipments of about 5,000-ton lots were made to test commercial viability of this high-grade resource. The deposit, in northeastern Burkina Faso near its borders with Mali and Niger, has been known for more than three decades but left undeveloped because of the lack of transport infrastructure. Initial output was being trucked about 250 kilometers to the nearest railhead at Kaya, which is intermediate between the mine and Ouagadougou, and then railed more than an additional 1,100 kilometers to the Côte d'Ivoire port of Abidjan. InterStar Mining Group Inc. of Canada, the operator, targeted production to begin at the annual rate of about 100,000 tons. Rated reserves reportedly were about 15 million tons of metallurgical-grade ore containing more than 51% manganese. An advantage of the Tambao ore is its relatively high manganese content. A disadvantage is its relatively high phosphorus content of about 0.15%, which has raised the possibility that the ore would be marketed for blending.

China.—Imports of 570,000 tons of manganese ore decreased about one-tenth from the 635,000 tons imported in 1992. Included in the reported ore imports for 1992 was 236,000 tons from Myanmar, which is not known to produce such quantities of manganese ore. Shipments from Myanmar to China have been categorized as small-lot boundary trade.[28]

China has become a significant factor in international marketing of manganese ferroalloys and metal. Chinese statistics indicated that Indonesia, Japan, and the Republic of South Korea were among the larger recipients of ferromanganese and silicomanganese from China in 1992. The volume of silicomanganese being exported from China to Japan led the Japanese Government to impose antidumping duties on silicomanganese from China beginning February 3, 1993. China's exports of manganese metal have been at the level of roughly 30,000 tons annually in recent years. The majority of those in 1992 were to Japan and the Netherlands.

France.—Pechiney ended its production of manganese ferroalloys in France. As of yearend, the furnaces at its Le Giffre plant in southeastern France that were being used to produce specialty manganese alloys had been shut down.

Gabon.—Production of metallurgical-grade ore from COMILOG's Moanda Mine decreased by 4%. An ownership link developed between COMILOG and South Africa's Samancor with purchase by Gencor Ltd., the major shareholder in Samancor, of the 15.1% shareholding in COMILOG formerly held by the U.S.'s USX Corp.

Germany.—In October, at the end of a production campaign, Thyssen terminated production of ferromanganese from its plants in the Duisburg area. Thyssen had been producing high- and medium-carbon ferromanganese on an intermittent basis. High-carbon ferromanganese was produced at the Hamborn plant via a blast furnace having an annual capacity of about 240,000 tons. The company stated that conditions in the markets for ferromanganese would not justify the cost of relining this furnace, due to be done in 1994. Thyssen's technology for converting high-carbon into medium-carbon ferromanganese was the subject of a recent report, which particularly focussed on attainment of low carbon and silicon contents.[29]

Ghana.—Exports of ore from the Nsuta Mine of Ghana National Manganese Corp. (GNMC) through the Port of Takoradi were 306,000 tons. Twenty-seven shipments were made to Japan and Europe (the Czech and Slovak Republics, Finland, Ireland, Norway, Romania, and Spain).[30] The level of shipments in 1993 was roughly the same as that maintained during the past 3 years.

GNMC, the subject of a recent brief review,[31] was among state-owned properties scheduled for privatization. Australia's BHP Minerals, which was among those reported to be interested in acquiring at least part ownership of GNMC, established a manganese exploration program in Ghana.

Indonesia.—P.T. Interferro Mangando (IM) initiated domestic production of manganese ferroalloys at Tangerang, near Jakarta in northwestern Java, with a ferromanganese-silicomanganese plant reported to have an annual capacity of about 40,000 tons. Production of high-carbon ferromanganese was begun in the first part of the year and later was broadened to include silicomanganese. Output was well below capacity in 1993, most of which was marketed domestically. IM was a joint venture between Taiwanese (55%), Indonesian (35%), and Hong Kong (10%) interests.

Japan.—Imports of metallurgical-grade manganese ore totaled 1,204,000 tons, an increase of slightly more than one-fourth over the relatively low 1992 quantity of 958,000 tons. As generally has been the pattern in recent years, the leading sources of ore containing more than 39% manganese were Australia and the Republic of South Africa, and for ore containing no more than 39% manganese Ghana and the Republic of South Africa. Imports of ferruginous manganese ore, almost all from India and the Republic of South Africa, totaled 140,000 tons, an increase of about one-half above that of 92,000 tons in 1992.

Production of manganese ferroalloys totaled 448,000 tons, again the least since 1987. Production of high-carbon ferromanganese remained virtually unchanged at 294,000 tons. Production of low-carbon ferromanganese increased by about one-third to 89,000 tons while that of silicomanganese decreased by about one-third to 65,000 tons.

Imports of manganese ferroalloys rose overall by about one-fifth to 266,000 tons. Imports of 211,000 tons of silicomanganese were about 9% greater than those in 1992; leading sources were China, the Republic of South Africa, and Ukraine. Imports of high-carbon ferromanganese more than doubled to 52,900 tons while those of low-carbon ferromanganese decreased about one-sixth to 2,500 tons.

After 14 months of investigation and deliberation, the Japanese Government reached a decision near the end of January to impose antidumping duties on imports of silicomanganese from China but not those from Norway and the Republic of South Africa. For the 1-year period beginning February 3, a basic duty rate of 27.2% was imposed on silicomanganese from China except that for specific exporters the rates ranged from 4.5% to 19.1%. This was the first instance of levying of antidumping duties by the Japanese Government.

Rising trends for increases in imports and relative cost of domestic production helped raise questions as to how far in the future Japan would continue to be a producer of manganese ferroalloys.[32] Nevertheless, exports of manganese ferroalloys increased overall by more than one-third to 11,500 tons. Most of the exports were low- and medium-carbon ferromanganese, which rose by 39% to 11,000 tons. An investigation of the use of a smelting furnace with a coke packed bed and injection of oxygen-enriched air and pulverized coal indicated that this might be a more competitive way for ferromanganese to be produced in Japan as compared with use of an electric furnace.[33]

For EMD, production increased moderately, by more than 3%, to 56,100 tons while exports rose by more than one-tenth to 33,500 tons, the highest level since 1988.

For manganese metal, production dropped for the third successive year, by 15% to 3,170 tons from 3,730 tons in 1992. Imports of unwrought metal, including scrap, advanced by nearly one-fourth to 24,500 tons, with China (56%) displacing the Republic of South Africa (40%) as the leading source.

Kazakhstan.—A modest production of manganese ore was concentrated in the Dzhezkazgan region of central Kazakhstan. Concentrates that tended to be siliceous and not high grade in manganese content were obtained by processing ores produced from deposits such as Ushkatyn and Dzhezdinsky at the Zhairemsky metallurgical complex. However, the low phosphorus content of these concentrates had caused them to be under consideration for some time in the former U.S.S.R. for use as charge material for manganese smelters.

Mexico.—The Grupo Ferrominero S.A. consortium took control of most of Mexico's manganese ore production and all of its manganese ferroalloy production by purchasing Autlán and Ferroaleaciones de México, S.A. (Ferromex). The sale of Autlán was completed in July about 4 years after Nacional Financiera, a development bank of the Mexican Government, foreclosed its controlling interest in Autlán. Autlán was sold for $23 million, which reportedly was only about one-eighth the value of the assets sold. Sale of Ferromex, a producer of manganese ferroalloys, was completed several months later and about 2 years after Ferromex had ceased to operate.

Ore output from Autlán's operations in the Molango District of Hidalgo State decreased for all categories, particularly for nodules and battery ore. Production data for 1993 and percentage decreases from 1992 (in parenthesis) were carbonate ore, 515,000 tons (-2%), of which 64,500 tons (-1%) was sold without nodulizing; oxide nodules, 278,000 tons (-12%); and battery ore from the Nonoalco Mine, 20,000 tons (-23%). Autlán's production of manganese ferroalloys, based on salable production, also decreased overall by roughly 4%. Manganese ferroalloys figures formerly were stated in terms of gross production. The product mix in 1993 consisted of 40,400 tons of high-carbon ferromanganese, 29,700 tons of low- and medium-carbon ferromanganese, and 55,300 tons of silicomanganese, for which the corresponding changes from the restated 1992 data were -14%, -7%, and +8%, respectively.

Norway.—As discussed more fully under Australia, Elkem and Australia's BHP Minerals announced in September the formation of a strategic business alliance. Under the agreement, ore from GEMCO would be supplied to Elkem's two Norwegian manganese smelters, Elkem PEA and Elkem Sauda, whose ownership became 51% by Elkem and 49% by BHP. At about midyear, Elkem's manganese smelters were reported to be operating at about 70% of capacity.

In March, the Government lifted investment and trade sanctions against the Republic of South Africa. This removed any need to extend the 2-year exemption that Norway's manganese ferroalloy producers, Elkem and Tinfos Jernverk A/S, had from sanctions against importing South African manganese ore. The exemption was due to expire in July.

Philippines.—Late in the year, efforts by Australia's Portman Mining and Philippine interests to develop small-scale production of manganese ore were reported to have been suspended after about 2 years of preparatory work. Sites examined were in the north of the northern island of Luzon and in the southern island of Bohol. Annual ore output in the range of 100,000 tons had been projected for shipment to consumers in the Far East.

Russia.—At the time of dissolution of the former U.S.S.R. in 1991, Russia had not been producing manganese ore for possibly two or more decades and largely had been dependent upon sources elsewhere for meeting its manganese ferroalloy requirements, as noted in a recent review.[34] Efforts were being made to reinstitute manganese ore production within the Federation even though manganese deposits in Russia have not been competitive with those in Georgia, Kazakhstan, and Ukraine. The Rossiyskiy Marganets stock company that was formed in 1992 reportedly was exploring development of manganese ore production at locations in northwestern Russia, the Urals, and Siberia.

South Africa, Republic of.—Overall production of manganese ore, which consisted nearly all of metallurgical-grade ore, increased slightly. Production of metallurgical-grade ore rose by about 3% to total 2,440,000 tons, of which about one-half was ore with a manganese content exceeding 48%. Compared with that of 1992, production of ore containing 45% or more manganese decreased about 8% while that of ore containing 30% to 45% manganese increased 26%.

Linkages developed between the manganese mining and smelting interests of Samancor and those of COMILOG. As aforementioned under Gabon, Gencor, Samancor's major shareholder, acquired a 15.1% interest in COMILOG. Samancor was exploring with SFPO the possibility of producing medium-carbon ferromanganese at SFPO's plant at Boulogne on the northern coast of France. The medium-carbon ferromanganese would have a low phosphorus content by virtue of its having been produced from low-phosphorus feed ore supplied by Samancor. SFPO was being supplied with manganese ore by COMILOG, which was also a part owner of SFPO.

Production of manganese ferroalloys rose to near full capacity during the year, at least at the two major producers. According to trade journal reports, Samancor's Metalloys manganese ferroalloy plant at Meyerton was operating at 70% of capacity early in the year but at full capacity near the end of 1993. Similarly, production of manganese ferroalloys at AMMOSAL's Cato Ridge smelter was reported to have built up during the year to near current effective full capacity. Production of low- and medium-carbon grades of ferromanganese at Cato Ridge was under consideration.

Spain.—The two producers of manganese ferroalloys remaining after the latest consolidation held a more optimistic outlook than has characterized Spain's ferroalloy industry in recent years. Ferroatlantica SL was constituted as a major European producer of bulk ferroalloys near the end of 1992 when the Villar Mir group purchased the ferroalloys and power generation businesses of the former Soc. Espan. de Carburos Metálicos SA. Ferroatlantica produced ferromanganese and silicomanganese at its Boo and Cee plants in northern Spain. The sale of Carburos also included a 12.5% interest in Hidro Nitro Española SA, a producer of specialty manganese ferroalloys at Monzon controlled by France's Pechiney.

Ukraine.—The Ordzhonikidze and Marganets metallurgical complexes continued to account for most of Ukrainian production of manganese ore and concentrates. Efforts were being made to increase capability to beneficiate a growing volume of carbonate ore. Development of the Tavrichesky metallurgical complex for utilization of the Bol'shoy Tokmak deposit still lagged. Current and planned developments at the two electrometallurgical facilities near the mines included use at the Nikopol' plant of a two-stage process to produce silicomanganese with lowered phosphorus content, production of medium-carbon ferromanganese in the near future at either the Nikopol' or Zaporozh'ye plant, and production of manganese metal electrolytically by the year 2000 to supplement the output of metal presently being obtained electrothermically at Zaporozh'ye.

United Kingdom.—In March, British Steel Plc ended production of high-carbon ferromanganese and foundry pig iron at the Cleveland Iron component of its Teesside Works on the northeast coast of England near Middlesbrough. This facility, commissioned in 1911, was one of the few remaining blast furnace producers of ferromanganese in Western Europe. In making the decision to buy rather than to produce ferromanganese, British Steel stated that it saw world overcapacity for ferromanganese and foundry iron, with demand for foundry iron being especially weak.

Current Research

Hydrometallurgical and biohydrometallurgical extraction of manganese, particularly from low-grade resources, was investigated by a number of researchers. The U.S. Bureau of Mines reported on its development of in situ leaching technology for potential application to manganese deposits in the region of the Cuyuna Range in Minnesota[35] and on bioleaching tests of wad ore from the Three Kids district in Nevada.[36] Workers in foreign countries presented at an international symposium their findings on bioleaching of such manganese minerals as those in an Italian pyrolusite ore,[37] various oxides investigated by Ukrainian scientists,[38] and tailings from the Groote Eylandt Mine in Australia.[39]

Carbothermic reduction of oxidic manganese-bearing resources and ores was investigated in the laboratory. In a study by the U.S. Bureau of Mines, the objective was to explore the possibility of prereducing domestic lower grade resource material to yield potential smelter feed.[40] The kinetics and mechanism of reduction of ore from the Wessels Mine in South Africa was the subject of another study.[41]

Among reports given at the Electric Furnace Conference that dealt with manganese pyrometallurgy, one identified zinc in the ore feed as the cause for an eruption of a submerged arc furnace producing high-carbon ferromanganese.[42] In another, the results were presented of a study of nitriding ferromanganese (mostly compositions similar to the medium-carbon grade) and how nitriding is influenced by carbon and silicon contents.[43]

Research on the behavior of manganese in steelmaking was conducted in Japan. Methodology was developed for estimating final manganese content and improving manganese yield when, in operations involving hot metal pretreatment and low slag volumes, manganese ore rather than ferromanganese was used.[44] For this type of operation, the thermodynamics of the effect of manganese on dephosphorization was analyzed.[45]

In using manganese as an alloying ingredient in aluminum, a factor to be considered is how to introduce manganese into liquid aluminum. Results of exploring the powder injection approach were reported for (1) pilot-scale tests made in the United States of equipment and procedures and (2) in-plant tests and laboratory studies conducted in Australia of dissolution fundamentals.[46]

Assessments of the thermodynamics of metal systems having manganese as a component included one by the U.S. Bureau of Mines on the manner in which a partial substitution of manganese for chromium in iron-nickel-chromium alloys affected the activities of these main elements of the alloy.[47] Two other investigations, of iron-manganese-nitrogen and iron-chromium-manganese-nitrogen systems, related to the potential development of high-nitrogen steels and the higher nitrogen contents attainable through additions of manganese.[48]

Developments in high manganese austenitic steels were assembled into a volume containing the proceedings of conferences held by ASM International in 1987 and 1992.[49] In the 1992 conference, M. O. Speidel and P. J. Uggowitzer noted (pp. 135-142) that of all materials in the world such steels have the highest product of strength times fracture toughness. R. A. Lula reviewed (pp. 229-231) the economics of using manganese to replace nickel in austenitic stainless steels. In the Republic of Korea, laboratory investigation of high manganese austenitic steels have shown that a steel containing 25% manganese, 1% aluminum, and 0.2% carbon has good potential for use as an automotive sheet material.[50]

Recent advances in battery applications of manganese have been based largely on various modifications of manganese dioxide prepared synthetically, chiefly dioxide made electrolytically. Sulfate solutions ordinarily have been used for manufacture of EMD, but research in India has indicated that use of a chloride electrolyte appears to have certain advantages.[51] So-called "rocking-chair" battery systems involving lithium ions were being intensively investigated because of the potential for using such systems in rechargeable batteries. One possibility reviewed was the combination of a lithium-manganese oxide spinel as the positive electrode with carbon as the negative electrode.[52]

OUTLOOK

The trend of manganese demand, domestically and globally, will continue to closely follow that of steel production. Although some nonmetallurgical components of manganese demand may experience higher growth rates than for steel production, especially batteries, this will have only a minor effect on overall manganese demand.

For the past decade, U.S. apparent consumption of manganese has not varied from 635,000 tons of contained manganese by much more than plus or minus 10%, as shown in table 15. This has largely been a consequence of similar variability in domestic steel production. Manganese demand as calculated in table 15 generally has corresponded to but not traced precisely the level of activity in the steel industry. Differences in the respective year-to-year variations are believed to show the influence of unmeasured changes in stocks of manganese materials, such as those of importers, the effect of which may outweigh changes in demand by steelmakers.

The outlook for domestic steel production in 1994, as discussed in the Annual Report for Iron and Steel, includes a further improvement of perhaps 3% over that for 1993, from which a small increase in domestic manganese demand can be anticipated. Forecasts of the International Iron and Steel Institute (IISI) continue to suggest only slow growth in U.S. steel output through 2000. This indicates that U.S. apparent consumption of manganese during the balance of the 1990's is unlikely to range far from 635,000 tons of contained manganese, on the assumption of insignificant change in manganese unit consumption in steelmaking. The majority of U.S. manganese demand will be met by imports.

Global forecasts of IISI and others suggest that world manganese demand during the balance of the 1990's also should increase only slightly. A late-1993 estimate by IISI was that world steel consumption in the year 2000 would be only 105% of consumption in 1990. IISI foresaw for steel consumption a relatively static condition for industrialized countries and growth in the developing countries of the Pacific Rim and Latin America that would offset decreases expected for countries of the former U.S.S.R. and Eastern Europe. Economic transition of the steel and manganese industries of the former U.S.S.R. appears likely to affect world manganese supply and demand for some years as those industries are rationalized to a smaller scale and modern steelmaking technology that also improves manganese utilization is more fully adopted. The condition of world overcapacity during recent years for production of manganese ore and ferroalloys, which has helped foster an increasing integration of ore and ferroalloy producers, seems unlikely to disappear soon.

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[23] The discussions that follow in this section of the more significant developments during 1993 by individual country were based in a number of instances on news items in trade journals such as American Metal Market, Metal Bulletin (London), Metals Week, and The TEX Report (Tokyo). These items have not been acknowledged individually because the information they conveyed often was aggregated, possibly with that from other sources.

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TABLE 1
SALIENT MANGANESE STATISTICS

(Thousand metric tons, gross weight)

	1989	1990	1991	1992	1993
United States:					
Manganese ore (35% or more Mn):					
Exports	52	70	66	13	16
Imports for consumption	580	307	234	247	232
Consumption	559	497	473	438	389
Stocks, Dec. 31: Consumers	470	379	275	276	302
Ferromanganese:					
Exports	8	7	15	13	18
Imports for consumption	432	380	320	304	347
Consumption	399	413	346	339	341
Stocks, Dec. 31: Consumers and producers	68	56	50	28	30
Consumption, apparent, manganese[1]	723	630	598	596	NA
Ore price, dollars per metric ton unit, c.i.f. U.S. ports	2.76	3.78	3.72	3.25	2.60
World:					
Production of manganese ore	[r]26,260	[r]26,108	[r]22,937	[r]21,608	[e]21,757

[e]Estimated. [r]Revised. NA Not available.

[1]Thousand metric tons, manganese content. Based on estimates of average content for all significant components except imports, for which content is reported.

TABLE 2
U.S. GOVERNMENT DISPOSAL AUTHORITIES AND YEAREND INVENTORIES FOR MANGANESE MATERIALS IN 1993

(Metric tons, gross weight)

Material	Disposal authority	Physical inventory, Dec. 31				
		Uncommitted			Sold, pending shipment	Grand total[1]
		Stockpile grade	Nonstockpile grade	Total[1]		
Natural battery ore	139,343	122,920	16,423	139,343	18,216	157,559
Synthetic manganese dioxide	2,732	2,732	—	2,732	—	2,732
Chemical ore	153,759	153,678	81	153,759	1,578	155,336
Metallurgical ore	1,206,679	831,546	375,134	1,206,679	[2]436,253	1,642,932
High-carbon ferromanganese[3]	792,799	992,655	—	992,655	[2]740	993,395
Medium-carbon ferromanganese[3]	—	24,559	—	24,559	[2]890	25,449
Silicomanganese	—	209	—	209	—	209
Electrolytic metal	12,857	12,857	—	12,857	—	12,857

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

[2]Includes quantities reserved for payment-in-kind disposal.

[3]Physical inventory as of Nov. 30.

TABLE 3
DOMESTIC PRODUCERS OF MANGANESE PRODUCTS IN 1993

Company	Plant location	Products[1]				Type of process
		FeMn	SiMn	Mn	MnO_2	
Chemetals Inc.	Baltimore, MD	—	—	—	X	Chemical.
Do.	New Johnsonville, TN	—	—	—	X	Electrolytic.
Elkem Metals Co.	Marietta, OH	X	X	X	—	Electric furnace and electrolytic.
Kerr-McGee Chemical Corp.	Hamilton, MS	—	—	X	—	Electrolytic.
Do.	Henderson, NV	—	—	—	X	Do.
Ralston Purina Co.:						
Eveready Battery Co.	Marietta, OH	—	—	—	X	Do.

[1] FeMn, ferromanganese; SiMn, silicomanganese; Mn, electrolytic manganese metal; MnO_2, synthetic manganese dioxide.

TABLE 4
U.S. CONSUMPTION AND INDUSTRY STOCKS OF MANGANESE ORE,[1] BY USE

(Metric tons, gross weight)

Use	Consumption		Stocks, Dec. 31	
	1992	1993	1992	1993
Manganese alloys and metal	W	W	W	W
Pig iron and steel	49,000	17,000	20,000	13,000
Dry cells, chemicals, miscellaneous[2]	W	W	W	W
Total	438,000	389,000	276,000	302,000

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

[1] Containing 35% or more manganese (natural).

[2] Natural ore, including that consumed in making synthetic manganese dioxide.

TABLE 5
U.S. CONSUMPTION, BY END USE, AND INDUSTRY STOCKS OF MANGANESE FERROALLOYS AND METAL IN 1993

(Metric tons, gross weight)

End use	Ferromanganese			Silico-manganese	Manganese metal
	High carbon	Medium and low carbon	Total[1]		
Steel:					
Carbon	198,989	69,555	268,544	80,074	3,419
Stainless and heat-resisting	13,237	(2)	13,237	4,575	1,855
Full alloy	20,120	5,347	25,466	16,006	386
High-strength, low-alloy	18,876	3,178	22,054	6,022	(2)
Unspecified[3]	408	649	1,057	572	181
Total steel[1]	251,630	78,728	330,358	107,249	5,842
Cast irons	8,957	569	9,525	1,530	—
Superalloys	W	—	W	—	132
Alloys (excluding alloy steels and superalloys)	1,206	354	1,559	2,747	[4]17,384
Miscellaneous and unspecified	W	—	W	W	W
Total consumption[1]	261,792	79,651	341,443	[5]111,526	23,358
Total manganese content[6]	204,000	64,000	268,000	74,000	23,000
Stocks, Dec. 31:					
Consumers and producers	24,111	6,337	30,448	6,996	(7)

W Withheld to avoid disclosing company proprietary data; included in "Alloys (excluding alloy steels and superalloys)."

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

[2] Withheld to avoid disclosing company proprietary data; included in "Steel: Unspecified."

[3] Includes electric and tool steel, and items indicated by (2).

[4] Approximately 85% of this combined total was for consumption in aluminum alloys.

[5] Internal evaluation indicates that silicomanganese consumption is considerably understated.

[6] Estimated based on typical percent manganese content (rounded).

[7] Withheld to avoid disclosing company proprietary data.

TABLE 6

U.S. UNIT CONSUMPTION OF MANGANESE IN IRONMAKING AND STEELMAKING

(Kilograms per metric ton of raw steel unless otherwise specified)

Form used	1992	1993
IRONMAKING		
Basis: Production of raw steel, million tons[1]	84.32	88.79
Ore[2]	[r].24	.08
STEELMAKING		
Basis: (Production of raw steel and steel castings) million tons	[r]85.22	[e]89.85
Ore[2]	(3)	—
Ferromanganese	3.00	2.89
Silicomanganese	.80	.79
Manganese metal	.06	.07
Total, steelmaking	[r]3.86	[4]3.74

[e]Estimated. [r]Revised.

[1] As ingots, continuous- or pressure-cast blooms, billets, slabs, etc.

[2] Containing 35% or more manganese.

[3] Less than 1/2 unit.

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

TABLE 7

TIME-PRICE RELATIONSHIPS FOR MANGANESE IN METALLURGICAL ORE

Year	Average annual U.S. price, dollars per metric ton unit, c.i.f.	
	Actual price	Based on constant 1987 dollars[1]
1973	0.64	1.55
1974	.89	1.97
1975	1.36	2.76
1976	1.43	2.73
1977	1.46	2.61
1978	1.38	2.29
1979	1.38	2.10
1980	1.67	2.33
1981	1.69	2.15
1982	1.56	1.86
1983	1.36	1.56
1984	1.40	1.54
1985	1.41	1.49
1986	1.32	1.36
1987	1.27	1.27
1988	1.75	1.69
1989	2.76	2.54
1990	3.78	3.34
1991	3.72	3.16
1992	3.25	[r]2.68
1993	2.60	2.09

[r]Revised.

[1] Based on Implicit Price Deflators for GDP (1987 = 100%). Source: Department of Commerce, Bureau of Economic Analysis.

TABLE 8
U.S. EXPORTS OF MANGANESE ORE, FERROALLOYS, AND METAL, BY COUNTRY

Country	1992		1993	
	Gross weight (metric tons)	F.a.s. value (thousands)	Gross weight (metric tons)	F.a.s. value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE				
Belgium	1,024	$82	—	—
Canada	10,612	1,942	8,705	$1,036
Korea, Republic of	1,308	175	1,336	159
Netherlands	—	—	2,810	294
Other	142	96	3,073	302
Total[1]	13,086	2,295	15,923	1,791
FERROMANGANESE, ALL GRADES				
Belgium	200	366	—	—
Canada	10,469	9,025	15,938	12,876
Mexico	995	860	460	433
United Kingdom	1,221	2,181	40	72
Venezuela	38	47	237	178
Other	[r][2]481	[r][2]517	1,365	1,283
Total	13,404	12,996	18,040	14,842
SILICOMANGANESE				
Canada	8,681	6,139	8,902	6,407
Mexico	416	277	347	213
Other	74	84	172	98
Total[1]	9,171	6,500	9,420	6,717
METAL, INCLUDING ALLOYS AND WASTE AND SCRAP				
Canada	1,798	4,777	1,053	2,510
Japan	1,011	2,028	1,007	2,927
Netherlands	1,545	3,564	927	2,026
Other	650	1,576	848	1,934
Total[1]	5,005	11,946	3,835	9,397

[r] Revised.

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

[2] Unspecified group of countries differs from that in the 1992 Annual Report.

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1992 Gross weight (metric tons)	1992 Manganese content (metric tons)	1992 Customs value (thousands)	1993 Gross weight (metric tons)	1993 Manganese content (metric tons)	1993 Customs value (thousands)
ORE AND CONCENTRATES WITH 20% OR MORE MANGANESE						
All grades						
Australia	50,518	25,519	$5,184	58,823	30,171	$5,833
Brazil	38,732	15,541	2,225	11,928	5,573	941
Gabon	148,617	75,354	20,970	131,315	66,659	15,347
Mexico[1]	8,566	3,930	1,556	17,829	7,317	1,805
Morocco	105	[2]56	32	83	[2]43	25
South Africa, Republic of	—	—	—	12,012	6,006	978
Total[3]	246,538	120,400	29,967	231,991	115,770	24,927
More than 20% but less than 47% manganese						
Brazil	35,426	13,953	1,916	8,000	3,688	664
Gabon	2,500	1,138	371	—	—	—
Mexico[1]	7,233	3,264	1,343	17,829	7,317	1,805
Total	45,159	18,355	3,630	25,829	11,005	2,469
47% or more manganese						
Australia	50,518	25,519	5,184	58,823	30,171	5,833
Brazil	3,307	1,588	308	3,928	1,885	277
Gabon	146,117	74,216	20,599	131,315	66,659	15,347
Mexico	1,332	666	213	—	—	—
Morocco	105	[2]56	32	83	[2]43	25
South Africa, Republic of	—	—	—	12,012	6,006	978
Total[3]	201,379	102,045	26,337	206,162	104,765	22,459
FERROMANGANESE						
All grades						
Australia	24,280	17,707	7,413	23,500	18,054	8,668
Brazil	33,468	25,786	16,189	43,942	33,746	18,946
China	2,620	2,154	2,014	700	560	557
France	81,793	64,247	41,883	77,185	60,151	35,259
Germany	15,497	12,657	12,784	6,258	4,977	4,157
Italy	4,978	4,477	7,256	6,916	6,274	9,701
Japan	1,567	1,230	971	6,529	5,229	4,739
Macedonia	—	—	—	3,879	3,026	1,416
Mexico	20,551	16,468	16,832	26,707	20,491	16,841
Norway	19,800	16,009	15,200	3,708	3,011	2,916
Russia	—	—	—	10,804	7,775	3,072
South Africa, Republic of	82,976	64,895	39,244	133,503	105,113	60,104
United Kingdom	16,005	12,369	6,833	2,734	1,787	576
Other	[r][4]622	[r][4]471	[r][4]195	1,043	776	643
Total[3]	304,157	238,470	166,815	347,409	270,969	167,595
1% or less carbon						
China	1,285	1,065	1,036	700	560	557
France	4,263	3,785	6,400	1,040	921	1,574
Italy	4,978	4,477	7,256	6,916	6,274	9,701

See footnotes at end of table.

TABLE 9—Continued
U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1992			1993		
	Gross weight (metric tons)	Manganese content (metric tons)	Customs value (thousands)	Gross weight (metric tons)	Manganese content (metric tons)	Customs value (thousands)
			FERROMANGANESE—Continued			
			1% or less carbon—Continued			
Norway	330	269	$316	708	558	$740
Spain	—	—	—	318	278	418
Other	[r][4]334	[r][4]304	[r][4]432	52	44	106
Total[3]	11,190	9,901	15,440	9,734	8,634	13,096
			More than 1% to 2% or less carbon			
Brazil	3,905	3,143	3,230	5,113	4,100	4,260
China	1,336	1,088	978	—	—	—
France	—	—	—	3,790	3,109	3,178
Germany	15,497	12,657	12,784	4,754	3,909	3,754
Japan	—	—	—	6,497	5,202	4,674
Mexico	20,551	16,468	16,832	22,180	17,592	15,708
Norway	17,470	14,230	14,003	3,000	2,454	2,176
South Africa, Republic of	7,368	5,926	6,150	10,834	8,758	8,537
Other	—	—	—	65	52	46
Total[3]	66,126	53,513	53,977	56,233	45,176	42,333
			More than 4% carbon			
Australia	24,280	17,707	7,413	23,500	18,054	8,668
Brazil	29,563	22,642	12,960	38,829	29,646	14,686
France	77,530	60,461	35,483	72,356	56,121	30,506
Macedonia	—	—	—	3,879	3,026	1,416
Mexico	—	—	—	4,526	2,899	1,133
Russia	—	—	—	10,804	7,775	3,072
South Africa, Republic of	75,608	58,969	33,095	122,649	96,338	51,526
United Kingdom	16,005	12,369	6,833	2,724	1,780	562
Other	[r][4]3,856	[r][4]2,907	[r][4]1,615	2,174	1,521	596
Total[3]	226,841	175,056	97,399	281,442	217,160	112,166
			SILICOMANGANESE			
Argentina	12,348	8,026	4,299	—	—	—
Australia	31,984	20,869	12,213	26,736	17,649	10,172
Brazil	57,056	37,140	24,479	64,774	42,137	26,288
China	11,423	7,476	5,096	51,193	33,543	20,473
Croatia	1,028	668	455	7,550	4,908	3,201
France	11,841	7,939	5,533	13,724	9,030	5,885
Italy	—	—	—	5,200	3,393	2,157
Macedonia	8,822	6,011	4,014	5,535	3,598	2,498
Mexico	19,812	12,728	10,228	22,960	14,779	9,883
Norway	10,746	6,940	7,881	6,523	4,103	5,597
South Africa, Republic of	64,013	42,315	31,063	57,571	37,887	26,373
Ukraine	7,992	5,971	3,237	37,642	26,468	13,668
Venezuela	8,900	5,594	3,921	13,987	9,074	5,344
Yugoslavia	8,699	5,792	3,954	—	—	—
Other	[r][4]2,512	[r][4]1,579	[r][4]2,090	2,696	1,699	1,875
Total[3]	257,177	169,047	118,464	316,091	208,266	133,413

See footnotes at end of table.

TABLE 9—Continued

U.S. IMPORTS FOR CONSUMPTION OF MANGANESE ORE, FERROALLOYS, METAL, AND SELECTED CHEMICALS, BY COUNTRY

Country	1992			1993		
	Gross weight (metric tons)	Manganese content (metric tons)	Customs value (thousands)	Gross weight (metric tons)	Manganese content (metric tons)	Customs value (thousands)
			METAL			
Unwrought:						
China	1,480	XX	$2,001	2,501	XX	$3,190
South Africa, Republic of	6,709	XX	10,304	7,625	XX	11,211
Other	183	XX	288	228	XX	431
Total	8,372	XX	12,593	10,354	XX	14,832
Other:						
South Africa, Republic of	5,152	XX	7,789	4,303	XX	6,626
Other	355	XX	1,563	313	XX	933
Total[3]	5,507	XX	9,353	4,616	XX	7,559
Waste and scrap:						
Canada	69	XX	41	112	XX	32
Mexico	4	XX	4	2	XX	2
South Africa, Republic of	—	XX	—	40	XX	51
			MANGANESE DIOXIDE			
Australia	9,939	XX	14,655	12,275	XX	18,321
Belgium	933	XX	1,502	1,175	XX	1,982
Brazil	1,130	XX	1,554	1,274	XX	1,773
Ireland	7,491	XX	10,758	8,563	XX	12,459
Japan	45	XX	98	183	XX	331
South Africa, Republic of	1,403	XX	1,960	238	XX	347
Other	[r][4]207	XX	[r][4]563	96	XX	322
Total[3]	21,149	XX	31,089	23,802	XX	35,536
			POTASSIUM PERMANGANATE			
China	116	XX	115	1,090	XX	995
Czech Republic[5]	—	XX	—	571	XX	852
Czechoslovakia[6]	664	XX	1,114	—	XX	—
Germany	158	XX	288	40	XX	74
Spain	26	XX	65	125	XX	277
Other	80	XX	353	133	XX	465
Total[3]	1,044	XX	1,935	1,959	XX	2,664

[r] Revised. XX Not applicable.

[1] Includes U.S. Bureau of Mines revision of part of reported data.

[2] Includes U.S. Bureau of Mines conversion of part of reported data (from apparent MnO_2 content to Mn content).

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

[4] Unspecified group of countries differs from that in the 1992 Annual Report.

[5] Formerly part of Czechoslovakia; shipments prior to Jan. 1, 1993, included in Czechoslovakia.

[6] Dissolved in Dec. 1992. Includes shipments from all Republics prior to Jan. 1, 1993.

Source: Bureau of the Census, adjusted by the U.S. Bureau of Mines.

TABLE 10
U.S. IMPORT DUTIES ON MANGANESE MATERIALS[1]

Item	HTS No.	Rate of duty effective Jan. 1, 1993	
		Most favored nation (MFN)	Non-MFN
Ore and concentrate	2602.00.0040/60	Free	2.2 cents per kg Mn.
Manganese dioxide	2820.10.0000	4.7% ad valorem[2,3,4,5]	25.0% ad valorem.
Ferromanganese:			
Low-carbon	7202.19.1000	2.3% ad valorem[2,3,5]	22.0% ad valorem.
Medium-carbon, 1% to 2% carbon	7202.19.5000	1.4% ad valorem[2,3,5,6]	6.5% ad valorem.
High-carbon	7202.11.5000	1.5% ad valorem[2,5]	10.5% ad valorem.
Silicomanganese	7202.30.0000	3.9% ad valorem[2,3,5,7]	23.0% ad valorem.
Metal, unwrought	8111.00.4500	14.0% ad valorem[2,8]	20.0% ad valorem.
Metal, other	8111.00.6000	5.5% ad valorem[2,3,9]	45.0% ad valorem.

[1] All subject to (1) 0.19% ad valorem Merchandise Processing Fee except for products from beneficiary countries under the Caribbean Basin Economy Recovery Act (CBERA) and least-developed developing countries and (2) 0.125% ad valorem Harbor Maintenance Fee for cargo unloaded from waterborne vessels at U.S. ports open to public navigation.

[2] Free from beneficiary countries under CBERA, the Andean Trade Preference Act, and for products of Israel.

[3] Free from certain countries under Generalized System of Preferences.

[4] Not duty free for India.

[5] Free for products of Canada.

[6] Not duty free for Mexico.

[7] Not duty free for Brazil.

[8] 7.0% ad valorem for products of Canada.

[9] 2.7% ad valorem for products of Canada.

Source for rates of duty: U.S. International Trade Commission (Harmonized Tariff Schedule of the United States 1993).

TABLE 11
WORLD ANNUAL MANGANESE MINE PRODUCTION CAPACITY, DECEMBER 31, 1993

(Thousand metric tons of manganese content)

Country	Rated capacity
Australia	1,250
Brazil	1,000
Bulgaria	15
Chile	17
China	750
Gabon	1,200
Georgia	600
Ghana	130
Hungary	20
India	650
Kazakhstan	60
Mexico	220
Morocco	35
South Africa, Republic of	2,300
Ukraine	2,200
Other:	
Asia	45
Europe	30
World total (rounded)	10,500

TABLE 12

WORLD MANGANESE RESERVES AND RESERVE BASE

(Million metric tons of manganese content)

Country	Reserves	Reserve base
Australia	26	72
Brazil	21	58
China	14	29
Gabon	45	150
Georgia	7	49
Ghana	1	4
India	17	25
Kazakhstan	8	15
Mexico	4	9
South Africa, Republic of	370	4,000
Ukraine	135	520
World total (rounded)	650	4,900

TABLE 13
MANGANESE ORE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	Range percent Mn[e] [3]	Gross weight					Metal content				
		1989	1990	1991	1992	1993[e]	1989	1990	1991	1992	1993[e]
Australia[4]	37-53	2,124	1,920	1,482	1,200	[5]1,789	[r]1,011	909	701	570	865
Bosnia and Herzegovina [6]	25-45	—	—	—	[r] [e]10	2	—	—	—	[r] [e]4	1
Brazil[7] [8]	30-50	1,904	2,300	2,000	[r]1,703	1,900	724	874	760	[r]647	722
Bulgaria	25-35	32	39	[r] [e]34	[r] [e]17	—	11	11	[r] [e]9	[r] [e]4	—
Chile	30-40	44	40	44	[r]50	50	14	12	[e]13	[r] [e]15	15
China[e] [9]	20-30	[r]3,200	[r]4,080	[r]5,150	[r]5,300	5,400	[r]640	[r]816	[r]1,030	[r]1,060	1,080
Gabon[7] [10]	50-53	2,592	2,423	1,620	1,556	1,460	1,197	1,118	748	718	674
Georgia	29-30	—	—	—	[e]1,200	1,000	—	—	—	[e]350	300
Ghana[7]	30-50	279	247	320	[r]276	295	110	96	120	[r]106	115
Hungary[7] [11]	30-33	84	60	30	18	18	[r]27	[r]18	9	[r]5	5
India[7] [10] [12]	10-54	1,334	[r]1,385	1,401	[e]1,400	1,750	497	[r]525	[r]532	[r]530	660
Iran[7]	25-35	81	54	48	[r]40	40	24	18	16	[r]13	13
Kazakhstan	29-30	—	—	—	[r] [e]35	50	—	—	—	[r] [e]11	15
Mexico[13]	27-50	394	[r]451	254	407	363	150	[r]166	93	153	135
Morocco[7]	50-53	32	49	59	[r]44	43	17	26	31	[r]23	23
Romania[7] [11]	25-30	[r]48	[r]40	[r]20	[r]15	15	[r]12	[r]10	[r]5	[r]4	4
South Africa, Republic of [7] [10]	30-48+	4,884	4,402	3,146	2,464	[5]2,507	2,044	1,911	1,369	1,077	1,076
Ukraine	29-30	—	—	—	[r]5,819	5,000	—	—	—	[e]1,700	1,500
U.S.S.R.[14]	29-30	9,141	8,500	7,240	—	—	[5]2,740	2,500	2,150	—	—
Yugoslavia[6] [15]	25-45	39	51	[e]40	—	—	14	18	[e]14	—	—
Other[16]	XX	[r]47	[r]66	[r]49	[r]54	76	[r]19	[r]29	[r]20	[r]22	31
Total[17]	XX	[r]26,260	[r]26,108	[r]22,937	[r]21,608	21,757	[r]9,249	[r]9,058	[r]7,621	[r]7,012	7,234

[e] Estimated. [r] Revised. XX Not applicable.

[1] Table includes data available through July 28, 1994. 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, Burkina Faso, Cuba, Panama, and Sudan may have produced manganese ore and/or manganiferous ore, but available information is inadequate to make reliable estimates of output levels.

[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] All production in Yugoslavia from 1989-91 came from Bosnia and Herzegovina.

[7] Gross weight reported; metal content estimated. Estimated metal content figures have been revised as necessary.

[8] Production of beneficiated ore as reported in Sumário Mineral (Brasilia).

[9] Includes manganiferous ore.

[10] Calculated metal content includes allowance for assumed moisture content.

[11] Concentrate.

[12] Much of India's production grades below 35% Mn; average content was reported as 38.7% Mn in 1989.

[13] Mostly oxide nodules; may include smaller quantities of direct-shipping carbonate and oxide ores for metallurgical and battery applications.

[14] Dissolved in Dec. 1991.

[15] Dissolved in Apr. 1992.

[16] Category represents the combined totals of Argentina (low-grade ore), Bolivia, Botswana, Burma, Colombia, Egypt, Greece, Indonesia, Italy (from wastes), Japan (low-grade ore), Philippines, Thailand, Turkey, and Zambia.

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

TABLE 14
FERROMANGANESE AND SILICOMANGANESE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons, gross weight)

Country	1989					1990				
	Ferromanganese			Silico-manganese	Grand total[2]	Ferromanganese			Silico-manganese	Grand total[2]
	Blast furnace	Electric furnace	Total			Blast furnace	Electric furnace	Total		
Argentina	—	24	24	21	46	—	24	24	22	46
Australia[e]	—	[3]67	67	55	122	—	70	70	65	135
Belgium[e]	—	30	30	—	30	—	25	25	—	25
Brazil	—	181	181	208	389	—	171	171	217	387
Bulgaria[e 4]	—	30	30	—	30	—	—	—	—	—
Canada[e 4]	—	185	185	—	185	—	185	185	—	185
Chile	—	7	7	(5)	7	—	4	4	1	5
China[e]	240	120	360	240	600	330	150	480	370	850
Croatia	—	—	—	—	—	—	—	—	—	—
Czechoslovakia[e 4 6]	—	100	100	—	100	—	102	102	—	102
Egypt	—	—	—	—	—	—	—	—	—	—
France[7]	325	[e]27	352	59	411	324	36	360	62	422
Georgia	—	—	—	—	—	—	—	—	—	—
Germany[e 4 8]	[9]305	112	417	—	417	[9]250	103	353	—	353
India	—	158	158	72	230	—	201	201	57	259
Indonesia	—	—	—	—	—	—	—	—	—	—
Italy	—	41	41	[e]47	88	—	42	42	56	98
Japan	—	394	394	122	516	—	452	452	77	530
Korea, North[4]	—	70	70	—	70	—	70	70	—	70
Korea, Republic of	—	85	85	87	172	—	84	84	83	167
Mexico	—	113	113	91	204	—	123	123	65	188
Norway	—	221	221	270	491	—	213	213	223	437
Peru	—	1	1	—	1	—	[e]1	1	—	1
Philippines[e]	—	—	—	—	—	—	—	—	—	—
Poland	90	1	92	[e]25	117	71	5	76	[e]25	101
Portugal	—	13	13	—	13	—	12	12	—	12
Romania[e]	—	80	80	40	120	—	60	60	30	90
Russia	—	—	—	—	—	—	—	—	—	—
Slovakia[10]	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of	—	394	394	258	652	—	404	404	234	638
Spain[e]	—	50	50	40	90	—	52	52	38	91
Taiwan	—	31	31	26	56	—	44	44	21	64
Ukraine	—	—	—	—	—	—	—	—	—	—
U.S.S.R.[e 11]	[3]609	[3]414	1,023	1,300	2,323	[3]281	410	691	1,300	1,991
United Kingdom	143	—	143	—	143	144	—	144	—	144
Venezuela	—	—	—	32	32	—	—	—	[e]31	31
Yugoslavia[12]	—	34	34	53	86	—	32	32	61	92
Total[2]	1,712	2,984	4,696	3,047	7,743	1,400	3,076	4,476	3,038	7,513

See footnotes at end of table.

TABLE 14—Continued
FERROMANGANESE AND SILICOMANGANESE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons, gross weight)

Country	1991					1992				
	Ferromanganese			Silico-manganese	Grand total[2]	Ferromanganese			Silico-manganese	Grand total[2]
	Blast furnace	Electric furnace	Total			Blast furnace	Electric furnace	Total		
Argentina	—	26	26	15	41	—	5	5	31	35
Australia[e]	—	45	45	74	119	—	55	55	75	130
Belgium[e]	—	25	25	—	25	—	25	25	—	25
Brazil	—	169	169	272	441	—	179	179	300	479
Bulgaria[e] [4]	—	—	—	—	—	—	—	—	—	—
Canada[e] [4]	—	45	45	—	45	—	—	—	—	—
Chile	—	7	7	2	8	—	7	7	2	9
China[e]	500	180	680	415	1,095	550	200	750	420	1,170
Croatia	—	—	—	—	—	—	10	10	40	50
Czechoslovakia[e] [4] [6]	—	90	90	—	90	—	70	70	—	70
Egypt	—	—	—	—	—	—	[e]10	10	—	10
France[7]	[e]320	[e]30	350	[e]30	380	[e]300	60	360	80	440
Georgia	—	—	—	—	—	—	[e]100	100	[e]50	150
Germany[e] [4] [8]	[9]220	40	260	—	260	[9]130	30	160	—	160
India	—	[e]211	211	70	281	—	[e]198	198	93	291
Indonesia	—	—	—	—	—	—	—	—	—	—
Italy	—	14	14	[e]55	69	—	[e]10	10	50	60
Japan	—	464	464	87	551	—	362	362	96	458
Korea, North[4]	—	[e]70	70	—	70	—	70	70	—	70
Korea, Republic of	—	95	95	74	169	—	86	86	83	168
Mexico	—	98	98	51	149	—	79	79	51	130
Norway	—	173	173	227	400	—	203	203	213	416
Peru	—	[e]1	1	—	1	—	[e]1	1	—	1
Philippines[e]	—	5	5	—	5	—	5	5	—	5
Poland	57	[e]5	62	[e]25	87	[e]50	[e]5	55	25	80
Portugal	—	—	—	—	—	—	—	—	—	—
Romania[e]	—	40	40	30	70	—	27	27	28	55
Russia	—	—	—	—	—	200	—	200	—	200
Slovakia[10]	—	—	—	—	—	—	—	—	—	—
South Africa, Republic of	—	255	255	235	490	—	270	270	266	536
Spain[e]	—	50	50	40	90	—	50	50	40	90
Taiwan	—	40	40	13	53	—	38	38	4	42
Ukraine	—	—	—	—	—	50	100	150	1,000	1,150
U.S.S.R.[e] [11]	[3]235	370	605	1,100	1,705	—	—	—	—	—
United Kingdom	178	—	178	—	178	137	—	137	—	137
Venezuela	—	[e]1	1	[e]31	32	—	[e]9	9	[e]32	41
Yugoslavia[12]	—	[e]20	20	[e]50	70	—	—	—	—	—
Total[2]	1,511	2,569	4,080	2,895	6,976	1,417	2,263	3,680	2,979	6,659

See footnotes at end of table.

TABLE 14—Continued

FERROMANGANESE AND SILICOMANGANESE: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons, gross weight)

Country	1993[e]				
	Ferromanganese			Silico-manganese	Grand total[2]
	Blast furnace	Electric furnace	Total		
Argentina	—	5	5	31	36
Australia[e]	—	75	75	75	150
Belgium[e]	—	25	25	—	25
Brazil	—	169	169	273	442
Bulgaria[e] [4]	—	—	—	—	—
Canada[e] [4]	—	—	—	—	—
Chile	—	8	8	2	9
China[e]	550	220	770	450	1,220
Croatia	—	10	10	40	50
Czechoslovakia[e] [4] [6]	—	—	—	—	—
Egypt	—	30	30	—	30
France[7]	250	30	280	80	360
Georgia	—	100	100	50	150
Germany[e] [4] [8]	[9]100	20	120	—	120
India	—	150	150	80	230
Indonesia	—	10	10	—	10
Italy	—	10	10	50	60
Japan	—	[3]383	383	[3]65	448
Korea, North[4]	—	70	70	—	70
Korea, Republic of	—	99	99	84	183
Mexico	—	70	70	55	125
Norway	—	200	200	210	410
Peru	—	1	1	—	1
Philippines[e]	—	5	5	—	5
Poland	40	5	45	25	70
Portugal	—	—	—	—	—
Romania[e]	—	27	27	28	55
Russia	150	—	150	—	150
Slovakia[10]	—	65	65	—	65
South Africa, Republic of	—	[3]393	393	[3]268	661
Spain[e]	—	50	50	40	90
Taiwan	—	[3]14	14	—	14
Ukraine	50	100	150	700	850
U.S.S.R.[e] [11]	—	—	—	—	—
United Kingdom	40	—	40	—	40
Venezuela	—	10	10	30	40
Yugoslavia[12]	—	—	—	—	—
Total[2]	1,180	2,353	3,533	2,635	6,168

[e] Estimated.

[1] Revisions of data given in prior year versions of this table are not indicated.

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

[3] Reported figure.

[4] Data for ferromanganese includes silicomanganese, if any.

[5] Less than 1/2 unit.

[6] Dissolved Dec. 31, 1992.

[7] Includes silicospiegeleisen, if any.

[8] Data for blast furnace ferromanganese includes spiegeleisen, if any.

[9] Western states only.

[10] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[11] Dissolved in Dec. 1991.

[12] Dissolved in Apr. 1992.

TABLE 15
MANGANESE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons, manganese content)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic mines[2]	4	4	10	2	1	2	1	1	1	—	—
Shipments of Government stockpile excesses	25	32	9	83	7	95	(2)	(5)	20	29	58
Imports, ore	101	161	150	171	205	155	225	271	149	117	120
Imports, dioxide	XX	XX	13	14	11	9	12	4	4	12	13
Imports, ferroalloy and metal	390	330	386	367	410	383	527	502	458	436	421
Industry stocks, Jan. 1	637	523	420	381	345	286	253	287	294	241	186
Total U.S. supply[3]	1,157	1,050	989	1,018	978	930	1,017	1,059	926	836	798
Distribution of U.S. supply:											
Industry stocks, Dec. 31	523	419	381	345	286	253	287	294	241	186	170
Exports, ore	13	9	27	28	21	34	32	26	42	33	7
Exports, ferroalloy and metal	12	15	12	12	9	8	16	15	13	19	25
Industrial demand	610	606	569	633	662	634	682	723	630	598	596
U.S. DEMAND PATTERN[4]											
Appliances and equipment	27	30	33	29	24	28	17	11	9	8	8
Batteries	19	23	31	35	39	39	44	41	42	52	50
Cans and containers	28	25	34	32	28	32	28	21	22	20	20
Chemicals[5]	26	20	31	20	21	40	42	39	36	33	34
Construction	138	137	154	149	134	150	221	138	138	122	101
Machinery	83	82	88	71	59	70	100	75	74	45	63
Oil and gas industries	36	25	33	31	23	27	19	9	14	10	10
Transportation	104	117	126	112	86	95	93	49	45	47	60
Other[6]	147	147	39	154	248	153	119	340	250	260	250
Total U.S. primary demand[3]	610	606	569	633	662	634	682	723	630	598	596

XX Not applicable.

[1] Where available, data for manganese dioxide included beginning in 1984.

[2] Including manganiferous ore.

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

[4] New series for steel-related end uses beginning in 1989.

[5] Includes miscellaneous nonmetallurgical uses of ore beginning in 1987.

[6] Not specifically based on reported data; includes processing losses. Through 1988, the distribution within this category is approximately the same as for end uses above exclusive of batteries and chemicals. Beginning in 1989, includes nonidentified uses of steel corresponding to about one-third of total steel shipments.

MATERIALS RECYCLING

By Arnold O. Tanner

Mr. Tanner is an industrial material specialist with 15 years of experience at the U.S. Department of the Interior, the first 7 years as a geologist at the U.S. Geological Survey. Since 1986 he has served at the U.S. Bureau of Mines as a physical scientist (commodity specialist), leading to his present position specializing in materials recycling. For the past 4 years he has conducted studies concerning materials recycling and solid waste management as a member of the Branch of Materials. The section on "Design for Recycling" Programs was prepared by Mr. Robert D. Brown, Jr., a physical scientist with the Branch of Materials. Some of the data and most of the tables and graphs were prepared by Ms. Grecia Matos, an industrial material specialist with the Branch of Materials.

INTRODUCTION

The recycling of scrap and waste materials provide an alternative material source to that of virgin supplies. Fairly rapid growth has occurred in recent years in the recycling of a wide variety of physical structure materials and products that are used in people's everyday lives. If a substance can be reused or recycled for part or all of its inherent value, it is a candidate for diversion from the solid waste stream. The longer a material's useful lifetime can be extended, the less Earth's virgin resources of that material must be consumed.

The greater the economic viability of a material's overall recycling process, the greater is its potential for continued recycling. Successful recycling provides opportunities for new businesses in the economy, thereby providing materials, services, and jobs. The recycling of the aluminum used beverage can (UBC) is a prime example of a profitable secondary/used material recovery operation. The reuse of UBC's requires significantly less energy resources than the equivalent processing of virgin aluminum and reduces the quantity of waste that is overcrowding our landfills.

The shrinking availability of landfill space is a very visible and politically active issue. Along with associated water and air pollution at some existing landfills, the growing question of how best to manage our waste and other used materials is coming under increasing scrutiny. Increased interest in more efficient materials use and reduction of the impacts of waste on the environment are part of the sustainable development approach to economic activity and environmental protection. Sustainable development was defined in the Bruntland report as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] Materials recycling, although far from a total solution for all of society's waste ills, is one avenue for managing used, or otherwise rendered-useless, materials.

A large variety of materials are recycled by different sectors of our society. The recycling that is mainly addressed in this chapter is from waste that is generated after manufacturing and consumer use. Included is the recycling of materials that is generally more apparent to the general public: the collection, reprocessing, and remanufacture of materials into new products from post-consumer UBC's, scrap metal, glass containers, paper goods, increasingly plastics, as well as rubber tires and other used goods. On the other hand, a variety of materials are recycled within the individual operations by mineral and material processors, the chemical industry, product manufacturers, utility companies, etc. This latter solid and liquid reprocessing and recycling is done internally in many industries and is generally less visible to the general public than the recycling of materials from municipal solid waste. Recycled materials in the various industries are commonly liquid or chemical in form, but also include the clean excess scrap from metal, paper, glass, and plastic manufacturers (often called "home," runaround, or flash scrap). A significant portion of pre-consumer scrap, sometimes called new scrap, is traded to industrial consumers of scrap materials to produce new products and is included in much of the data that follow. Most of the physical structure materials that are recycled back to the consumer as new products are solid materials. Other materials, such as lubricating oils, solvents, and increasingly, household hazardous substances, such as paints, home solvents, and cleaners, are currently categorized as "solid" waste, but are not addressed in this chapter.

The U.S. Bureau of Mines (USBM) publishes several annual reports that address many of these recycled materials and products. For the most part, these publications address metals that society traditionally has recycled. This chapter attempts to cover several of the basic materials and products that are not covered in other USBM writings and yet are very basic and fundamental, as are other mineral and material commodities, to our society and our way of life. The three materials treated in depth—paper, plastic, and rubber—are diverse in their makeup. Paper is produced from the renewable resource of trees and other vegetation. Virtually all plastic is produced from nonrenewable hydrocarbon feedstocks, and rubber is produced primarily from the same nonrenewable hydrocarbons as plastics in addition to a smaller, yet very significant, portion produced from renewable, natural rubber feedstocks. Because of their diverse natures, the general title "Materials Recycling" was used. While bearing fundamental differences, one "characteristic" does tie them together (along with a variety of other basic consumer commodities): if, following their initial intended use they are not: (1) reused relatively "as-is"; (2) recycled following material reprocessing; (3) incinerated in a waste-to-energy (WTE) facility; or (4) otherwise processed into usable material, such as through composting, then they become waste and are landfilled. Society always may produce some quantity of waste products that cannot be used again and must be disposed of. The important consideration here is how much must be discarded at what rate. Solid waste management, or resource management as some professionals more positively characterize it, is the overall theme surrounding the growing efforts to reuse and recycle our used materials. Of equal importance for future generations is the conservation of our natural resources, especially nonrenewable resources. This also has been a motivational force behind recent efforts to increase the recycling of materials.

DOMESTIC DATA COVERAGE

Data in this report are derived from a variety of published and unpublished sources that are mostly external to the USBM. Much of the solid waste data and some of the recycling data come from U.S. Environmental Protection Agency (EPA) studies. The other main data sources were various industry, trade association, and independent contractor studies and journal and media reports. At this writing, limited Federal Government surveys existed concerning the quantities of post-consumer materials in the municipal solid waste stream or of those being recycled. Several agencies, in particular the USBM, the U.S. Bureau of Census in the Department of Commerce (DOC), and the EPA, have been meeting to evaluate the possible gathering of such data.

BACKGROUND

Definitions, Grades, and Specifications

Overall Solid Waste Material Flow.—Post-consumer materials become part of the solid waste stream unless otherwise diverted into secondary material use. Although commonly used by various industries to refer to pre-consumer scrap, the term secondary also can be applied to used or post-consumer waste materials that are recovered for recycling. The most publicized waste is municipal solid waste (MSW), and much of the materials recycling that has become an important public issue in the past decade comes from MSW. MSW, however, is an extremely small portion of the total solid waste stream. Estimates of solid waste from all sources vary greatly, and most are based on incomplete, mid-1980's data. But from estimates of between 11.5 and 13.5 billion metric tons[2] of legally designated "solid" waste, only about 187 million tons (preliminary estimate for the United States in 1992) is MSW, a little more than 1.5% of total solid waste, as shown in figure 1. *(See Figure 1.)* Also note that these "solid" waste streams are perhaps 80% or more liquid, a common constituent being wastewaters as well as other liquid wastes. Much of these liquid-form "solid" wastes are contained in surface impoundments for treatment, storage, or disposal. True solid wastes that are not recycled, composted, or incinerated are generally managed by way of landfills, waste piles, or in other land disposal areas. All wastes are either categorized or defined as solid (meaning nonhazardous), hazardous, or radioactive/nuclear wastes. Hence, a waste that is in liquid form, but is by appropriate definitions, concentrations, etc. judged to be nonhazardous, is legally categorized as a "solid waste."

Municipal Solid Waste Material Flow.—MSW, while being a small portion of our total solid waste stream, is mostly (about 95%) solid in nature when introduced into the wastestream. Two of the included categories of waste, yard waste and food waste, are mostly solid in form but have low to moderate liquid (commonly water-based) contents. These liquid-containing wastes contribute liquid to landfill effluent as landfill wastes degrade. Together, yard and food wastes comprise about 25% of MSW.

Solid Waste Management Options.— **The Hierarchy.**—A hierarchy of solid waste management methods has been established by the EPA. Although a strong emphasis often is placed upon its first two levels, the solid waste hierarchy is a list of "method preference" rather than a rigid set of hard and fast rules. The hierarchy includes: (1) source reduction, (2) reuse, compost, or recycle, (3) waste-to-energy incineration, and (4) landfilling.

The EPA has been conducting municipal solid waste characterization studies since 1960. Estimates of solid waste that would fall under the category of source reduction are very difficult to quantify. The problem with such numbers is as much a matter of definition as it is of presenting hard numbers. No attempt is made in this chapter to quantify these materials that, because of planning and forethought, never became waste. Nevertheless, some professionals are attempting to devise methodologies to indicate the progress made in this important aspect of resource and solid waste management. Preliminary 1992 estimates for the percentage of MSW being managed by the methods in the hierarchy follow. In 1992, approximately 18% of MSW was recovered for recycling and 3% was recovered for recycling from yard waste and other composting for a total recovery of 21%. This was up from the commonly publicized EPA 1990 total recovery estimate of 17%, which included yard waste and other composting but often was not reported in the media using a similar breakdown. MSW incinerated with energy recovery accounted for about 16% of total MSW in 1992 and that incinerated without energy recovery was about 1%, for a total of 17% MSW incinerated. This was up from the total 16% that was combusted in 1990. The remaining 62% of MSW was landfilled, down from 67% in 1990.

A balanced approach in choosing the best methods for managing wastes in each particular situation is called integrated waste management (IWM). In IWM, the different methods are intended to be utilized, as most appropriate, for the varied locales or States. Recycling is not always the answer because of such reasons as geography and sparse population, local economics, lack of accessible technology, etc. Likewise, the next preference, incineration, also in some cases may be impractical. For example, an adequate future supply of solid waste "fuel" must be confidently anticipated to justify the high capital cost of building an incinerator. Local or regional economics can restrict the use of these options, especially in sparsely populated areas. Landfilling in conjunction with minimal recycling activities may at times be the most workable and beneficial waste management choice for the solid wastes in a certain community.

Source Reduction.—The first preferred option is actually a "preoption" called source reduction, sometimes referred to as waste reduction. Solid waste source reduction is the design, manufacture, purchase, or use of materials or products in ways that directly or indirectly reduce their amount, toxicity, or other toxic effects before they are produced, thus avoiding any potential entry into the solid waste stream. Not creating the waste in the first place is better than having to deal with it later. Because source reduction efforts are intended to reduce pollution as well as conserve natural resources, such activities also should not increase the net amount or toxicity of wastes generated throughout the life of the product.[3] Reduction of the quantity of materials in a particular packaging application is one example of source reduction. Another example is the design of a product, such as the automobile or a home appliance, with its materials recycling in mind. A more easily disassembled vehicle, refrigerator, or stove made of readily recyclable materials will reduce the amount of discarded material. One related design factor, the energy necessary to reprocess the materials, may either encourage or discourage a source reduction effort. The total energy expended by recycling must be considered as well as the metals, plastics, and glass materials that may be kept out of the wastestream by the future recycling of them into new, qualitative hard goods and materials. This energy factor is very important because the energy is commonly derived from hydrocarbon resources that are as nonrenewable as many of the materials that are being reprocessed.

Recycling and Composting.—Direct reuse or the physical or chemical recycling of a product or other waste material is given second preference. The goal is to recover materials from the wastestream and thereby minimize the use of virgin resources. Recycling is not 100% effective because there is always some waste that results during the recycling process. Some portion of the material either degrades too much to be reused or is otherwise lost in the process. But, recycling, while not being a perfect solution, does extend the lifespan of a material by keeping it in use. Recycling decreases the introduction of materials into the wastestream and thereby slows the filling up of valuable landfill space.

Composting also is included in this level of preference. It involves the chemical breakdown of materials into different, usually more basic, materials or chemical compounds. This contrasts with the physical breakdown of a material into smaller pieces that are chemically the same. The recycling of paper is a physical process in which the individual paper fibers may be reduced in size but remain chemically unchanged. The composting of food and yard wastes is increasingly becoming an integral part of the solid waste management efforts of many communities, especially where laws have been passed banning the landfilling of yard wastes. Composting provides an alternative to chemical fertilizers in a variety of applications. Municipal solid waste also is compostable after the removal of metals, plastics, rubber, and glass. Three factors that tend to limit its desirability are: (1) the concentration levels of some contaminates, especially metals such as lead and cadmium; (2) small pieces of glass, metals, and plastics that remain; and (3) competition from the other waste management methods, especially the recycling of paper.

Waste-to-Energy Incineration.—The next choice in the hierarchy is MSW incineration, particularly when used in conjunction with the production of energy. Waste-to-Energy (WTE) incineration, producing energy either in the form of steam or electricity, often is a viable waste handling option that makes use of the energy values contained in MSW rather than simply burying it. Both plastic and rubber material comprise an important portion of MSW "fuel" in a WTE incinerator because they can provide higher energy values than the other components of MSW. The combustion of MSW also reduces the volume of the waste that remains to be disposed of to as little as 15% of the incinerated materials' original volume. Some components of MSW, such as plastics, are virtually reduced to zero, with only a very minute portion of char remaining. This volume reduction is especially important with regard to plastics because, when compared to other MSW materials of like weight, plastics commonly take up about twice as much landfill space. Some plastics consume considerably more; for example, polystyrene foam plastic can take up as much as seven times the space. Although volume reduction is a significant reason for incinerating landfill-bound waste, MSW incinerators without energy recovery have of late been on the decline, and those with such recovery are becoming the norm. Very few, if any, new plants without such an energy recovery capability are currently in the planning stage or under construction.

Sanitary Landfilling.—Although it is still the most common form of waste management, or as some prefer to say, used material management, landfilling is becoming the least preferred choice. Minimizing the quantity of discarded materials that are landfilled has been stressed during the past several years because of the shrinking availability, of landfill space due to physical limitations or political considerations. The diversion of materials from landfills and the overall solid waste stream is the dominant force driving current material reuse and recycling efforts.

Material Resources and Related Economic Issues.—**Collection, Utilization, and the Market.**—Supplies of materials collected for recycling are relatively large in the United States. Old newspaper, mixed paper, green glass, and some plastics are examples of materials that have been collected in quantities beyond the markets' capacity to absorb them. Causes for the oversupply of some recovered materials include: (1) lack of a recycling industry infrastructure; (2) inadequately developed markets; (3) an often uneven playing field of competition with competing virgin materials; (4) low prices for recovered materials; and (5) the recently weak, though mildly improving, state of the U.S. economy. In most cases, collection of recyclables increased in 1993, adding to some oversupplies remaining from the previous year.

On the other hand, within the oversupply, undersupplies of materials that are sufficiently clean or uncontaminated add to this problem. A load of an otherwise usable material can be rendered useless if it includes too high a level of other unlike materials. The processing of such loads can be limited for technological or economic reasons. Further development of collection practices and sorting procedures and technologies, such as those for sorting plastic containers of different types, may serve to increase supplies of more competitive, marketable materials.

Domestic Recycled Material Economics.—The U.S. economy experienced increasing, though gradual, improvement during 1993, but its effects were not strongly evident in the recycling marketplace where prices for most recycled materials either declined somewhat or were flat. Overall, 1993 was not a year of attractive prices for those involved in the selling and trading of recycled materials. Steel scrap was an exception, and less so recovered plastics (containers), which exhibited a modest average increase in prices during the year. Fluctuating prices for recovered plastic, combined with the continued low price of virgin resin, hindered a more consistent and healthy development of the commodity. In the final weeks of 1993, prices for most recycled material commodities were rebounding modestly from the lows experienced earlier in the year.[4]

Despite the economics involved, most U.S. industries recorded increases in recovered material use. Substantial increases occurred in the steel and paper industries, and a little less so in the plastics industry. Modest increases occurred in the use of recovered glass containers, aluminum scrap, and steel cans, whereas there was a modest drop in the use of aluminum cans. The decline in the consumption of used aluminum cans was somewhat of a temporary lull in the marketplace. The decline was due, in part, to large volumes of scrap cans that were withheld from the market at the end of the year in anticipation of a rebound to higher prices in 1994. Prices paid for scrap aluminum cans, both by processors and end users, dropped significantly in the last quarter of 1993. Exports of several recovered materials declined. The export of aluminum cans decreased modestly, whereas drops in the exports of aluminum scrap overall and plastic scrap were more significant.[5]

Germany's Recycling Experiment.—A foreign example of collection that exceeds secondary markets is found in Germany's Green Dot program. Green Dot is the program that resulted in response to the German Packaging Ordinance, effective January 1, 1993. It specified quotas for the collection of used packaging materials, and made the manufacturer responsible for both collecting and recycling the materials. During 1992, the nationwide recycling collection organization, Duales System Deutschland (DSD), collected more than 4.5 times as much tonnage of scrap plastic as it had initially anticipated. This 204,000 tons [about 450 million pounds (lbs)] of plastic was more than 3 times the amount that the country had the capacity to handle. One-third of the plastic was exported, and the rest was stockpiled awaiting future increases in capacity and better markets for the materials.

Part of the problem in the German system has been the success of recycling collection activities, while growth in the recycling infrastructure and the marketing of recycled products overall have not been able to keep pace. Oversupplies were felt beyond the German border. In at least one district in England, secondary raw materials from Germany could be purchased for less than it cost the district to collect its own. DSD collected almost 4.2 million tons [4.6 million short tons (st)] of these materials in 1993. But the oversupply of plastic packaging was the most difficult problem with which to deal. In 1993, DSD expected a doubling of plastics collection to about 410,000 tons (more than 900 million lbs) to be used in almost the same proportions as in 1992. Almost one-third, 135,000 tons (just under 300 million lbs), was estimated to be added to current stockpiles, and exports increased beyond the one-third proportion of 1992.

DSD, a not-for-profit consortium of nearly 600 companies, twice in 1993 came close to bankruptcy.[6] Following a management reorganization, an influx of new cash, and cost cutting measures, the program appeared to be stable. Other changes included a tightening of license fee collections and commitments from local industry to step up the development of reprocessing technology and to establish plants. Two major changes were undertaken to address the oversupply of plastics. First, a separate consortium called DEKUR Kunstoff Recycling GmbH was formed and made responsible for recycling plastics packaging in the country.[7] Second, DSD moved to a sliding fee scale, based on material types, rather than weight alone. Manufacturers were charged more for plastic and composite materials, which are more expensive and difficult to collect and reprocess than other materials, such as paperboard and glass. Although the system was very troubled and near failure during the year, source reduction was achieved in 1992 and 1993. The total amount of packaging in Germany was reported to have decreased 3.1% in 1992 and about 4% in 1993.[8] This followed packaging increases of 11.7% and 3.5% in 1990 and 1991, respectively.[9]

Economic Factors Within the Recycling Industry.—The basic economic structures for each commodity within the recycling industry are similar. Metal recycling, particularly of steel and aluminum, is the most established. The paper and glass recycled material markets also have been in place for a long time.

The market for recycled plastics is still in development and, in most cases, secondary plastic resin is more expensive than virgin material. Makers of plastic bottles sometimes buy the recycled material in spite of the price disadvantage because they have faced potential legislation or other regulations that would restrict bottle disposal in landfills. The increased use of more expensive recycled materials sometimes is economically more favorable to the industry than a ban of the material or other costly restrictions.

Plastics recycling businesses are not as vertically "integrated" as those for other materials. A significant number of small firms perform only one or a few of the various steps involved in recycling and reproducing plastic materials and manufacturing new products that go to market ("horizontal" business structure). Companies in the other, more established, marketplaces commonly undertake many or all of the steps. These businesses are vertically "integrated;" they have diversified their business into multiple stages, or steps, of the production cycle. This allows for greater efficiency and leaves the companies less vulnerable to changes in markets and prices. For example, when several companies are involved in various steps of the recycling of a material, the transportation costs alone between sites can significantly add to overall processing costs compared with a more "integrated" company handling the entire process at a single site.

Some of the more successful recyclers are vertically integrated. For example, the large North American plastics recycler Wellman, Inc.,[10] located in New Jersey, is integrated forward into the production of fibers and thermoform extruded plastic sheet, as well as backward into the waste collection process. Another approach taken by some companies is to structure their businesses in accordance with agreements or alliances with other companies in support of each other.[11] This provides more security for the company while making unnecessary the direct expansion of their business into work with which they may have little experience. In addition to being a potentially difficult transition, such expansions can be very capital intensive.

Another difficulty for materials recycling is that of classic supply and demand. Most recycled materials, with the exception of scrap metals, face similar basic economic problems: high supply, low demand, high cost, low quality (compared to virgin), and low, unsteady prices. The high supplies have been caused by somewhat enthusiastic collecting by the public that increases yearly, and in part by mandatory recycling without sufficient building of the product marketplace. Low quality, commonly due to contamination by unlike materials, such as paper mixed in with a load of post-consumer plastics, limits the use and value of the materials. Contamination results in higher processing costs, or even rejection of the otherwise good material load. Virgin material is usually less expensive and quality is far more consistent and easier to control. Oversupply and unreliability of the material quality only adds to the standard costs of recycling, which are collection, transportation, sorting, further processing, and the specific technologies involved in reproducing a useful new material and final product. The recycled material marketplace can be made more stable through: (1) continued improvements in material quality, (2) the continuous reliability of that supply, and (3) emphasis on the demand for the final product to better match increasing quantities of collected materials.

The primary sources of pricing information for most recycled material commodities have thus far been weekly and monthly trade publications, which calculate the prices by polling traders. In recognition of the often low, unstable pricing for recycled materials, the National Recycling Coalition's (NRC) Recycling Advisory Council (RAC) and the Chicago Board of Trade (CBOT), a nonprofit futures exchange market, commenced an experimental project to help develop a more secure and mature recycled materials market. The National Recycling Coalition is a nonprofit organization that unites large and small businesses, recycling and environmental groups, state and local governments, and individuals in a concerted effort to maximize recycling across the United States. The RAC was created by NRC to build consensus and provide national leadership and coordination on issues affecting recycling and resource management. The RAC meets at least three times per year to review current issues and recommend recycling initiatives to both the public and private sectors and is in part funded by the EPA.

The CBOT, in allegiance with the RAC, is creating the country's first cash exchange market for recycled materials commodities. Plans call for an electronic trading market in which sellers would list offers and buyers would post bids on a computer bulletin board. This may provide potential buyers with more accurate pricing information and, in the near future, standardized quality specifications. CBOT believes that the unregulated and volatile nature of dealing recyclables has been partially responsible for the slow development of recycled material and product markets.

Polyethylene terephthalate (PET), high-density polyethylene (HDPE), and glass were projected to be the first post-consumer materials traded because of support from those industries and interest from buyers and sellers of those post-consumer materials. Paper and metals may follow as the next traded recycled materials.[12]

The "Not-In-My-Back-Yard" Factor.—"NIMBYism," as it is often called, refers to resistance by citizens to the siting of certain nonresidential facilities near to where they live. Whether the resistance is based on legitimate concerns or is more an emotional reaction, it represents a real problem for both the solid waste and recycling industries. The siting of a needed recycling facility, incinerator, or landfill can be a very difficult process. Most people do not want one "in their back yard," but reality dictates that they must be constructed somewhere. The public must be protected from unreasonable or harmful facility sitings and at the same time be served in their needs for solid waste management and materials recycling. Various facilities are needed to recycle the different kinds of used and waste materials. Some examples of these are materials recovery facilities (MRF's), where collected materials are sorted and made ready for shipment to recycled material processors, and materials transfer stations that handle and process the materials that the public puts out at the curbside for collection. Location is not the only issue; general economic issues involved can prohibit the siting of a facility in a location even when most of the people concerned accept the site.

Legislation and Government Actions

A Presidential Directive.—In October, the President signed an Executive order to modify the Federal Government's procurement practices by significantly increasing and specifying the recycled material content required for various purchased goods and supplies. Specifically, Federal agencies were directed to purchase printing and writing paper containing a required 20% post-consumer content material by the end of 1994 and 30% content by the end of 1998. Prior to this order, Federal agencies were encouraged, but not required, to purchase paper with 50% total recycled content, only 10% of which was to be post-consumer content. In support of the new requirement and standards, a revision of the brightness specifications for paper were ordered to allow, though not require, the use of stationary produced without chlorine bleaching, which can potentially be harmful to the environment. U.S. mills use chlorine more commonly than foreign manufacturers to brighten paper to meet the specifications or desires of its customers, including the Federal Government.

The new policy also strongly encouraged agencies to use retreaded tires and re-refined motor oil. Whereas purchase of recycled paper by the Government has become increasingly common, purchase of these latter two have not been usual for a variety of reasons. Only 6,000 retread tires have been purchased in the past several years for a Federal Government fleet of 60,000 passenger cars. This is partly because the Government normally keeps its vehicles only for 3 years or 30,000 miles, and often the original equipment does not wear out in time for replacement to be necessary. Virtually no re-refined oil has been bought for passenger cars owned by the U.S. Government, in part, because of concerns surrounding the validity of a car's warranty when re-refined oil is used. Additionally, the order directed the EPA to provide a publication listing "environmentally preferable" products, such as nontoxic cleansers and less cumbersome packaging.

Increased development of the recycled material marketplace was a major reason for this action, which could have significant effects for two reasons. First of all, by itself the Federal Government buys 300 million tons of paper per year, about 2% of the national market; and overall, Federal procurement accounts for about 8% of all goods and services nationwide. Also, the Executive order was applied to Government contractors. By the end of 1994, when a company responded to a request for proposal (RFP), the RFP was to be submitted on double-sided paper with no less than the same required 20% post-consumer content.[13]

Secondly, besides the direct impact of Federal Government purchases, its actions are intended "by example" to influence State and local governments and U.S. industries, as well as the general public, both to accept and to purchase more recycled-content goods. Not uncommonly, when the Federal Government "sets a standard," it is followed, in time, by a significant number of other government entities and U.S. industries.

Two exceptions to the basic rules were included in the Presidential order. The first concerned what materials could be categorized as "recycled content." Recycled content was defined as containing post-consumer paper, that is, paper that had been used by the public, except in the case of sawdust that would otherwise be discarded in landfills. When sawdust, a virgin material byproduct at lumber mills, was to be included as part of the recycled content, the mills would be required to deliver paper with a 50% recycled content. A second provision concerned costs. Higher prices for recycled paper of 3% to 4% more than virgin paper were anticipated for the first several years while the market was growing and expanding. This would have to be absorbed by the agencies' more conservative use and reduced waste of paper. More conservative use of paper, such as through two-sided copying, would be encouraged to make up for some of this extra cost. As the exception, agencies would be exempt from buying paper with the specified recycled content if certain conditions, such as price, were deemed "unreasonable." The order did not define or quantify "unreasonable," although the EPA indicated that a price differential of up to 10% would not be unreasonable.[14]

Federal Actions.—As in 1992, efforts to fully reauthorize the Resource Conservation and Recovery Act (RCRA), last accomplished in 1984, did not succeed in 1993 and were similarly not expected to succeed in the remaining year of the 103d Congress. Reauthorization of the Comprehensive Environmental Response, Compensation and Liability Act, "Superfund," and resolution of related hazardous waste issues still had priority and yet were to be accomplished.

Issues surrounding the transportation of solid waste and hazardous waste across State lines, flow control of recyclable materials and solid waste, and the hazardous or nonhazardous characterization of MSW incinerator ash received significant attention. This occurred both in the U.S. Congress and on the Federal Court scene, but nearly all were continued over into 1994 without resolution.

State Legislation and Government Actions.—The focal point of recycling legislation on the State level has changed during the past several years. A shift has occurred from collection-oriented legislation to demand-side legislation. A variety of State recycling laws were passed, but none were comprehensive solid waste or collection laws. This was the case partly because most States already had adopted them, especially since the mid-1980's. The number of legislative bills addressing packaging issues dropped 50% from those of 1992. Additionally, efforts to institute controversial recycled content mandates on packaging were successful only in a small number of cases. Debate continued concerning what methods would better increase recycled material use while minimizing adverse effects. Altogether, State legislatures created or amended 110 recycling laws in 1993.[15]

In response to the overall weak market for recovered (post-consumer) materials, many States passed laws designed to encourage the market for recycled materials, boost local economies, and create jobs. Also supporting market development, a total of 36 States had programs by the end of 1993 aimed at creating jobs and economic development in the recycling industry. Many of the other 14 States and the District of Columbia had laws or were in some other way encouraging recycling. The EPA was distributing grants to promote jobs in the recycling industry to 13 States, at least 2 of which did not have programs of any kind.

A variety of market development tools were used by State governments. Tax incentives, such as tax credits for the purchase of recycling equipment, were used by many States as they usually require no direct funding. Eight States—Arkansas, Iowa, Maine, Montana, Nevada, North Dakota, Virginia, and West Virginia—initiated or expanded tax incentives for recycling in 1993, bringing the total to 27 States. Nevada and Iowa passed property tax exemptions for recycling enterprises. Three States passed legislation in 1993 creating task forces or councils to promote market development. Government procurement was another method used: nearly all States have some form of procurement laws that affect recycling. Fifteen States strengthened their purchasing preferences for recycled materials during the year. The State of Florida used fee legislation to encourage greater use of recycled materials. The Florida Advance Disposal Fee on packaging significantly amended the original 1988 law. The fee, 1 cent on bottles, cans, jars, and beverage containers from 5 ounces to 1 gallon in size, was collected—at the wholesale level instead of the retail level—and took effect in October 1993. It applied to packaging materials not meeting a 50% recycling rate, effectively exempting aluminum and steel.[16]

Two other approaches used to encourage increased recycling were landfill bans on certain materials and implementation of recycling and waste diversion goals. Eight State legislatures passed disposal bans to bring the total to 46 States that had materials or products banned from landfill disposal. The most common materials that have been banned from landfills to date are vehicle batteries, tires, yard trimmings, motor oil, and white goods. A total of 44 States have either legislated or otherwise announced goals for recycling or waste diversion, which range from 20% for Maryland to 70% for Rhode Island. Fifteen States have goals that are 50% or greater, including the two most populous States, New York and California. Two States set new goals in 1993. Connecticut approved some of the most significant legislation in 1993 aimed at diversion of waste from disposal facilities. The State raised its recycling and source reduction goal to 40%, from 25%. The earlier goal had a deadline of 1991; the new target gives the State until the year 2000. The State reported a recycling rate, including composting of yard trimmings, of 21% for 1993. The Governor of the State of Colorado announced a 50% waste reduction target to be achieved by the year 2000. The goal was not passed into law but government grants, a funding mechanism, and a program tracking mechanism were set in place in support of the initiative.[17]

ANNUAL REVIEW

Paper Recycling

Paper and paperboard materials initially are produced almost exclusively from wood pulp, which is wood or "cellulose" fiber mainly processed from softwood timber, and to a lesser degree, from hardwood timber. Softwood fibers impart strength and tear resistance while hardwood fibers provide density and printability. The major categories of paper products include: paperboard; kraft paper, including that used for corrugated container board; cardboard; newsprint; printing and writing paper; and various utility papers, such as for bags, plates, tissues, and towel products. These products, as well as fiberboard used in construction and paper-based insulation materials, are potential markets for both pre-consumer and post-consumer recycled paper fibers to supplement virgin fiber content and reduce the quantity of paper in the solid waste stream.

Issues.—Two issues with potential to affect increases in paper recycling are: (1) how to reduce the consistently growing quantities of paper in MSW and (2) how to best balance environmental problems and conflicts related to virgin material supply with tradeoffs related to increased substitution of recycled paper. Our society has become a heavy consumer of paper and paperboard products. The "paperless society" speculated by many in the past does not appear to be close at hand. We are using more and throwing away more with each passing year.

According to the EPA, the total generation of paper and paperboard products in MSW has grown steadily from 27 million tons in 1960 to almost 67 million tons in 1990. (More recent EPA data were not yet available for this report.) As a percentage of the total MSW generated, paper (by weight) represented about 34% in 1960. Although the percentage has varied over time, it has generally increased, to 37.5% of the total MSW generated in 1990. Much of the paper that we use comes in the form of nondurable goods with relatively short lifespans. Waste from paper packaging materials and newspapers having lifespans of less than 1 year (often only several days) have followed this same trend. When added together, they account for about 60% of total paper waste. However, the actual quantities going to landfills have shown small decreases of late. Based upon EPA data, the quantity of paper being landfilled dropped by about 5% between 1985 and 1990. During this time, paper recovery for recycling and incineration (usually involving energy recovery) has significantly increased.

Paper recycling, a common practice during the newspaper drives since the 1950's and 1960's, has greatly increased in the past two decades. The recycling of paper reduces the need for virgin wood fiber. The diversion of paper alone could significantly reduce the quantities of waste filling up our landfills.

Quantities of solid waste managed by incineration substantially declined from the mid-1970's through the mid-1980's, but rebounded to above 1970 levels by 1990. Since 1985, numerous new facilities—cleaner, more efficient, and almost exclusively with energy recovery systems—have come into operation. This includes both mass-burn and refuse-derived-fuel (RDF) plants. RDF is MSW that has had certain materials, especially metals, separated out, after which the remaining materials are processed into a fairly consistent, uniform-sized feed of combustible material.

Secondly, because paper materials are produced from wood fibers, the production of paper and paperboard products promotes significant use of timber resources. About 25% of U.S. timber production goes into the making of woodpulp, of which about 95% is used in the production of paper. Increasing attention is being paid to a variety of environmental issues. Growing controversies over various endangered species, the loss of virgin forests with relatively untouched biological diversity, and the erosional effects of the clear-cutting of forests are several issues related to the harvesting of timberland. These factors have a potential to influence the increased use of recycled paper fibers in new paper products.

Currently at issue is the establishment of a generally acceptable standard or legal definition of "recycled paper." Much effort was put forth by Federal Government agencies and joint committees, as well as trade associations and independent materials standards organizations, to do so. But final definitions for recycled paper and related terms were still in the discussion stage at yearend. The use of pre-consumer scrap paper in paper production is a common practice of many manufacturers because it is a good alternate source of raw material. It generally yields a high-quality product more easily, and most often at a lower cost than when post-consumer paper is used. Post-consumer paper tends to be "dirtier" with more contaminants than the more consistent and controlled quality of pre-consumer scrap that often has not left the factory. The need to divert more post-consumer paper from the Nation's landfills is becoming increasingly emphasized. Settling on ways to accomplish this while continuing to encourage the recycling of pre-consumer scrap has been difficult. Proper definitions are needed for Government procurement procedures to be effective. The Federal Government is a significant potential market for recycled paper. It is not only the largest single consumer of paper, but additionally, it may serve to set an example for the voluntary efforts of other organizations. State agencies and private industry tend to follow its lead.

Annual Supply and Recycling Rates.—All recycling rates are not based on the same type of data. EPA and the American Forest and Paper Association (AFPA) report paper recycling from two different perspectives. EPA compares the total post-consumer paper recovered for recycling to the estimated total paper waste generated each year. EPA estimated that 28.6% (19 million tons) of the paper waste generated (66.5 million tons) during 1990 was recovered. This was up from the 22% and 21% rates of the early and mid-1980's, respectively.

AFPA compares the combined total of pre-consumer and post-consumer paper recovered to the total "new supply" (apparent consumption) consumed in the United States during that year. Fabrication scrap is included in its pre-consumer recycled scrap numbers as part of the recycling rate. Also, AFPA's total recovered fiber data and resulting recovery rates percentage include recovered material that is exported. In 1993, exports totaled almost 5.35 million tons (5.9 million st). This was down from 1992 when 5.85 million tons was exported (6.5 million st). But the total material recovered for recycling increased in 1993, showing a gainful trend in the allocation to domestic use of recovered paper fibers.

AFPA reported that, during 1993, almost 32.5 million tons (35.8 million st) of paper and paperboard was recovered for recycling and reuse out of a total supply of about 82.8 million tons (91.2 million st). (Total supply includes total consumption in the United States of all paper and paperboard, including construction paper and board.) Both quantities represent increases from 1992 when 30.5 million tons (33.6 million st) of paper and paperboard was recovered out of a total supply of almost 80 million tons (88.15 million st). The recovery rate for 1993 was 39.2%, slightly less than the 38.1% of 1992. As shown in figure 2, both the quantities recovered and the related recovery rates have been consistently increasing for a number of years. In the years 1985 and 1990, the respective rates were 26.8% and 33.6%. Also shown are the recovery rates for the two leading types of paper products. According to AFPA, old newspaper (ONP) recovery grew from almost 45% in 1990 to 58% in 1993 (up from 55% in 1992). Old corrugated containers (OCC's) are the highest tonnage source of recovered paper, as shown in figure 3. *(See figure 3.)* The recovery of OCC's grew from almost 55% to 62% of the total supply of new OCC paper between 1990 and 1993.

The pattern of growth in the consumption of fiber used at U.S. paper and paperboard mills between 1980 and 1993 is shown in figure 4 and table 1. *(See figure 4 and table 1.)* The quantities of primary (virgin) wood fibers have consistently grown during this time period, but its percentage of total consumption has remained relatively constant, and the use of other (virgin) plant fibers, a relatively small quantity, has dropped by 1%. The greatest growth by percent, from 22.6% to 32%, has come from the increasing use of fiber from recovered paper. Quantities of wood residues and waste, also a recovered and recycled material, have consistently been in a state of flux since 1980, reaching their highest use in the mid- to late 1980's. Current use is just minimally above 1980 levels.

Consumption and Uses.—Although more than 70 different types, or grades, of paper exist, the paper industry uses 5 basic classifications: corrugated containers, newsprint, mixed, pulp substitutes (clean converting scrap), and high-grade deinking. A summary of the quantities of recovered paper and paperboard between 1983 and 1993, as reported by AFPA, is provided by category in table 2. *(See table 2.)* These data include both post-consumer scrap and pre-consumer scrap, the latter generally being easier and more economical to recycle than post-consumer scrap. Consumption of growing supplies of collected waste paper is complicated by contamination by other waste materials, reduced secondary fiber quality (shorter fibers), and readily available markets for the secondary paper fibers that are economically viable. Though not without its own difficulties, a collection program can be set up in a relatively short period of time. But creating cost-competitive, marketable products is the greater challenge.

Kraft paper can serve as an example of a paper material with a secondary market. Kraft paper is the brown paper used to make corrugated containers and paper bags. According to EPA, it makes up about 36% of the total generation of paper waste. The previously mentioned 39.2% paper recycling rate is possible because of a specific market for recycled kraft paper fiber. The outside sheets of corrugated board, called liner paper, often need to meet rigorous specifications for resistance to bursting, puncturing, and crushing. This is especially true for paper that is to be made into boxes for shipping fragile products such as electronics, appliances, and glassware.

Recycled paper has shorter fibers than does virgin paper and consequently, it is not as strong. As the recycled content of the liner paper increases, the paper's strength decreases. This limits the potential use of recycled fibers in the liner paper of corrugated boxes. The specifications for the paper from which the inner fluting of the corrugated box is made are much less rigorous. The inner fluting is the curved middle paper material between the two paper liners that gives a box the structure and look that we think of as "corrugated." It provides the transported product protection from potential damage.

Another example where significant opportunity exists for using recycled paper in lower grade applications is that of used newsprint recycled to manufacture cellulose insulation and garden mulch. In such less demanding types of applications lie a significant potential for the use of large volumes of waste paper.

Technology.—Contamination can make the recycling of post-consumer paper very expensive, if not economically impractical. OCC's sometimes include wax coatings, plastics, food, mill wrappings, etc. The recycling of office paper is complicated by a large diversity of paper grades, as well as quantities of contained groundwood fiber, nonwater-soluble glues, paper clips, and rubberbands. Although improved cleaning equipment and technological advances are minimizing these impacts, continual improvements in collection methods and an evolving education of the public concerning the problems caused by contamination are an important part of the solutions. Probably the most significant technological progress is occurring in the deinking industry, in which new methods and technologies are being developed and many new plants have been coming on-line or are in the planning stages.

Steam explosion deinking technology is a current state-of-the-art and increasingly utilized method to deink office paper, especially the lower and mixed grades of paper. The process can be used as well to process OCC's at roughly two-thirds the cost of a similarly sized plant using conventional technology. A number of new plant projects were begun in 1992, both in the United States and in Canada. Steam explosion, a process used in the past to break apart wood chips and other biomass, deinks by "exploding" waste paper. This is accomplished by feeding the paper into a high-pressure chamber and then releasing it to atmospheric pressure. This process enables the recycling of even contaminated and low grades of waste paper. The steam explosion system results in more uniform pulp than other processing alternatives, requires no hazardous chemical deinking, and can process problem feedstocks, such as coated and waterproof stocks. Also, it requires substantially less water and energy than the more commonly used technologies. When used for newsprint and writing paper-grade sheets, some further deinking by the more common methods of flotation and washing is needed to remove small quantities of ink that remain.[18] In flotation methods, ink and other contaminants are chemically induced to be hydrophobic (water-repelling). Air is injected in the lower half of the flotation tank. Ink and contaminants attach to rising air bubbles because they are repelled by the water and the bubbles are the only way to get away from the water. Washing, the oldest deinking technology, involves chemically inducing ink particles to be hydrophilic (water-attracting) so that the ink is washed away with the water. A company in Virginia and another in Maryland were developing cogeneration plants to turn coal (VA) and natural gas (MD) into electricity and steam. New waste paper facilities were to be added, using the electricity generated to run the plants and provide the steam for the deinking processes.[19]

In late spring, International Paper Co. announced a new recycling initiative for recovering milk and juice cartons into recycled-content copier and printing papers and a variety of other recycled paper products. The company had completed a pilot project on the west coast and was planning to install a new carton processing plant in one of its existing mills in the northeast. Recovered cartons there will be used to produce copier and printing papers. The initial concern has been to establish an adequate flow of suitable materials. For this reason, the company was holding ongoing discussions with several major metropolitan areas about adding cartons to their curbside collection programs.[20]

Markets and Prices.—Markets for recovered paper and reprocessed paper pulp vary with the type and grade of paper that is collected or processed. A large variety of paper products with recycled content is produced in the United States. According to AFPA, more than 80% of all the paper recovered in the United States is recycled at domestic mills. The rest is exported or reused domestically to make other products, such as animal bedding, insulation, hydromulch, and compost. Significant quantities of scrap and discarded paper, notably newsprint, OCC's, and office paper, are exported. The third largest market for ONP in the United States is the export market. These ONP exports primarily go to Pacific Rim mills that use waste paper as a primary raw material. As for OCC's, about 2.3 million tons of the 15.1 million tons that industry reported as recycled in 1993 was exported. More than one-half of the office paper collected for recycling is generally exported, again primarily to Pacific Rim countries.[21] Quantities of recovered paper being recycled have been continually increasing in spite of market prices. Except for minor upswings in 1992, the prices paid for recovered paper products remained relatively flat during that year through early spring 1993. After that time, prices for most recovered paper began a slow decline, and only OCC began to recover and rise a little by the end of the year. Prices have been relatively low in part because of oversupplies of recovered paper in addition to the sluggish overall economy. At the same time, efforts continue to collect increasing quantities of post-consumer paper. Without significant improvements in the general economy, the stabilization of current recovered paper markets, and the creation of new markets for recovered paper and pulp fiber, prices for secondary fiber were not expected to improve greatly.

Market Development: The Great Lakes Recycle Project.—In 1992, the Council of Great Lakes Governors (CGLG), composed of the Governors of the eight U.S. States bordering the Great Lakes, determined that their States had problems related to materials recycling in the region. Post-consumer materials were piling up in warehouses and at collection sites and far too often ultimately ended up in the region's landfills. This was happening because the markets for many of these secondary materials were weak or often nonexistent.

The Governors realized that a stronger secondary materials market was needed. In response to this need, they created the Great Lakes Recycle Project to promote materials recycling by way of joint procurement of recycled products through multistate contracts. The initial product purchase was for high-speed xerographic paper with a specified secondary material content. The success of that purchase resulted in the recycling of 1,360 tons of secondary paper, a Presidential citation, and the decision to further expand multistate procurements to other products and materials. To accomplish this, a Materials Board was created. The Materials Board consisted of representatives from manufacturing industries, secondary material suppliers, and State and Federal governments.

The primary objective of the board was to promote joint State procurements of goods with recycled content within the region. With the creation of the board, the need was realized for information on where State government procurement policies could have the greatest effect in promoting secondary materials use. The Governors and the board also recognized the need to minimize any possible negative effects on virgin material producers or other industries potentially affected by their good-intentioned actions. CGLG did not want to remedy one problem while creating another. The USBM, because of its extensive experience in conducting minerals and materials flow studies, was invited to be an ex officio member of the board. Also, the USBM was deemed an appropriate partner because it is a comprehensive source of information on mineral and material production, consumption, recycling, and waste handling.

The USBM's involvement with the Great Lakes Recycle Project centered on developing an analytical framework for quantifying specific material flows in the region and identifying potential procurement opportunities for recycled materials to the Materials Board. A USBM materials study group set out to define the flow of both primary and secondary material resources within the eight-State region. The paper industry was selected for the study in the initial analytical framework development phase, in part, because the State governments already had established a successful track record in the procurement of recycled-content high-speed xerographic paper. Also, the State data on these paper procurements, together with data from the analytical framework, help provide the necessary verification of the framework prior to its implementation into other material sectors. The analytic framework was designed to be nonregion specific, and therefore a generic model, allowing it to be equally useful for assessing material flows in other areas of the country or elsewhere for replication of the Great Lakes initiative.

The paper industry was a good practical starting point for this project because of the scope of the industry and, perhaps more noteworthy, the considerable dollars expended on paper and paperboard products in the region. In 1990, the eight Great Lakes States consumed $57.7 billion dollars worth of paper and paperboard products. Of that total, State and local government purchases accounted for $5.4 billion, or almost 10%. Most recently, under a joint bid, the States purchased 12,300 tons of paper in 1992 and 9,700 tons of paper with a 50% recycled waste paper content in 1993.

The USBM materials group used the computerized, economic input-output model, Impact Planning for Analysis (IMPLAN), to determine the paper product purchases and paper material flows in the region. IMPLAN, currently maintained by the University of Minnesota, depicts dollars expended for materials by 528 domestic industry sectors based upon surveys conducted by the U.S. Bureau of Census. In the paper industry, the three basic industry sectors—pulp mills, paper mills, and paperboard mills—are the integral fiber and paper material suppliers. In addition to supplying products to final consumers, these three sectors supply feedstocks to 20 paper-intensive, manufacturing industry sectors, such as envelope producers, book publishers, and producers of periodicals, paper bags, paperboard containers, etc. The project's next phase was to convert the IMPLAN data from value terms to tonnage terms for all paper materials produced primarily from virgin sources and purchased in the Great Lakes region. To follow was identification of the region's secondary paper materials flows. Upon completion of the paper materials flow study, the same basic model may be adapted by the USBM team to materials used in highways and construction, office machinery, and plastic goods. In addition to paper, the Great Lakes Materials Board discussed possible future studies concerning re-refined oil and solvents and rubber tires for future joint procurement activities.

Plastics Recycling

Plastics are long-chain polymer and resin materials that are synthetically produced almost entirely from nonrenewable hydrocarbon resources, most notably natural gas and petroleum. During the past three decades, rapid growth has occurred in the use of plastics for a seemingly countless variety of purposes. Production in the United States has shown an average annual growth rate of 10%, with continued growth expected into the future. This growing flow of plastic materials has resulted in gradually accelerating increases in the quantity of plastic waste annually generated in the United States, as shown in figure 5. *(See figure 5.)* The increasing use of plastics in packaging accounts for much of the waste. According to the EPA's municipal solid waste characterization study, containers and packaging accounted for almost 43% of all the plastic waste generated in the United States in 1990. (More recent data are not yet available). Plastic packaging is a target for recycling because most packaging material has a relatively short period of use (less than 1 year) before discard. Packaging is usually a temporary "transportation" medium for another product and is not intended to have a long useful life. The typically more durable products it contains are generally not intended for such immediate discard, and the packaging material is quickly available for use in another product.

Other sources of waste plastic in MSW are appliances, furniture, carpets, and lead-acid battery cases, in addition to a variety of nondurable goods, such as plates and cups, trash bags, footwear, disposable diapers, and both synthetic and natural material textiles. Textiles are in an industry separate from the plastics industry and are sometimes forgotten as a source of waste resin. In 1990, approximately 62% of the fibers consumed in the U.S. textile industry was synthetic resin fibers. Textile resin fibers also become part of the municipal solid waste stream. Domestically, significant quantities of used textiles were reused for their original purposes, mainly clothing, while even larger quantities were exported for similar reuse. Domestically, reuse included old textiles materials used as wiping rags. A variety of U.S. industries used about the same quantity of "rag" material as was reused as clothing. However, only small quantities were actually recycled in the United States as of 1990. Recycled textiles mostly included textile fabric fibers that were reprocessed to make specialty papers (these require a 100% cotton textile source), carpet padding and upholstery in cars and trucks, and certain wool products (only pure wool textiles are useable). Although not included in MSW data, significant quantities of waste plastic result from the discard of automobiles and from the construction—and even more so the demolition (C&D)—of houses, buildings, and other humanmade structures.

Issues.—**Used Plastic Material Management.**—Plastic products, especially as used in packaging and containers, are a low-weight but high-volume waste material that contributes to filling up our landfills. Although being about 9% by weight of our municipal solid waste that is landfilled each year, they account for possibly 20% or more of the volume, as reported by the EPA. A recent estimate of the volume of plastics in landfills was reported by William Rathje of the University of Arizona. In archeological digs of landfills across North America, as part of his "The Garbage Project," he determined that plastics compact better in landfills than has generally been believed. In these excavations, plastics took up about 16% of the space in the landfill. Although they may take up less space than previously believed, plastics by weight still take up a significantly larger portion of landfill space than other typical MSW materials. Because they are a significant nonbiodegradable material, they are often a target for recycling or incineration. Some of the very qualities, such as durability and corrosion resistance, for which plastic materials are used are the same "qualities" for which they are criticized upon discard. The management of plastic products when they have outlived their usefulness is an ongoing issue.

Although some States and counties have attempted to restrict the entry of certain plastics into the solid waste stream by banning their use, this approach has so far only been instituted in a few cases. Two U.S. locales that have attempted plastic material bans are Suffolk County on Long Island, NY, and the town of Fairfax, CA, just north of San Francisco. Suffolk County's ban on plastic grocery bags and polystyrene and polyvinyl chloride food packaging at retail food establishments was under reevaluation. A study of the future effectiveness of the policy was performed under the direction of the Waste Management Institute at the State University of New York/Stony Brook (SUNY), by request of the county executive. Among the reasons for the study were questions as to the law's possible negative effects on the county's recycling program. The study was undertaken with respect to the original goals of the legislation, including a survey of the county's current litter situation, and how the law was likely to succeed in those intended purposes. Lawmakers met 2 months after the SUNY report was issued and, by a narrow margin, defeated a measure that would have repealed the 1988 plastics law. The ban in the town of Fairfax included polystyrene packaging for food prepared on a firm's premises. The law took effect in December, having been passed by the town's voters the previous month. Thus, little time has passed to fully address any results.[22]

Under the EPA's waste management hierarchy, recycling used or waste plastic products into new products is preferred to the incineration or landfilling of them. Plastics recycling is further encouraged by some advocates because plastic is derived from nonrenewable energy resources. But to be successful recycling must result in a product with (1) high enough quality, (2) low enough cost, and (3) be done with an efficient expenditure of energy and other natural resources. If not, incineration of waste plastic is a potentially valuable alternative. When its hydrocarbon origins are considered, plastic is, not surprisingly, a highly energy-intensive material. In the WTE incinerator, it is a very valuable component of the mixed municipal solid waste. As well as having high energy values, the heat it gives off promotes better burning of the surrounding mixed wastes. Incineration is a final one-time use of the material promoted by its advocates as more productive than simply burying it.

Biodegradability.—Although some degradable plastics have been produced and others are under design, they are only a small part of the solution to related landfill and litter problems. These materials may be useful in specific applications; for example, for 6-pack beverage container rings, packing peanuts, compost bags, and possibly disposable diapers. But they are not practical for many uses of plastic. Also, the production of truly degradable plastics in the large scales necessary would currently be technologically and economically prohibitive. The large majority of "degradable" plastics at present are more accurately labeled as "biodisintegratable" or "photodisintegratable" because the plastic itself does not truly degrade. Disintegratable plastics, such as everyday plastic grocery bags, break down into a plastic sand or dust when the starch molecules that join them together truly degrade, due either to biological agents or solar energy reactions. The polymer in these materials does not degrade—it is the same durable plastic in miniature. The environmental consequences of this plastic dust is unknown. For some applications, the desired characteristics of plastics, such as durability and corrosion resistance, would be adversely affected by formulating the plastic to be degradable. Another issue is the recyclability of other plastic materials, which for technological or economic reasons, can be limited when contaminated with quantities of biodegradable plastics.

One innovative manufacturer of biodegradable polymers, Novon Products Group, ceased operations near yearend for economic reasons. Novon products included yard waste collection (compost) bags; cutlery, medical disposables, and personal care items; and blow molded bottles for the vitamin and pharmaceutical industry. Recycled plastic materials cannot be used for pharmaceutical applications owing to U.S. Food and Drug Administration compliance issues and rules, thus limiting the use of biodegradable plastic as an appropriate alternative to virgin resin. Novon's polymers are derived from the starch of corn and potatoes, in addition to other completely biodegradable ingredients, states a company report on the process. When disposed of in a "biologically active environment," such as compost, they are designed to be broken down by microbes into water, carbon dioxide, biomass, and other trace amounts of naturally occurring minerals.[23] The company had established customers in Australia, Canada, Europe, and Japan, and the United States, where its products were being used by a wide variety of institutions, including Walt Disney World Co. The shutdown was in part the result of the restructuring and consequent downsizing of their parent company, Warner Lambert Co. The decision was deemed necessary in light of the restructuring because further development of the Novon products would take more investment and financial support than was available. Novon committed itself to indefinitely continue production of the polymers at its main manufacturing facility in Illinois to fulfill current customers' orders, while looking for suitable investors for its patented technology.[24]

An ongoing, controversial issue for many recycled plastic material and product producers is that they conduct business on an uneven, unfairly competitive playing field with virgin plastic producers, resulting in unfairly stiff competition. Recyclers contend that virgin producers have the advantage of buying their raw materials from the oil and gas industry, which receives either subsidies or tax breaks, thereby reducing the expense of their raw materials. In efforts to encourage more recycling, a number of alternative approaches to this controversial problem was under discussion in the EPA and the U.S. Congress, as well as other Government agencies and independent task forces.

The Recycling Advisory Council (RAC), formed in 1989 in part under a grant from EPA, consists of representatives from business, industry, environmental organizations, and public interest groups, as discussed earlier in this chapter. In a major effort to find ways to increase recycling in the United States, RAC's mission was to investigate the crucial issues concerning and surrounding materials recycling, not the least of which were barriers to the development of the various scrap commodity markets. From the latter part of 1992 through 1993, its market development committee conducted a study of the barriers to recycling and possible approaches to solve these problems. Results of this study were to be used in 1994 to develop a "tool box" of policy options for decisionmakers to consider when addressing the challenges facing recycled material market development. The tool box was intended to consist of information concerning the possible national frameworks or systems that had been evaluated and could be used to increase the utilization of recovered materials in the United States. Also, the options for funding the suggested recycling market development approaches would be presented. Possible national frameworks under consideration included the basing of secondary material utilization rates on waste reduction goals, targeting specific waste streams, and/or establishing commodity-specific rates. Funding options were to include: a subsidylike national secondary materials utilization "trust fund" for rebates to companies using recycled materials; a virgin material tax/recycling incentive fee; several packaging stewardship models; industry-funded price support systems, where the manufacturer of a product would be, at least in part, responsible for its recycling; and a waste utilization tax.

Annual Supply and Recycling Rates.—Most survey-based plastics recycling data came from trade groups and consulting groups that conducted studies of the relatively young plastics recycling industry. The American Plastics Council (APC), a major plastics recycling trade group, reported the results of its fifth annual post-consumer plastics recycling study, conducted by R. W. Beck and Associates. The study examined six resins commonly used in consumer packaging that also were recycled: PET, HDPE, polyvinyl chloride (PVC), low-linear low-density polyethylene (LDPE/LLDPE), polypropylene (PP), and polystyrene (PS). Various other plastics, such as polycarbonate and nylon, were included in the survey totals as they also were reported as recycled by some of the companies. For a detailed breakdown of these reported quantities of plastics recycled during 1992 and 1993 see table 3.

The annual APC survey, as well as other more limited surveys, has consistently reported increases in plastics recycling each year. Total plastics recycling during 1993, including both packaging and nonpackaging, grew 11.6% over that of 1992, while the recycling of packaging plastic, based exclusively on the APC study, grew virtually at the same rate with an 11.8% rise over that of 1992. More than 638,340 tons (1,407 million lbs) of post-consumer plastics was recycled in 1993, up from more than 572,100 tons (1,261 million lbs) in the previous year. Almost 75% of the recycled plastic was from packaging materials. The packaging component grew from about 425,020 tons to 476,270 tons. The APC/Beck annual study is a relatively new canvass study of a relatively young recycling industry. As this survey has been refined each year, not only have newly formed companies been added, but also some companies missed in a previous year were picked up and added the following year. Thus, some of the increases in recycled quantities in the past 2 years could show slightly inflated percentage increases over previous years due to the absence of these companies' data from earlier years' surveys. On the other hand, this also suggests that actual quantities recycled may have been better in earlier years than those previous surveys suggested. Nonetheless, the APC/Beck survey appears to be the most complete, physical data canvassing of companies that recycle commodity plastic materials that has been conducted for the public record to date.

PET has become the most recycled of all post-consumer plastic in the United States. Recycling of PET has grown from 3,600 tons in 1979 to nearly 228,000 tons in 1993. Just over 83% (or 189,420 tons) of the 1993 total PET recycled resulted from the recycling of soda bottles alone. This quantity was almost 41% as much as the virgin PET plastic sales for soda bottle production for the year. Almost 24,900 tons of nonpackaging PET, 11% of total recycled PET, was recycled in 1993. Total HDPE recycled in 1993 was 215,910 tons, principally from the recovery of milk and water bottles (called natural bottles), and less so from pigmented bottles and soft drink base cups. The recovery rate for the common milk jug was approaching 25%, according to the APC.

PS is used in packaging applications in the form of PS foam. Both its very high volume-to-weight ratio and its common use with food products makes collection and some associated processing more difficult than other plastics. Nevertheless, in 1993, more than 18,780 tons of PS, 11% more than the previous year, was recycled in the United States. This was a more modest increase than that of the previous year; in 1992 there was a 53% increase over that of 1991.

Going along with the slowdown in recycling growth in 1993 was that of the nonpackaging application of lead-acid vehicle battery casings made of PP plastic. Numbers revised following last year's publication showed that recycled quantities of PP from this source increased not 41% but, nevertheless, a healthy 30.1%, from 65,500 tons in 1991 to 85,411 tons in 1992. In 1993, the amount of PP battery casings recycled rose only 1.6% to 86,772 tons. One major reason for the recycling growth in 1992 was the regulations by State and local governments that required lead-acid vehicle battery retailers to return spent batteries directly back to the manufacturer for recycling purposes, and/or prohibited the flow of the same batteries into solid waste landfills. As of mid-1993, 35 States had enacted battery recycling legislation, and by the end of the year 44 States had banned the MSW disposal of lead-acid batteries.

Whereas the reported increases are an indication of positive movements in the industry, there is still a long way to go. Weak prices for many recyclable commodities in 1993 ended the year much lower than had been hoped. Based on conservative estimates of plastic waste contained in the MSW that was generated in 1993, the total plastic recycled was, at best, near 3% of the total consumed. Although small, this does show progress from the slightly less than 2% sometimes estimated for recent previous years.

Consumption and Uses.—The two major types of plastic, thermosets and thermoplastics, have significantly different limitations and challenges in recycling. Thermosets are long-chain polymers that have been "set" chemically or "cured" in a cross-linked pattern. When heated to the proper temperature, these molecules do not melt in the manner that thermoplastics do. The cross-linked bonds remain intact and the degraded or charred material cannot be formed into a new and usable shape. To date, thermosets have very limited use in recycled products. They are limited to being crushed or cut up into small pieces and used as a filler or aggregate material in certain product applications. Thermoplastics also are composed of long-chain polymers, but they have not been chemically linked together, allowing them to slide by each other when properly heated. They melt into a liquid or moldable form. When the temperature drops, they resolidify or harden into the new product form.

Recovered and reprocessed plastic is consumed by a large number of industries, consequently resulting in a wide variety of new products. Consumption by individual industry is difficult to quantify. Recycled PET plastic is used in the manufacture of carpets, industrial strapping and pallets, fiberfill for sleeping bags and ski jackets, automobiles parts, nonfood containers, plastic lumber, and a continuing variety of other products. An important market for recycled PET is the synthetic fiber (textile) industry that uses the PET for carpet backing and other fiber products. HDPE is commonly formed into bottles, industrial and consumer containers, drums and oil storage containers, fuel and other tanks, tank liners, toys, housewares, corrugated pipe, pipe for irrigation and oil, gas and mineral production, consumer bags, some food packaging, sheeting, wire, and cable. Some of the products manufactured from recycled PS are park benches, office equipment, videotape cartridges, pallets, the new compact disc "jewel" cases, and a variety of household products.

Most recycling of plastics is based on physical alteration or breakdown (crushing and shredding) and melting of the material to produce another product. As with other recycled materials, when this is accomplished with uncontaminated scrap plastic of which the composition is fully known, this is categorized as "primary recycling." The term "primary" is restricted almost exclusively to the recycling of pre-consumer (in-house) scrap because, no matter how clean some shipments of post-consumer materials are, virtually all shipments come with a measure of uncertainty. Most have some quantity, whether minute or considerable, of a variety of impurities. The recycling of post-consumer scrap—often clean, of one or a few known types, and of high quality—is called "secondary recycling" and is the bulk of the materials recycling that has generated the most controversy.

"Tertiary" plastics recycling is different and accounts for a very small portion of plastics recycling. The old material is chemically broken down into fundamental components or chemical substances. Recycling occurs when a new, "virginlike" polymer is then produced from the resin components into a new, marketable product. The technology needed to chemically break down plastics into fuels and into the basic feedstock hydrocarbons has been known for decades. But, until recently, it was used principally within manufacturing plants where it was economically beneficial to do so. In part because of the limited one-time reuse, the chemical recycling of plastics into a fuel is generally not considered recycling in EPA's solid waste hierarchy; it is in effect comparable to WTE incineration.

Since late 1990, tertiary recycling by methanolysis, glycolysis, and pyrolysis has been used by three soft drink companies to recycle PET plastic. In these processes, used PET bottles are chemically recycled back into new PET soda bottles that are usually composed of a mix of 25% of the recycled material and 75% virgin material. Bottles made of 100% chemically recycled PET are technologically possible but currently cost-prohibitive. The quantities recycled by this method are a very small portion of the PET bottle recycling data. Because of the associated economics, thus far apparently marginal at best, this practice is not flourishing. However, most, though not all, of the original projects are still ongoing. Although virgin PET supplies were sufficient, virgin PET material output was at times near capacity. This measure of uncertainty created a demand for raw materials from the tertiary recycling operations to more securely guarantee supplies of needed new bottle material.

A significantly higher portion of plastic was recovered for WTE incineration to produce energy via steam or more directly to produce electricity than was recycled. In 1993, an estimated 17% of the plastic waste portion of the generated MSW generated was combusted in WTE incineration plants. When the resin fibers in the textile portion of MSW is included, the total percent of plastic incinerated rises to about 20%.

Technology.—Possibly the greatest difficulty in processing post-consumer plastics, both technologically and more so economically, is that of sorting or separating the different types of plastics. A high-quality recycled plastic material of a particular type may be feasible, but many products demand that recovered materials be uncontaminated with glass, dirt, and other types of plastic. In some cases, minute quantities of contamination greatly or even critically reduce the quality and usability of the recycled material. A good example of this is PVC-contaminated PET soda bottle plastic. Their similar densities complicate the process of segregating the two plastics before melting, and during melting PVC, which has a sufficiently lower melting point, contaminates the PET with a detrimental char product. Some materials and products demand very pure "recyclate" material; others, such as some plastic lumber and park bench materials, are more forgiving and can accommodate a combination of plastics.

Highly reliable separation technologies that demand little to no labor and also are cost-effective are needed for the continued and accelerated growth of recycling in the plastics industry. The human sorter cannot recognize all the different variables of plastic categories and subtypes, as well as different colors, particularly at the speeds necessary to make the process economical. Numerous plastics sorting technologies have been invented and range from those achieving limited results to some very effective and sophisticated systems. Most of these are based on various spectroscopic and X-ray analyses, infrared recognition, and laser technologies. Other systems under development include a water surface tension technique, a selective "dissolution system," and a near-infrared light system that incorporates specialized "neural networks" instead of conventional computers. Because of the problem of similar densities, in particular that of PET and PVC, one company is developing a flotation-type system to separate the two by means of their differing surface tensions.

The Rensselaer Polytechnic Institute (RPI) was testing and developing a selective dissolution system to separate individual resins. In the process, all plastic resins are commingled, shredded, and subjected to several solvent baths. Each bath is heated to the precise dissolving point of a certain resin and the resulting liquid is siphoned off into a holding tank. The temperature increases with each bath until all resins are removed. According to an associated consulting company, after further processing by "flash devolitization," the remaining resin is nearly as pure as virgin plastic and may be sold at a discount of at least 2.25 cents per kilogram. To further extend testing of the technology, RPI applied to the U.S. Food and Drug Administration for approval to use food packaging material in a future pilot devolitization process.

The Sandia National Laboratories of the U.S. Department of Energy is developing a system that uses the near-infrared light/neural network system. Modeled after the assimilatory abilities of human nerve cells, these networks will be capable of "learning" the characteristics of the resins—a process less arduous and time-consuming than preprogramming. In some test runs, once the networks have been trained through trial-and-error for all types of resins, accuracy levels of 100% have been reported in the lab. A prototype was undergoing testing by a recycling equipment manufacturer.[25]

With the increasing effectiveness and sophistication of sensing systems often comes a higher cost that limits their use by many companies because of the relatively low prices for scrap plastic. But, cost factors aside, some very accurate sensing systems are still hindered by mechanical difficulties encountered in separating the material. Two problems that researchers are working on are how to provide the automated systems with single plastic bottles or pieces and how to effectively mechanically segregate the different plastics.

Because of the bailing of plastics that is necessary for economical transport, used plastics become clumped together and a foolproof method of breaking of these clumps into the individual pieces is expensive and difficult. Several new technologies have been claimed to be virtually 100% effective in sensing the different plastics, but if the plastics are still stuck together, then the sensor reads the clump as one object. If there is more than one resin or color in that clump, rather than jeopardize the rest of the stream, the system rejects the clump. The more this happens, the larger the amount of material that has to be sent through the system a second time, proportionately reducing the efficiency and increasing the costs of the sorting and processing operation. If bottles are not completely separated into individual pieces, even perfect sensing and physical sorting technologies cannot finish the job as needed. Most, if not all, "singulation" systems are having these problems. The other mechanical difficulty is that of doing the physical sorting. This is generally done by air jet nozzle systems that are becoming increasingly accurate, although not foolproof. These systems balance the sensors' recognition time with the speed of the conveyor belt to eject the different bottles via streams of air into the proper collection bins. Some systems use a negative sort in which a plastic is sorted by not being jettisoned, but by merely dropping off the belt into another bin. The greater the variety of plastics being separated, the more difficult the process is. Some of the most sophisticated systems can separate plastics into four main streams or types. One operation has combined two systems and is able to separate a mixed stream of baled or loose plastics into five categories: colored HDPE, natural HDPE, PVC, green PET, and clear PET.[26]

A major source of waste plastic is that of scrapped automobiles. Following shredding, the auto shredder residue (ASR) that remains, composed of plastics, fluids, glass, rubber, and various other mixed materials, including dirt, is most often landfilled. Plastics compose about one-third or more of the total. About 10 million automobiles are shredded each year. At an approximate average of 100 kilograms of plastic per car, this amounts to 1 million tons (1.1 million st) of plastic that could potentially be diverted from landfills annually. The Argonne National Laboratory (ANL) is one of a number of labs and companies working on technologies to process ASR. Argonne's technique uses solvents in an effort to dissolve the residue into products that could be economically substituted for, or mixed with, virgin material without reduction in final product quality. According to ANL, this process reduces the residue to 50% reusable materials and 50% residue remaining for disposal. Argonne claims to have achieved a 92% recovery of the processing solvents in its laboratory work, and expects even higher anticipated percentages of recovery possible in commercial applications. These recycled plastics potentially could be used in products such as park benches, lamp posts, traffic cones, and construction materials. Under present economic conditions, these recycled materials have limited marketability because most impurities are not removed, and the cost of making the products can be as much as if virgin materials were used.[27]

The Japan Recycle and Research Center, formed in association with the Japan Iron and Steel Scrap Association, is taking a different approach in attempting to deal with the 5 million automobiles that are annually scrapped in Japan. The Center has begun a new research program to design and construct a new type of WTE incineration plant for elimination of ASR. Remnant ashes are to be processed into concrete materials.[28]

Markets and Prices.—The marketing of recycled plastic products generally suffers because of high costs and insufficient demand for recycled materials. Materials for many products are very specialized and either need a quality that cannot be produced from recycled plastic, or when proper quality can be achieved, the cost would be noncompetitive with virgin resins. Other plastic products can be produced more easily with recycled plastic but are still simply too expensive as compared with the same product made from virgin plastic. An additional factor affecting markets and prices is growing acceptance by the public, which is becoming increasingly enthusiastic about the idea of recycling and materials conservation. Municipalities want plastic materials and goods to be diverted from the solid waste stream. But both individuals and institutions have been slow to translate these notions into expressed demand for recycled material content used in lieu of virgin materials in the products that they buy off the shelves every day. The general public often is not readily confident that recycled products may be as good as the virgin products sitting next to them on the same shelf. In addition, when the recycled products are more expensive, the incentive to purchase the recycled product is further reduced.

Thus far, PET and HDPE are the only plastics that have commanded high enough prices with sufficient demand to achieve a measure of consistency in the recycling industry. PET plastic has been the most cost-effective and consistently recycled of the two with many marketable products that can be made from clean, processed PET scrap. Its main challenge has been to be cost-competitive with virgin PET, the price of which has been relatively low during the same period. Recyclers of HDPE, while experiencing a higher percentage increase in output in 1992 than recycled PET processors, faced greater competition in the marketplace. One major processor of recycled HDPE shut down its HDPE operations altogether to concentrate its efforts in the better market opportunities of recycled PET, although it planned to restart its HDPE operations when the market showed sufficient improvement and stability. While the recycling of HDPE packaging, mostly in the form of bottles, increased by 8% in 1993 (see table 3), this is significantly down from the 50% growth spurt experienced in 1992. Competition continued to increase in 1993. One major factor was the oversupply of virgin HDPE resin, which reduced the resin price below the cost incurred by most processors of recycled HDPE producing the post-consumer resin. Another factor that affected HDPE recycling concerned typical collection practices in the United States. About one-third of the HDPE containers—in particular, injection molded tubs and other nonbottle HDPE containers—are not targeted for collection because markets for them are almost nonexistent.[29]

Rubber Recycling

Rubber recycling includes both synthetic rubber and, to a lesser degree, natural rubber. Synthetic rubber (SR) is a major member of the family of materials called the elastomers. Like plastic, it is made up of long-chain polymers that are produced from hydrocarbon feedstocks. In addition, the SR polymers have been synthesized to consistently reproduce, at ambient temperatures, natural rubber's best properties, most notably its "rubberlike" elasticity. Sources of rubber waste products are discarded clothing, footwear, rubber tires, and a variety of miscellaneous durable and nondurable goods, such as gaskets on appliances, various automobile parts, furniture, floor coverings, and hot water bottles. But rubber tires are the predominant source of rubber in MSW. As many as 250 million waste tires (about 2.3 million tons) are generated annually in the United States. Of equal concern is the backlog of tires that have accumulated across the country, especially since the end of World War II. By illegal dumping and by legal stockpiling, an EPA-estimated 2 billion to possibly as many as 3 billion "units" (tires) have been thus "disposed" of in preference to being landfilled, incinerated, or recycled.

Issues.—Tires, about 85% of which come from automobiles, are a significant portion of MSW. For decades they have been a growing problem because, landfilled or stockpiled, discarded tires can be a threat to human health and the environment. Landfills traditionally have been the method of disposal for scrap tires in the absence of a market. Today, landfill bans are restricting this practice, especially the burial of whole tires. Their composition and shape do not allow easy compaction in the landfill, and they do not decompose, thus occupying significant amounts of valuable landfill space. Additionally, whole tires trap gases due to their round and hollow shape and over time "float" to the surface, breaking the landfill cover and allowing landfill gas to escape.[30] Following exposure at the landfill's surface, they then become a breeding ground for insects, rodents, and birds.

Stockpiled tires have similar associated problems, which can be amplified because greater quantities are crowded into one place. Because of their shape, tires hold water at any angle, which makes them a very attractive breeding site for mosquitoes and other insects, some of which can carry disease. North American varieties of mosquitoes can be of concern by themselves, but in recent years other strains of insects have been "imported" from other countries. For example, in 1985 the Asian Tiger Mosquito, which is known to carry some relatively dangerous sicknesses, arrived in Houston, TX, aboard a shipload of used tires from Japan. This same mosquito has since been located in other parts of the country.

Another danger is that of fire. A tire fire is extremely difficult to extinguish and can burn for a long time. Uncontrolled tire combustion at the characteristically low temperatures at which these fires usually burn tends to release significant amounts of thick, black smoke. Both the air is fouled and the rubber melts into a toxic substance or "goo" that can adversely affect ground water. A few tire piles that have caught fire have been designated Superfund cleanup sites by the EPA.[31]

Currently, the overriding issue is of how to use or safely dispose of scrap tires and other rubber products—whether to incinerate them for their contained energy values or to stress the reuse and development of recycling uses for waste rubber and tires. Incineration of tires for their energy values is currently the leading method of use or disposal after that of landfilling or stockpiling. While markets for materials and products that include recycled rubber are increasing, the greatest potential to date is the use of ground rubber tires in the production of rubber-modified asphalt for the Nation's roads.

Annual Supply and Recycling Rates.—EPA estimated that in 1990 about 181,400 tons (200,000 st) of rubber from tires was recovered for recycling. At an average of 9 kilograms (20 lbs) per tire, the average weight of a passenger car tire, this amounts to more than 20 million tires. More recent estimates have been projected by the Scrap Tire Management Council (STMC). In 1992, the estimated annual recovery in the United States stood at 68 million tires, 58 million of which was estimated to be used as fuel by several major industries. For 1993, the council estimated the annual recovery had risen to about 80 million tires, 69 to 70 million of which was estimated to be used as fuel. Of the remaining 10 to 11 million tires, 40% to 45% was used in rubberized asphalt. The remaining tires were used in civil engineering applications and the manufacture of recycled rubber products. An increasingly smaller portion was chemically broken down to more basic chemicals and materials by the process of pyrolysis. The apparent discrepancy between the two recovery estimates (STMC's and EPA's) is not as great as it may appear because the EPA's estimate does not include tires that were combusted either as a fuel or for the production of energy.

According to an EPA study, an estimated 12 million used, commonly called "waste," tires were exported in 1990. If included with STMC's estimated 1993 recovered quantity of 80 million tires, approximately 92 million tires potentially were recovered for the production of energy, recycled products, reuse, and export for similar purposes. Thus, about 35% of all waste tires in 1993 (presuming a similar exported quantity as reported for 1990) was potentially diverted from the Nation's landfills, stockpiles, and "illegal dumps." If exports are not included, then the recovery rate was nearly one-third of total discards.

Retreaded tires usually are not included in recovery and recycling data as they are considered a reuse. But they are a valuable "recycling" of the tire body as a whole and their reuse also slows their introduction into the solid waste stream.

Consumption and Uses.—Pulp and paper mills are a major user of tires as a fuel. Tires, like coal, are used as a fuel to supplement wood chips, their traditional fuel. Consumption in this industry has remained fairly constant in the past several years. The pulp and paper industry consumed an estimated 14 to 15 million tires as a supplemental fuel in 1993. The industry has burned tire-derived fuel (TDF) since the early 1980's. TDF is tire rubber that has been chipped into pieces 2 inches or less in size, called crumb rubber, and is processed to be clean of contaminants, including the steel belts. The steel belts are sold as scrap metal. The pulp and paper industry needs this clean, uncontaminated TDF if it is to use tires as a fuel. In conjunction with this need, the industry's major constraint is the cost of competing fuels, such as wood chips, petroleum coke, and coal. Lower prices for competing fuels can limit the use of TDF. Two other limiting factors are the remote location of many mills, which results in higher transportation costs, and the reliability of TDF supply.

Tire recovery has increased substantially during the past 2 to 3 years as a fuel in electric utility boilers, cement kilns, and in new, dedicated tire-to-energy plants. In 1993, almost 18 million tires were combusted in utility company boilers or in other boiler facilities, such as agricultural product processors and chemical companies. TDF is the common rubber fuel that is used in electric power companies' utility boilers, although requirements for clean TDF sometimes are less stringent than those of the pulp and paper industry. Some systems allow for the burning of whole tires. In parts of the Midwest and the east, high-sulfur coal is burned in utility plants. At times when coal costs less than TDF, using TDF as a fuel can still be competitive because of its low sulfur content. TDF and whole tire combustion are reported to produce less ash than burning coal, emit less carbon dioxide, and produce lower sulfur dioxide emissions when replacing a high-sulfur coal.[32] Very significant growth has occurred in this sector in the past few years alone, and according to STMC, some of the major utilities are currently considering using scrap tires.

The cement industry has increased its use of waste tires from 3 million tires in 1990 to 14 million in 1992 and to as much as 21 million in 1993. Cement kilns are heavy users of coal, making the use of the cleaner burning rubber an attractive option. As with some utility users, a growing number of cement kilns are able to burn whole tires, avoiding the associated costs of buying processed TDF. Tires offer these kilns other advantages. Tires have a higher energy value than coal, and a tire's steel belts and beads can replace the iron ore needed in the cement making process, thus reducing the manufacturer's raw material costs.

Only two major tire-to-energy facilities, both built by one company, were operational in 1992, but between them they consumed about 16 million tires. The same company was in the planning stages of building two more plants. The completion of one of these units by 1997 was expected to more than double the current 15-million-unit capacity. Even though these operations have been successful, the use of this technology usually is practical only in regions with high electric rates and high solid waste tipping (disposal) fees. The capital costs per megawatt of generating capacity for these facilities is about two to seven times higher than coal-fired plants.

In 1993, between 4 and 5 million scrap tires were recycled either as asphalt binder material or as aggregate in rubber-modified asphalt (RMA). This was at the previous year's level or slightly below as a result of the debates surrounding the Intermodal Surface Transportation Efficiency Act (ISTEA) legislation regarding amounts of rubber required in new roadways. The market for scrap tires for use in RMA would significantly increase under the requirements of the originally passed ISTEA legislation. Nevertheless, its use in independent, State, and local projects has remained relatively steady, especially in the southwestern United States.

Rubberized asphalt can cost up to twice as much as conventional asphalt, but recent experience has indicated that it can be applied in thinner layers and often lasts significantly longer. A more widespread use of the basic technology and the expiration of a patent on one of the most frequently used processes should help to reduce costs of this rubber-modified product. Some questions as to the safety and durability of this product and its recyclability in the construction of future roadways have been raised, mostly due to a lack of long-term experience with it. But to date, roads made of this material appear to be more durable, longlasting, and safe to travel on. According to a recent report to Congress jointly submitted by the EPA and the Department of Transportation, the use of asphalt containing recycled rubber is not substantially different from conventional asphalt in terms of health and environmental effects, recyclability, or adequacy as a paving material.

Another 5 to 6 million tires were used mostly in civil engineering applications and, to a lesser degree, in recycled rubber products. Civil engineering applications include embankments, clean fill, leachate collection in lieu of sand or gravel, artificial reefs, breakwaters, sideslope stabilizers, crash barriers, sound barriers, and playground structures and protection. Other applications include use in products such as railroad crossing ties, dock bumpers, a variety of flooring materials and mats, carpet underlay, sound insulation in automobiles, truck and trailer liners, and drip irrigation pipes.

Less than 1 million tires were consumed by tire pyrolysis, the process of chemical and physical breakdown of the whole tire into oil, gas, and char (low-grade carbon black) byproducts, and steel from the steel belting. This use has not flourished because of inconsistent markets for the oil and many differing char byproducts. Not all char byproducts are necessarily of too low a grade. Their salability is lowered because they are not easily distinguishable, one from another. According to STMC, although there were a number of test and demonstration level projects processing tires by pyrolysis, by yearend there were no commercially viable operations in the United States.

Although making new tires out of old tires may seem to be the most obvious choice, this is not possible. Tire rubber is a thermoset or "vulcanized" material. To date, no technology has been able to reverse or "devulcanize" this process. As a result, the new, strong chemical bonds necessary for new tire production cannot be achieved. Only a very minimal and relatively inconsequential amount of rubbings—very fine crumb rubber—can be used as noncritical filler in the manufacture of some tires.

Virtually the only way that old tires are currently used in tire manufacture is as retreads. The retreading of tires is a direct reuse of the basic tire and thus is not included in reported recycling amounts and rates. The American Retreaders Association (ARA) contends that it should be considered recycling because of fine lines of difference between retreading and some other recycling uses of used tires. The life of the tire is extended and consequently the annual quantity of tire waste that must be managed is reduced. Additionally, natural resources are conserved because annual demand is reduced for new, virgin tire material.

The ARA reported that the retreading process gave new life to almost 30.25 million tires in 1993. This was down somewhat from the 31.5 million tires and 31 million tires in 1991 and 1992, respectively. Of the 1993 total, 6.6 million (22%) were passenger car tires, down from 8.5 million in 1991; 7.35 million (24%) were light-truck tires (almost even with 1991); and 15.4 million (51%) were medium truck tires, up from the 15 million 2 years before. In the smaller markets of off-the-road vehicles and specialty tires, 0.66 million and 0.22 million retreads were produced, respectively (together, 3% of the market). ARA reported that the recent drops in passenger car retread production was mostly the result of highly competitive (low) retail pricing of new tires and a gradual increase in consumer interest in expensive, high performance, and the relatively new 70,000- and 80,000-mile premium tires. Fueling lower tire prices was the increasing entrance of wholesale clubs and discount chains into a relatively flat, new tire replacement market. This market for passenger tires decreased slightly in 1993, primarily because of strong sales of new automobiles. Continuing gradual growth in the production of medium truck retreads was encouraged because of the high replacement cost that makes retreading more cost effective.[33]

Technology.—A significant, source reduction-related technology has been the longer-wearing vehicle tire. The development of the radial tire more than a decade ago increased the tread life expectancy from the range of 20,000 to 25,000 miles, for the standard bias-ply tire, to 40,000 miles and more for the then new radial-ply tire. An added advantage of the radial tire was that it delivered better fuel mileage. A trend to smaller cars began somewhat earlier, during the 1970's. Smaller cars usually use smaller tires. These factors caused a reduction in the amount of rubber used in the manufacture of tires and, consequently, in the quantities of tire waste generated. According to a World Rubber & Tire Report issued in 1992 by the Freedonia Group of Cleveland, OH, the amount of natural and synthetic rubber used in tires dropped from 45% of all rubber consumed in 1980 to 42% in 1990. The International Institute of Synthetic Rubber Producers in Houston, TX, estimated that almost 52% of all synthetic rubber currently consumed goes into tire production. Both of these percentages could change further during the next decade if the most recent advanced tire technology is significantly integrated into the tire marketplace. In 1991, the original producer of the radial tire introduced a new radial tire in the United States that it warranted for 80,000 miles. Although the new technology has not been fully revealed by the manufacturer, these tires include the use of a newly developed family of elastomers.[34]

Raw material markets are being affected by the mix of raw materials used in the radial tire. Radial tire design produces higher operating temperatures than that of other types of tires, and this affects the composition of the tire material. The higher temperatures perpetuated an increase in the percent of natural rubber needed. Synthetic rubber helps tire tread last longer, but natural rubber is less heat sensitive. Radial-ply tires are composed of about 16% natural rubber as compared to their bias-ply predecessors that used 11% natural rubber. Thus a small yet significant portion of synthetic rubber, which is manufactured from nonrenewable hydrocarbon resources, is being replaced with natural rubber, a renewable resource.

Two companies claim to have developed tire pyrolysis technologies which are economically feasible. Up to now, pyrolysis generally has not been viable. Too small a portion of the byproducts—pyrolytic oil, gas, char, and metal from the char—have been profitably marketable on a consistent basis. The gas is usually used to fuel the process, and the metal, approximately 1.1 kilograms (2.5 lbs) of the typical 9-kilogram (20-lb) tire, is clean enough to market. But the grade of pyrolytic oil and char is often below market standards. Both companies claim that their more sophisticated pyrolysis technologies produce higher quality materials. One of the proposed processes operates at a relatively low temperature, 177° to 205° C (350° to 400° F), as opposed to the traditional operations at 925° to 980° C (1,700° to 1,800° F). The char or "carbon black" is sold to manufacturers of low-grade carbon products, such as hoses and tires for lawn mowers and forklifts. Thus far, pyrolysis technologies have not been able to produce a carbon black of high enough grade to reuse in tire production.[35] But even if low-temperature methods prove to be successful, widespread commercialization of them appears likely to be several years away.

Since 1990, the STMC reports that one significant technological change has occurred in the tire-to-energy industry. In the second of the two commercial facilities in the United States, certain innovations have allowed for whole tires, as well as processed TDF, to be combusted, thereby lowering everyday operational expenses.

Markets and Prices.—Continued growth is projected for most scrap rubber markets. But the two market areas that offer the most potential are incineration as a fuel and for energy generation, and the use of crumb rubber in the maintenance and rebuilding of highways. Most of the current uses are expanding and some, such as cement kilns and utility plants, are limited principally by reliable tire supply. However, the expansion of these uses would require significant capital outlay for plant modifications needed to use TDF or whole tire fuel.

Depending on final revisions to the ISTEA legislation, originally passed in December 1991, the use for scrap tires could grow significantly through 1997 because, as originally written, the law mandated a recycled content of rubber material on federally funded State roads. Beginning in 1994, 5% of all federally funded roads paved with asphalt was to contain recycled scrap tire rubber at the approximate minimum rate of 9 kilograms of rubber per ton applied. The 5% was to increase another 5% each year through 1997, when 20% of federally funded roads thereafter would be so affected. Although rubber is likely to be the main component of the recycled materials that are mandated under the law, the use of other materials, such as glass, asphalt pavement, or plastic, could reduce the anticipated quantities of crumb tire rubber that is included in the mix. The final interpretation by the Federal Government of mandated or recommended recycled material percentages to be used in accordance with the law will determine how much is actually consumed each year following implementation. Under the ISTEA legislation STMC estimated that up to 68 million tires could have been used for this application by 1996 if the law had been implemented as originally written.

OUTLOOK

Alternative Material/Waste Management Methods

The degree to which an integrated waste management system is instituted will greatly affect the future and the effectiveness of recycling, composting, incineration, and landfilling. Since 1988, the number of recycling collection programs and yard waste composting facilities have increased considerably. Curbside collection programs have risen from little more than 1,000 in 1988 to more than 5,400 in 1992 on up to 6,678 by the end of 1993. Yard waste collection and disposal facilities during the same period have increased from 700 in 1988 to 3,014 in 1993. The number of incinerators during this period also rose, although at a slower rate, from more than 135 in 1988 to more than 171 in 1991, before dropping back to 162 units in 1993. Even with increasing quantities of MSW being landfilled, the number of landfills have dropped from nearly 10,000 in the early 1980's to about 8,000 in 1988 to nearly 5,400 in 1992 on down to 4,482 by the close of 1993. Closures of many smaller, less profitable sites and others no longer environmentally permissible accounted for the large drop.[36] Fewer in number, but much larger and better environmentally designed, new state-of-the-art sanitary landfill facilities, or expansions of existing operations, have replaced some of the reduced landfill capacity. Appropriate local ordinances, and State and Federal laws and regulations have mandated these changes, as concerns over clean, freshwater supplies and a clean natural environment have risen. Recycling, composting and probably WTE incineration is likely to increase, but landfilling will probably continue to decrease in comparison to the other alternatives in the foreseeable future.

Source reduction will continue to be stressed as the weight and size of the materials and products that we produce are lowered to levels that are still adequate for the required task. Efficiency and practicality will guide these efforts. A new material may make some forms of packaging lighter and thinner than its predecessor, but if it is not cost effective or if it uses an excessive amount of energy to produce it, then it is neither efficient nor practical. The development of longer lasting materials is likely to be the target of many future research efforts.

"Design For Recycling" Programs

A variety of products, if designed with recycling in mind, could have significant, favorable impacts by reducing the amount of solid wastes generated and increasing the amount and quality of recycled materials. Automobiles, major appliances, and some packaging applications are just a few examples. This concept is becoming an integral part of the design and research efforts of some companies in the manufacturing and service industries. "Design For Recycling" is an official program and policy of the Institute of Scrap Recycling Industries (ISRI). Through its program, ISRI is seeking a national policy to promote the design and manufacture of goods that, at the end of their useful lives, can be recycled safely and efficiently. Major thrusts of the program are to motivate and assist the manufacturing industry to make consumer products and durable goods recyclable; reduce environmental risks from consumer products; and control any related special environmental problems.

The concept of design for recycling is relatively simple. But full or significant implementation may be difficult to achieve, especially in a culture where the "disposable" product often has become preferred to a similar but reusable one. This shift has been especially evident in the past two or more decades. U.S. manufacturers currently have no legal obligation to plan ahead for the obsolescence of their products. New products are designed to meet the increasingly complex needs of modern society. The necessary materials sometimes are more complex and difficult to recycle. They may even contain toxic materials that not only have the potential to harm the environment but can pose a particular risk to recycling workers if released during the recycling process. A current example is the sodium azide capsule in automobile air bag inflation mechanisms. Being both explosive and toxic, it has complicated automobile recycling processes. An example of a product that is not dangerous but is complicated to recycle is multilayered food packaging. Although this product is highly effective in protecting food from the environment, the many layers of different materials make it difficult to recycle. The scrap recycling industry is aware of these problems, and an objective of ISRI's program is to alert manufacturers.

The Automobile.—Weight reduction and lower emissions remain important, but increasingly, U.S. automobile manufacturers are instructing designers to give recyclability high-priority consideration. Currently, about 75% of each auto is recycled in the United States, and the domestic auto industry is striving to do better. Additionally, a number of foreign manufacturers have been in the forefront of recycling-conscious automobile design. One problem that is encountered in automobile design is that, as weight reduction is achieved, the use of nonmetallic components increases. These materials comprise most of the 25% of the car that is difficult, or currently not possible, to recycle. Plastics are particularly difficult because of the many different types that are used and, generally speaking, the lack of compatibility between them.

In its first year of publishing a recycling rate for steel in old cars, the American Iron and Steel Institute announced a 94% rate for 1993. This was calculated by comparing the steel used to produce new cars in 1993 to the amount of steel scrap collected from auto shredders and dismantlers.[37]

General Motors (GM) has been using recyclable plastic for body panels on its Saturn automobile. Defective panels at the plants can be ground for immediate recycling into other molding parts. Used body panels can be recovered and recycled when Saturns are scrapped. Chrysler Corp. has developed an award-winning prototype car, the Neon, which contains recyclable interior and exterior panels, wheels made from previously recycled aluminum, and is painted with water-based paint. In an attempt to maximize recycling potential, two Chrysler vehicle lines were introduced in 1992 that were designed for 90% recyclability. Du Pont supplies the glass-reinforced, PET-based plastic for the fenders on these cars. This material can be reground, remolded, and reformed. A methanolysis process, also developed by Du Pont, can be used to return the material to its original feedstock components, which can be used again on various applications, including new fenders.

Although the phrases "design for recycling" and "design for disassembly" go hand in hand, they are different. Design for recycling aims not only at ease of disassembly but also minimum disassembly so that subassemblies may be removed and recycled without further separation. Several European automakers have taken an early lead in establishing programs in these areas. In 1991, Bayerische Motoren Werke AG (Bavarian Motor Works, BMW) and Volkswagenwerk AG (Volkswagen, VW) started pilot disassembly plants to recover metals, plastics, glass, and other materials from old cars, and BMW announced plans to build a commercial plant. The German Automobile Club (ADAC) has a research dismantling facility at which its goal is the design of a 100% recyclable automobile. The French automaker Peugeot SA (Peugeot) has entered a joint venture with a leading French scrap metals processor and a cement manufacturer to maximize recycling and to convert nonrecyclable components into fuel for the cement plants. The company planned to recycle more than 7,000 Peugeot and Citroen cars by 1994. In the United Kingdom, the Rover Group has joined with the Bird Group, a leading scrap processor in Europe. The company plans to develop rapid dismantling techniques and set up standards and procedures. In Japan, similar efforts began with Toyota's collection of used plastic bumpers. The bumpers were sold to recyclers and manufactured into products such as pallets. This program was started with 26 dealers in Tokyo and was expanded to all dealers in the Tokyo area.

The U.S. big three automakers formed a consortium in 1992 to research and promote the maximum recovery and reuse of materials from junked cars. The Vehicle Recycling Partnership also is expected to develop industry guidelines for new vehicle manufacturing in such areas as materials selection and compatibility and optimum materials and techniques for joining, coating, etc.

The Automotive Group of the Durables Committee of the Society of the Plastics Industry has established a pilot study to develop economical and environmentally sound methods of recovering and recycling post-consumer automotive plastics and an industry infrastructure to support such processes. The use of as many as 40 different types of hard-to-identify plastics in automotive applications, such as fan shrouds, fender liners, radiator end caps, windshield washer bottles, interior trim pieces, and grill panels, has made auto plastic recycling difficult. GM and Ford Motor Co. now require labels that identify the type of resin in each plastic part. Auto dismantlers, an auto shredder, a nonferrous metals separator, plastics recovery and reclamation facilities, and industry laboratories will participate in the project. The difficulties encountered and information gathered during this project will be used to advise manufacturers in their design for recycling efforts in future cars.

BMW will be cooperating in a pilot automobile recycling program with three recycling companies in California, Florida, and New York that are members of the Automotive Dismantlers and Recyclers Association (ADRA). They were chosen by meeting criteria that included outstanding adherence to the ADRA Code of Ethics and use of the ADRA Hazardous Waste Management Booklet as the basis for environmentally sound practices. Fluids will be drained and recycled and batteries will be removed and properly disposed of. If the car has air bags, they will be deployed per BMW specifications to eliminate the risk of sodium azide contamination. All economically salvagable components will be removed before the metal shell is shipped to an auto shredder. BMW will use a monetary incentive to encourage the return of old BMW cars for the project.

During 1993, Ford began a pilot project for the recycling of obsolete plastic bumpers. The material from the bumpers was used to make taillight housings for the 1993 Taurus models leased to a California company. This is the first case in North America where an automaker is using recycled plastics from its junked vehicles to make parts for new ones.[38]

Another opportunity for recycling involves used oil filters. More than 400 million used auto oil filters are available for recycling in the United States annually, but most of them are landfilled. Research conducted by USBM has shown that crushed and drained filters have a higher (better) bulk density than many standard grades of steel scrap. The analysis of the material is very low in all residual elements except tin from tinplate used in filters, and overall yields of up to 85% were achieved. A California steel company expected to recycle 18 million oil filters in 1993.[39]

White Goods.—U.S. steel producers have begun talks with scrap processors and home appliance designers to develop washing machines, refrigerators, freezers, and stoves that will result in more efficient disassembly and recycling. These discussions thus far have been bilateral rather than industrywide. Steelmakers are enthusiastic because they believe that their material has the advantages of significant recyclability and the potential for easy disassembly. Plastic materials hold the advantages of lower weight and component integration.

Carnegie-Mellon University in Pittsburgh began a 4-year study in 1993 to monitor trends in recyclability, not only in automobiles, but also in microcomputers, telephones, and other consumer goods. The purpose of the program was to monitor progress and encourage greater efforts by U.S. industry in design for recycling. The study, funded by IBM and Ford, is designed to help manufacturers anticipate shifting responsibility for disposal from consumers to themselves.[40]

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TABLE 1
FIBER USED AT U.S. PAPER AND PAPERBOARD MILLS, BY WEIGHT AND PERCENT

Year	Weight (thousand metric tons)						Percent				
	Recovered paper	Wood residues	Total secondary	Primary fibers	Other fibers	Total fibers	Recovered paper	Wood residues	Total secondary	Primary fibers	Other fibers
1980	13,534	18,428	31,962	27,186	668	59,816	22.6	30.8	53.4	45.4	1.1
1985	14,848	19,485	34,334	28,865	268	63,467	23.4	30.7	54.1	45.5	.4
1987	16,956	21,045	38,001	31,700	290	69,991	24.2	30.1	54.3	45.3	.4
1989	18,340	20,420	38,760	33,995	288	73,043	25.1	28.0	53.1	46.5	.4
1991	21,461	18,891	40,352	35,983	170	76,505	28.1	24.7	52.7	47.0	.2
1992	23,762	19,176	42,922	36,389	161	79,472	29.9	24.1	54.0	45.8	.2
1993	26,188	18,790	44,978	36,744	170	81,892	32.0	22.9	54.9	44.9	.2

Source: American Forest and Paper Association.

TABLE 2
U.S. PAPER RECOVERY,[1] BY GRADE

(Thousand metric tons)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Corrugated	7,741	8,493	8,509	9,401	10,166	11,230	11,689	12,163	12,687	13,875	15,119
Old newspaper	3,153	3,423	3,506	3,889	4,075	4,313	4,890	7,277	6,037	6,266	6,705
Mixed paper	2,248	2,478	2,459	2,433	2,518	2,638	2,847	3,257	3,487	3,895	4,193
Pulp substitutes	2,426	2,693	2,463	2,856	3,052	3,250	2,697	2,830	3,218	3,263	3,309
High-grade deinking	1,433	1,534	1,556	1,848	1,915	2,316	2,438	2,680	2,885	3,163	3,126

[1] Recovery includes pre-consumer and post-consumer scrap for domestic use and export.

Source: American Forest and Paper Association.

TABLE 3
POST-CONSUMER PLASTICS RECYCLED

(Thousand metric tons)

Plastic type/product type	Calendar year 1992			Calendar year 1993		
	Plastic recycled[1]	Virgin plastic sales[2]	Percent of sales recycled[3]	Plastic recycled[4]	Virgin plastic sales[5]	Percent of sales recycled[3]
PET:						
Soft drink bottles	173.0	425.9	40.6	189.4	462.2	18.6
Custom bottles	9.3	203.7	4.6	13.5	224.5	6.0
Other packaging	.1	35.8	.3	.2	38.1	.5
Total PET packaging	182.4	665.4	27.4	203.1	724.8	28.0
Other applications[6 7]	26.5	—	—	24.9	—	—
Soft drink bottles and base cups[8]	194.5	469.0	41.5	207.1	511.2	40.5
Total PET	208.9	665.4	31.4	228.0	724.8	31.5
HDPE:						
Natural bottles	105.1	448.1	23.5	117.0	482.2	24.3
Pigmented bottles	57.3	662.2	8.7	64.8	701.3	9.2
Base cups	21.5	43.1	(9)	17.6	49.0	36.0
Other packaging[10]	5.0	657.7	.8	4.7	692.2	.7
Total HDPE packaging	189.0	1,811.2	10.4	204.2	1,924.6	10.6
Other applications[7]	12.3	—	—	11.7	—	—
Total HDPE	201.3	1,811.2	11.1	215.9	1,924.6	11.2
PVC:						
Bottles	.5	86.6	.6	.5	80.3	.7
Other packaging[11]	2.2	241.8	.9	2.0	244.9	.8
Total PVC packaging	r[12]2.7	328.4	—	2.5	325.2	.8
Other applications[7]	r[12]2.9	—	—	2.9	—	—
Total PVC	5.6	328.4	1.7	5.4	325.2	1.7
LDPE/PVC:						
Bottles	—	34.9	.1	—	34.9	.1
Other packaging[13]	28.8	2,115.6	1.4	40.1	2,083.3	1.9
Total LDPE/LLDPE packaging	28.8	2,150.5	1.3	40.1	2,118.3	1.9
Other applications[7]	5.5	—	—	13.1	—	—
Total LDPE/PVC	34.3	2,150.5	1.6	53.2	2,118.3	2.5
PP:						
Bottles	1.5	61.7	2.4	1.0	67.1	1.5
Other packaging[14]	2.7	612.3	.4	5.2	676.3	.8
Total PP packaging	r[12]4.2	674.0	—	6.2	743.4	.8
Vehicle battery casings	r[12]85.4	33.6	(15)	86.8	23.6	(15)
Other applications[7]	r[12]4.5	—	—	6.7	—	—
Total PP	94.1	707.6	13.3	100	767.0	13.0
PS:						
Total PS packaging[16]	14.3	982.0	1.5	16.1	1,076.4	1.5
Other applications[7]	2.6	—	—	2.6	—	—
Total PS	16.9	982.0	1.7	18.8	1,076.4	1.7

See footnotes at end of table.

TABLE 3—Continued
POST-CONSUMER PLASTICS RECYCLED

(Thousand metric tons)

Plastic type/product type	Calendar year 1992			Calendar year 1993		
	Plastic recycled[1]	Virgin plastic sales[2]	Percent of sales recycled[3]	Plastic recycled[4]	Virgin plastic sales[5]	Percent of sales recycled[3]
Commingled:						
Rigid	3.1	(17)	(17)	2.4	—	—
Flexible	.1	(18)	(18)	3.7	—	—
Total commingled	3.2	—	—	6.1	—	—
Other miscellaneous						
Packaging	.3	(19)	(19)	.2	—	—
Other applications	[20]7.5	(21)	(21)	[20]11.1	—	—
Total bottles[22]	368.3	1,966.3	18.7	404.1	2,108.7	19.2
Total bottles and rigid containers	374.1	2,431.3	15.4	408.9	2,577.3	15.9
Total packaging[23]	424.8	6,611.6	6.4	474.8	6,912.7	6.9
Total postconsumer plastics	572.1	6,645.1	8.6	638.3	6,936.3	9.2

[r] Revised.

[1] Based on results of a survey of post-consumer plastics processors and exporters conducted from Feb. 1993 through Mar. 1993.

[2] Based on data provided by SPI's committee on resin atatistics.

[3] Percentages shown are based on virgin sales and do not account for recycled resin used in the manufacture of the product types listed, except the PET bottle, HDPE pigmented bottle and base cup categories for calendar year 1993.

[4] Based on results of a survey of post-consumer plastics processors and exporters conducted from Feb. 1994 through Mar. 1994.

[5] Based on data provided by SPI's committee on resin statistics and the results of a survey of plastic bottle manufacturers conducted in Feb. 1994 which documented recycled resin usage for the PET custom bottle, HDPE pigmented bottle, and HDPE base cup categories.

[6] Recycling consists primarily of X-ray film.

[7] Due to this Study's focus on recycling in packaging categories specifically, recycling quantities reported for non-packaging plastics may not reflect total non-packaging plastics recycling amounts. Recycling rates and resin sales have been omitted based on this fact.

[8] Includes polyester bottle and polyethylene base cup. 1992 recycling rate could not be calculated due to significant quantities of recycled resin used in the manufacture of the polyethylene base cup.

[9] 1992 recycling rate could not be calculated due to significant quantities of recycled plastic used in manufacture.

[10] Other packaging includes tubs/containers, film packaging, and other miscellaneous packaging.

[11] Other packaging includes film and sheet packaging and other miscellaneous packaging.

[12] 1992 numbers have been adjusted based on data received after publication or changes to category definition.

[13] Other packaging includes shrink/stretch wrap, film packaging and other miscellaneous packaging.

[14] Other packaging includes tubs/containers, flexible packaging, and other miscellaneous packaging.

[15] Percent of sales recycled could not be calculated due to large quantities of recycled polypropylene used in the manufacturing of new batteries and imports of batteries that could not be estimated by SPI's committee on resin statistics.

[16] Packaging includes rigid (non-foam) packaging, rigid (foam) packaging, protective packaging, food service, and other miscellaneous packaging.

[17] Sales data are reflected in segregated rigid containers categories above.

[18] Sales data are reflected in segregated flexible categories above.

[19] Sales data are reflected in segregated packaging categories above.

[20] Category consists of polycarbonate, ABS, nylon, plastics coded #7, and other miscellaneous nonpackaging.

[21] Sales data re reflected in segregated other applications categories above.

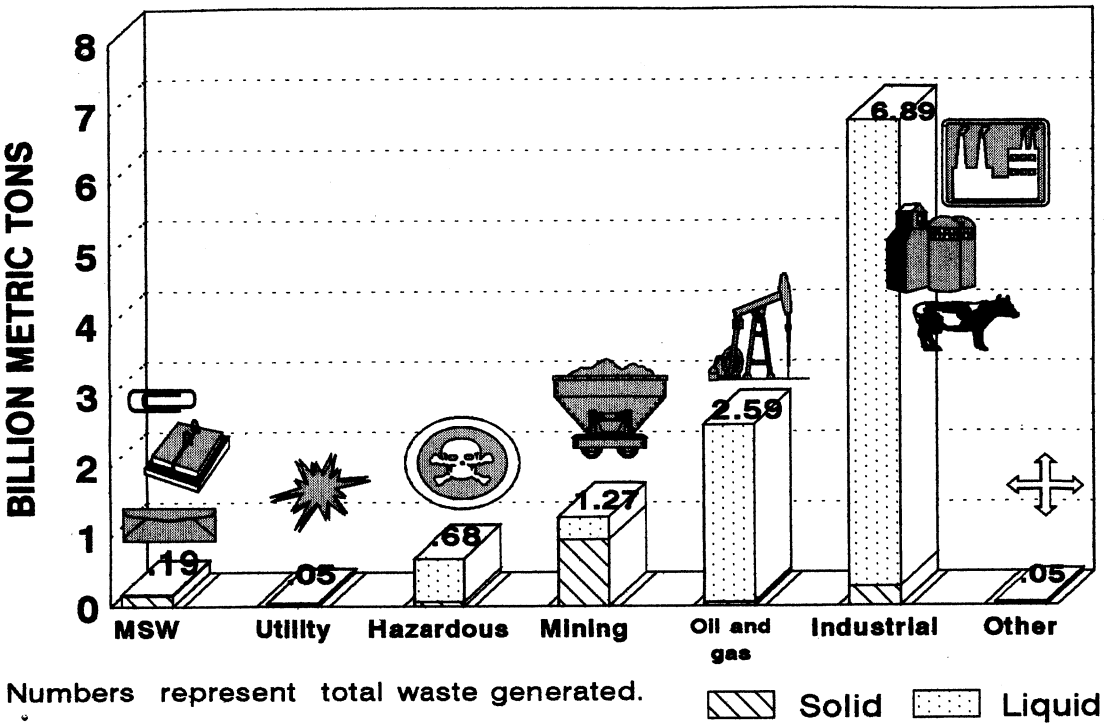
[22] Total of bottles in all six resins categories and HDPE base cups.

[23] Packaging totals for the six resins above, the rigid commingled category, and the other miscellaneous packaging category only.

Source: R. W. Beck; American Plastics Council.

FIGURE 1

ANNUAL SOLID WASTE GENERATION IN THE UNITED STATES

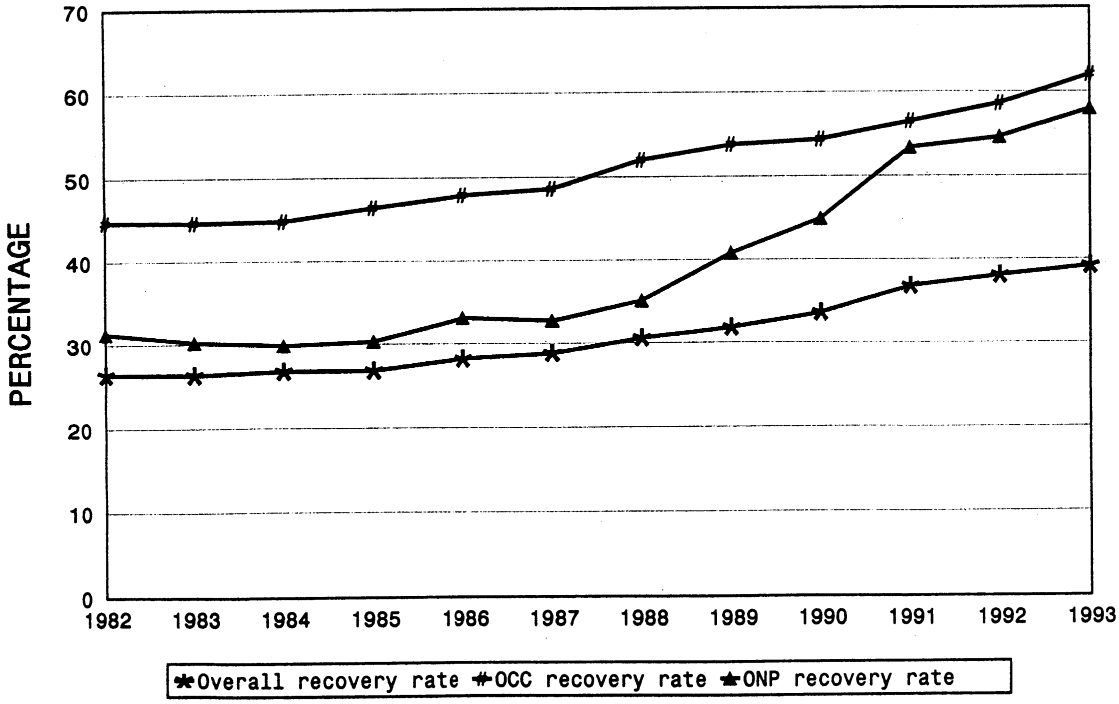


Numbers represent total waste generated.

Source: USBM/USEPA

FIGURE 2

U.S. PAPER AND PAPERBOARD RECOVERY

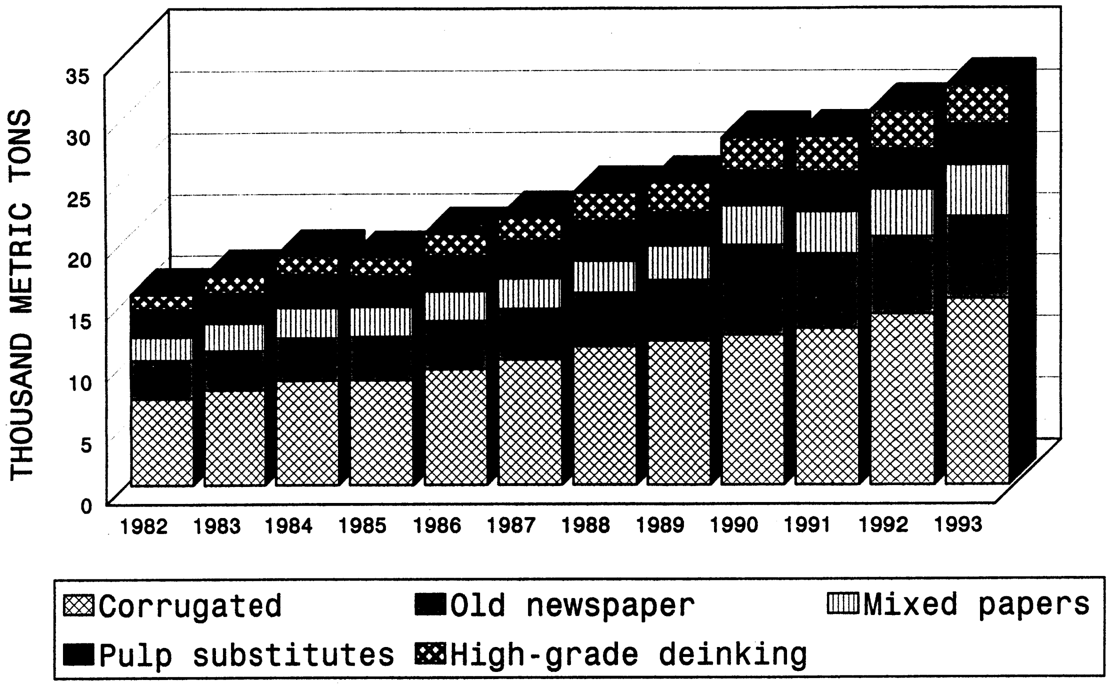


1 Recovery rate is the ratio of recovered paper to new supply (apparent consumption) of paper.

2 Recovery includes pre-consumer and post-consumer scrap recycled or exported.

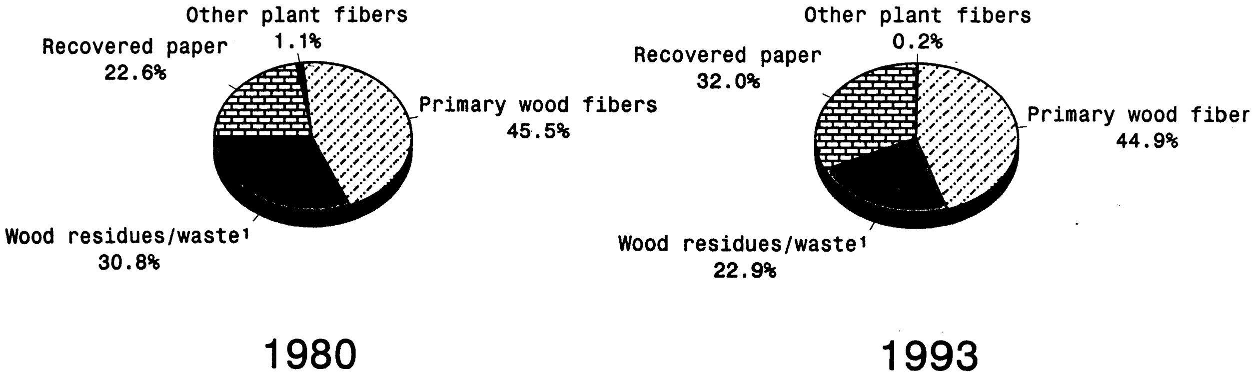
Source: American Forest and Paper Association.

FIGURE 3
U.S. PAPER RECOVERY,[1] BY GRADE



[1] Recovery includes pre-consumer and post-consumer scrap recycled or exported.
Source: American Forest and Paper Association.

FIGURE 4
FIBER USED AT U.S. PAPER AND PAPERBOARD MILLS, 1980 VS. 1993

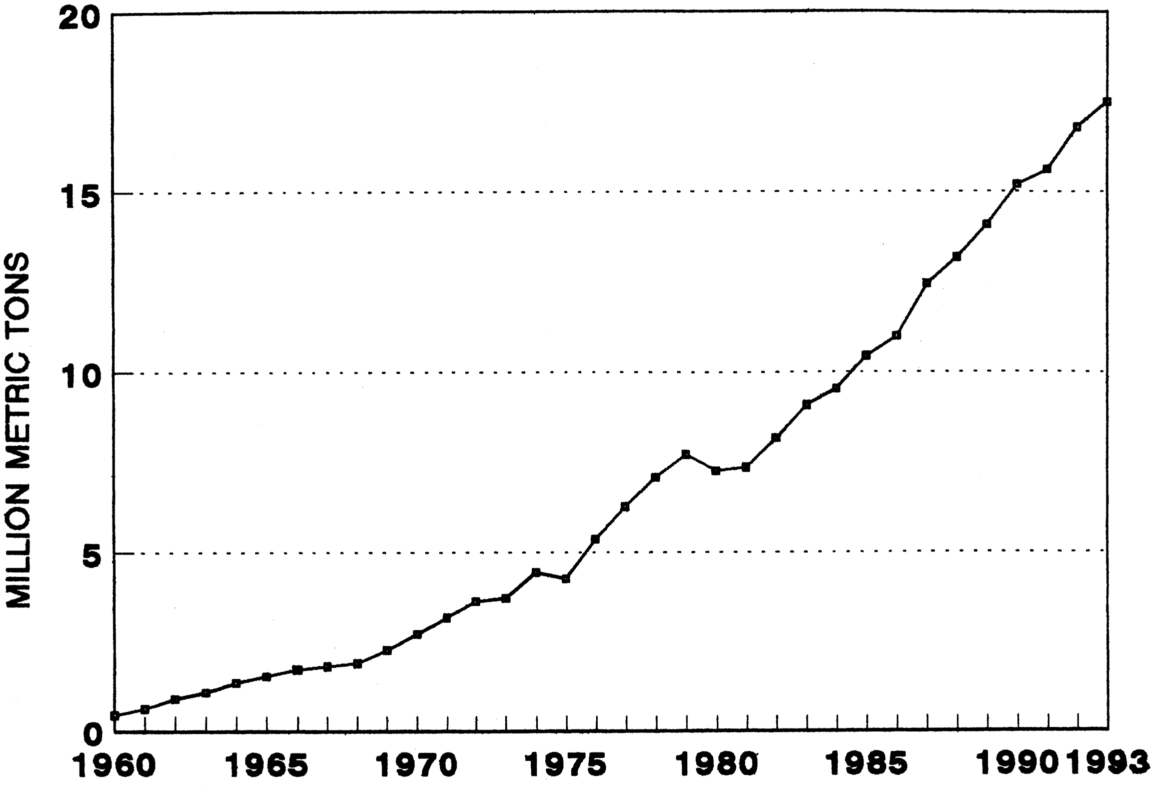


[1] Wood residues/waste denote mill residue such as slabs,edgings, trimmings, cores, planar shavings, sawdust or other similar residues and wastes.

Source: American Forest and Paper Association.

FIGURE 5

GENERATION OF PLASTIC IN MUNICIPAL SOLID WASTE



Source: EPA.

MICA

By Lawrence L. Davis

Mr. Davis, a physical scientist with 38 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for mica since 1983. Domestic survey data were prepared by Linder Roberts, statistical assistant; and international data tables were prepared by Virginia Woodson, international data coordinator.

In 1993, about 88,000 metric tons of scrap and flake mica was produced in the United States, an increase of 4% from 1992 production. Ground mica sales were 92,000 tons valued at $27 million, an increase in tonnage of about 10%.

Almost all sheet mica supply continued to be imported. Consumption of muscovite block mica decreased 4% to 5.4 tons. Consumption of mica splittings decreased slightly to 826 tons. The value of sheet mica exports increased 27% to $9.5 million. The value of imports for consumption of sheet mica increased 8% to $11.9 million. *(See table 1.)*

DOMESTIC DATA COVERAGE

Domestic production and consumption data for mica are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys and one mandatory survey. Of the 17 operations to which the crude scrap and flake mica production form was sent, 15 operations, or 88%, responded, representing 81% of the production shown in table 1. Of the 17 operations to which the ground mica form was sent, 15 responded, representing 87% of the production in table 1. Of the five canvassed operations to which the mica block and film consumption form was sent, four, or 80%, responded, representing 93% of the consumption shown in table 1. Of the nine canvassed operations to which the mica splittings consumption form was sent, six operations, or 67%, responded, representing about 72% of the splittings consumption shown in table 1. Consumption for the nonrespondents was estimated using prior-year production data.

BACKGROUND

Definitions, Grades, and Specifications

Mica is a group name for a number of complex hydrous potassium silicate minerals with differing chemical compositions and physical properties. Crystals of mica have excellent basal cleavage and split easily into tough, flexible sheets. The important mica minerals are muscovite and phlogopite.

Commercial qualities of sheet mica are relatively free of defects and tough enough to be punched or stamped into specific shapes. Sheet mica is classified as block, film, or splittings. Block mica is not less than 0.018 centimeter thick and has a minimum usable area of 6.45 square centimeters. Film mica is split to specified thicknesses ranging from 0.0030 to 0.010 centimeter. Splittings are sheets with a maximum thickness of 0.0030 centimeter and a minimum usable area of 4.84 square centimeters. Punch mica, which includes circle and washer mica, is low-quality, hand-trimmed mica up to about 5 centimeters in diameter. The American Society for Testing and Materials (ASTM) designates 13 quality groups for sheet mica, based on quantity of visible inclusions and structural imperfections, ranging from black- and red-stained to perfectly clear. ASTM also designates 12 grades based on the maximum usable rectangle. The sizes range from grade 6 (with 6.45 usable square centimeters) to grade OOEE special (with 645 usable square centimeters).[1]

Block and film mica products are small, flat pieces of uniformly thin mica cut or stamped to close tolerances into a variety of shapes and sizes, depending on the use. Shapes can vary from simple circles, squares, or rectangles to very intricate patterns. Fabricators make their own dies to be able to cut the mica into any pattern desired.

Built-up mica, or micanite, consists of partly overlapped and irregularly shaped and arranged splittings cemented together with either an organic or inorganic binder. Large sheets of built-up mica are made by alternating layers of splittings and binder. Sheets of any thickness are made by pressing the layers at high temperatures. Built-up mica is sold in large, uncut sheets or is cut or molded to any size and shape specified by the customer. It is often bonded to another material such as fiberglass cloth to form a composite sheet.

Reconstituted mica or mica paper is a paperlike material made by depositing fine flakes of scrap mica as a continuous mat, which is then dried. The mica paper is sometimes impregnated with an organic binder.

Scrap and flake mica is generally of a quality and size that is not suitable for use as sheet mica. Mine scrap varies greatly in quality but usually is a heterogeneous mixture that must be crushed, screened, and washed to yield the scrap mica in usable form. Mine scrap may be the sole product of mining a pegmatite or may be a byproduct of sheet mica production. Bench scrap or shop scrap is the mica discarded during the processing of handcobbed mica into sheet. Factory scrap is the waste that results from cutting and stamping sheet mica into pieces of definite size and shape. Factory scrap is usually the highest grade and quality material. Scrap mica that is recovered from schists and from the beneficiation of feldspar, kaolin, and lithium pegmatites is commonly referred to as flake.[2]

Industry Structure

The sheet mica industry in the United States is small, consisting of processors and fabricators of imported mica. Worldwide, India dominates the production of muscovite sheet mica. Madagascar is an important producer of phlogopite sheet mica. Sheet mica mining, trimming, and splitting are very labor intensive, and producing countries have the advantage of low wages and a large labor force that is usually trained at an early age. India's sheet mica industry is characterized by a large number of small operations, most of which sell to larger companies or the Government's Mica Trading Corp. of India Ltd. for further processing and export. India is putting more emphasis on exporting fabricated mica products. This is expected to reduce further the amount of mica that will be fabricated in the United States.

The U.S. flake mica industry ranks first in world production. Most production comes from surface mining of mica schists and as a byproduct of feldspar, kaolin, and lithium beneficiation. Nearly all flake mica is ground to final specifications depending on the use. Other countries producing significant amounts of flake mica are Canada, China, India, the Republic of Korea, and Russia. Many other countries produce small amounts.

Geology-Resources

Sheet muscovite is obtained from coarse-grained igneous rocks called pegmatites. Pegmatites also contain feldspar, quartz, and various accessory minerals. Pegmatite dikes and veins range from 1 kilometer or more long and 100 meters wide to thin veins and veinlets of approximately 2 centimeters in width.

The United States has no reserves of sheet mica. Small U.S. reserves were extensively worked in the past, and the high cost of labor has kept the mines shut down since the Government's purchase program ended in 1962. The primary sheet mica resources are in New England, the southeastern Piedmont from Virginia to Alabama, the Blue Ridge Mountains in North Carolina, the Black Hills of South Dakota, and northern New Mexico. Other States with some sheet mica resources are California, Colorado, Idaho, Montana, and Wyoming.

No formal evaluation of world resources of sheet mica has been made, mainly because of the sporadic occurrence of this mineral. The most productive sheet mica districts in the world are in the States of Bihar, Andhra Pradesh, and Rajasthan in India. India's large reserves and resources of sheet mica have been the primary world sources for many years. Large reserves of sheet mica also are found in Brazil and western Africa. In Russia, sheet mica reserves are known in the Lake Baikal and Sayan upland areas as well as in the South Eniessy Range. Smaller but substantial reserves occur in Argentina, Australia, and Zimbabwe.

Phlogopite deposits are in areas of metamorphosed sedimentary rocks intruded by masses of pegmatite-rich granitic rocks. The phlogopite is found as veins or pockets in pyroxenite interlayered with or intersecting marble or gneiss. Canada and Madagascar have the world's major reserves of phlogopite. Additional reserves are known in Mexico, Sri Lanka, and the Sludyanka River district and Alden area of Russia.

The primary domestic source of flake mica for grinding purposes is weathered alaskite bodies and pegmatites in North Carolina, where most domestic flake mica is produced. The mica is recovered as a coproduct of feldspar and kaolin beneficiation. Flake mica is also recovered from muscovite schists. These schists bodies range in size from 3 to more than 100 meters thick and several kilometers long. The mica content ranges up to 90%. Another form of flake mica is fine-grained muscovite called sericite, which is an alteration product of various aluminosilicate minerals.

World reserves and resources of scrap and flake mica are not well known but are considered to be very large. All countries with sheet mica reserves or resources have even larger quantities of scrap mica because only a small fraction of the mica present is of sheet quality. Many other countries have reserves or resources of mica that, although not of sheet quality, are suitable for grinding.

ANNUAL REVIEW

Legislation and Government Programs

The Government inventory of stockpile-grade mica decreased slightly to about 9,500 tons. The U.S. Department of Defense sold 37 tons of muscovite block, stained and better; 33 tons of muscovite film; 44 tons of muscovite splittings; and 51 tons of phlogopite splittings. *(See table 2.)*

Strategic Considerations

Sheet mica and high-quality scrap mica used for making mica paper are important in the electronic and electrical industries. The United States is not self-sufficient in these materials and imports all its supplies, mostly from India. The United States competes with the rest of the world for Indian mica, and availability is sometimes limited, particularly for high-quality mica. Long delivery times and quality inconsistency also adversely affect sheet mica availability.

In a short-supply situation during an emergency, the National Defense Stockpile would be able to meet short-term demand until substitutes could be made available. It is unlikely that domestic sheet mica production could replace or significantly reduce imports. Of the five strategic stockpile categories, only muscovite block mica has ever been produced domestically in significant quantities, and then only under the stimulus of above-market prices paid by the Government. Domestic production in this century never provided more than a small fraction of domestic requirements.

The domestic supply of flake mica is adequate. Scrap and flake mica are not considered to be strategic materials. The United States is self-sufficient in flake mica but does rely on imports of high-quality scrap for the manufacture of mica paper.

Production

Scrap and Flake Mica.—Mica was mined by 9 companies with 11 mines in 5 States. North Carolina remained the major producing State, with 58% of the total production. The remainder was produced in Georgia, New Mexico, South Carolina, and South Dakota. Most mica was recovered from mica schist, high-quality sericite schist, and as a byproduct of feldspar, kaolin, and lithium beneficiation.[3] The five largest producers were, in alphabetical order, The Feldspar Corp., Spruce Pine, NC; Franklin Mineral Products Co., Hartwell, GA; KMG Minerals Inc., Kings Mountain, NC; Lithium Corp. of America, Gastonia, NC; and MICA, Fairview, NM. These five companies produced 74% of the national total.

Low-quality sericite, used primarily in brick manufacturing, is excluded from tabulated data contained in this report. In 1993, three companies, one in North Carolina and two in South Carolina, mined low-quality sericite and reported an average value of $3.31 per ton.

Ground Mica.—Ten companies operated twelve grinding plants in 6 States. Eight plants produced dry-ground and four produced wet-ground mica. The five largest producers accounted for 82% of the total. They were, in alphabetical order, Franklin Mineral Products Co., Hartwell, GA; KMG Minerals Inc., Kings Mountain, NC; MICA, Fairview, NM; Spartan Minerals Corp., Pacolet, SC; and USG Corp., Spruce Pine, NC. *(See tables 3 and 4.)*

Consumption and Uses

Sheet Mica.—Sheet mica is used principally in the electronic and electrical industries. Its usefulness in these applications stems from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, or stamped to close tolerances.

The largest use of block mica is as an electrical insulator in electronic equipment. High-quality block mica also is used to line the gauge glasses of high-pressure steam boilers. Transparency, flexibility, and resistance to heat and chemical attack are the properties that make mica suitable for this use. Other uses include diaphragms for oxygen-breathing equipment, marker dials for navigation compasses, optical filters, retardation plates in helium-neon lasers, pyrometers, thermal regulators, and stove windows.

Muscovite film mica is used as a dielectric in capacitors. Only high-quality mica, at or near the top of the quality scale, is used. The highest quality goes into capacitors that are to be used as standards. The next highest qualities are used for transmitting capacitors. Receiving capacitors use slightly lower quality film.

Consumption of muscovite block (ruby and nonruby) totaled 5.4 tons, a 4% decrease from that of 1992. Stained and lower-than-stained quality remained in greatest demand, accounting for 87% of consumption. About 60% of the muscovite consumed was grade No. 4 or larger. The decrease in consumption was a continuation of a long-term decrease in block mica use. Five companies continued to consume muscovite block and film in five plants in four States: two in North Carolina and one each in New Jersey, Ohio, and Virginia.

Splittings represent the largest part of the sheet mica industry in the United States. Muscovite and phlogopite splittings are used to make built-up mica. Consumption of mica splittings decreased slightly to 826 tons. Muscovite splittings from India accounted for nearly all of the consumption. The remainder was phlogopite splittings from Madagascar. The splittings were fabricated into various built-up mica products by nine companies operating nine plants in seven States.

Built-up Mica.—The primary use of this mica-based product, made by mechanical or hand setting of overlapping splittings and alternate layers of binders and splittings, was as electrical insulation material. Principal built-up mica products are segment plate, molding plate, flexible plate, heater plate, and tape.

Segment plate acts as insulation between the copper commutator segments of direct-current universal motors and generators. Phlogopite built-up mica is preferred because it will wear at the same rate as the copper segments. Muscovite has a greater resistance to wear, causing uneven ridges that may interfere with the operation of the generator.

Molding plate is sheet from which V-rings are cut and stamped for use in insulating the copper segments from the steel shaft at the ends of a commutator. Molding plate also is fabricated into tubes and rings for insulation in transformers, armatures, and motor starters.

Flexible plate is used in electric motor and generator armatures, field coil insulation, and magnet and commutator core insulation. Heater plate is used where high-temperature insulation is required.

Some types of built-up mica have the bonded splittings reinforced with special paper, silk, linen, muslin, glass cloth, or plastic. These products are very flexible and are produced in wide, continuous sheets that either are shipped in rolls or cut into ribbons, tapes, or any desired dimensions.

Total production, sold or used, of built-up mica decreased 24% from that of 1992. Segment plates and molding plates were the major end products, accounting, respectively, for 33% 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 1993 were Corona Films Inc., West Townsend, MA; General Electric Co., Coshocton, OH; and US Samica Corp., Rutland, VT. *(See tables 5, 6, and 7.)*

Ground Mica.—The largest domestic use of ground mica was in gypsum plasterboard joint cement. The mica acts as a filler and extender, provides a smooth consistency, improves the workability of the cement, and imparts resistance to cracking.

In the paint industry, ground mica is used as a pigment extender that also facilitates suspension, reduces checking and chalking, prevents shrinking and shearing of the paint film, increases resistance of the paint film to water penetration and weathering, and brightens the tone of colored pigments.

Ground mica is used in the well-drilling industry as an additive to drilling muds. The coarsely ground mica flakes help prevent lost circulation by sealing porous sections of the drill hole.

The rubber industry uses ground mica as an inert filler and as a mold lubricant in the manufacture of molded rubber products such as tires. The plastics industry uses ground mica as an extender and also as a reinforcing agent.

Ground mica is used in the production of rolled roofing and asphalt shingles, where it serves as an inert filler and surface coating to prevent sticking of adjacent surfaces. The coating is not absorbed by freshly made roofing because mica has a platy structure and is not affected by the acid in the asphalt or by weathering. Other uses include decorative coatings on wallpaper and on concrete, stucco, and tile surfaces; as an ingredient in some special greases; as a coating for cores and molds in metal casting; and as a flux coating on welding rods.

In 1993, the major end uses were joint cement, 53%; paints, 17%; plastics, 4%; and well-drilling muds, 4%. *(See table 4.)*

Stocks

Reported yearend consumer stocks of sheet mica decreased slightly to 463 tons; of this, mica splittings represented 92% and mica block and film represented 8%.

Markets and Prices

Prices for sheet mica vary with grade and quality and can range from less than $1 per kilogram for low-quality mica to more than $2,000 per kilogram for the highest quality. The average values of muscovite sheet mica consumed in the United States in 1993 compared with 1992 were as follows: block increased 10% to $95 per kilogram, and splittings increased slightly to $1.55 per kilogram. The average value of phlogopite block remained at $26 per kilogram, while the value of phlogopite splittings decreased slightly to $4.37 per kilogram. The changes in average value are more a reflection of the quality of mica consumed during the year than actual changes in price. The average value of crude flake mica, including high-quality sericite, was $51 per ton. The average value per ton for North Carolina flake mica, predominantly a flotation product, was $53.

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 3,000 tons, 44% more than those in 1992. Worked mica imports were about 1,400 tons, 4% less than those in 1992. About 13,100 tons of ground mica was imported mostly from Canada, while about 4,600 tons was exported to 32 countries. The combined value of all mica imports increased 9% to $21.2 million, while the combined value of all mica exports increased 26% to $12.2 million. *(See tables 8, 9, 10, 11, 12, and 13.)*

World Review

World production of mica decreased 5% to 190,000 tons. The United States continued to lead in the production of flake mica. India continued to lead in the production of sheet mica. *(See table 14.)*

Canada.—Suzorite Mica Products Inc., currently the only active mica producer in Canada, was purchased by Zemex Corp. Zemex, headquartered in Asheville, NC, is the parent of The Feldspar Corp., a major producer of mica in the United States.[4]

Stratmin Graphite Inc. was investigating the feasibility of separating phlogopite mica at its graphite operation at Lac des Iles, Quebec.[5]

Finland.— Kemira Oy was planning to increase the capacity of its pearlescent pigment facilities in Pori. Mica production from Kemira's mine at Siilinjarvi will be increased accordingly.[6]

India.—Political changes in the former U.S.S.R. and Eastern European countries have had a serious impact on India's mica exports. Exports to those countries have dropped dramatically.[7]

OUTLOOK

Demand for sheet mica has decreased dramatically during the past 30 years. For block and film mica, the major cause of decreased demand was technological change, specifically the introduction of semiconductor technology in electronics to the detriment of vacuum tube electronics that used large quantities of mica. Although the major impact of the technology change was felt in the 1960's and 1970's, consumption of block and film mica continues to decrease, albeit more slowly. Substitute materials cause part of the decrease, and increased imports of finished electronic gear mean fewer mica parts are fabricated in the United States. Since 1979, consumption block mica has decreased at an average annual rate of about 20%. This decline is expected to continue, and, by 1995, consumption will decrease to 2,500 kilograms. Consumption of mica splittings, the major type of sheet mica consumed in the United States, also decreased sharply through the 1960's and

1970's. During the 1980's, consumption leveled off to between 900 and 1,000 tons per year. Decreases were due to the development of substitute electrical insulating materials, miniaturization of electrical equipment, and increased imports of foreign-built products. Consumption of splittings is expected to decrease very slightly in the near future, remaining between 800 and 1,000 tons through 1995.

Scrap and flake mica enters markets as ground mica, and demand tends to follow construction activity levels. With increased construction activity in 1993, ground mica consumption increased about 12%. In the near future, modest increases in construction activity are expected to continue, which will probably bring ground mica consumption to about 100,000 tons by 1995.

The major end use, as a filler in joint compounds, will continue to account for about one-half of the market. Consumption for other uses—in paints, well-drilling muds, and plastics—is expected to increase slightly by 1995.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Mica. Ch. in Minerals Yearbook, annual.
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Industrial Minerals and Rocks, 6th ed., AIME, 1994.
Mining Engineering.
The Economics of Mica 1989, Roskill Information Services Ltd.
The Mica Industry Association.

TABLE 1

SALIENT MICA STATISTICS

		1989	1990	1991	1992	1993
United States:						
Production (sold or used by producers):						
Scrap and flake mica	thousand metric tons	119	109	103	85	88
Value	thousands	$6,273	$5,811	$5,542	$4,638	$4,453
Ground mica	thousand metric tons	101	97	75	84	92
Value	thousands	$22,443	$21,610	$17,286	$21,755	$26,986
Consumption:						
Block, muscovite	metric tons	7	6	6	6	5
Value	thousands	$599	$554	$502	$447	$509
Splittings	metric tons	1,108	842	854	836	826
Value	thousands	$1,703	$1,414	$1,427	$1,388	$1,386
Exports	metric tons	5,327	5,659	4,901	5,035	5,858
Imports	do.	15,834	1,587	15,695	18,815	22,171
World: Production	do.	[r]277,746	[r]213,682	[r]206,699	[r]199,502	[e]190,314

[e]Estimated. [r]Revised.

TABLE 2

STOCKPILE STATUS AND GOVERNMENT INVENTORIES FOR MICA, DECEMBER 31, 1993

(Metric tons)

Material	Inventory: Stockpile grade	Inventory: Non-stockpile grade	Available for disposal	1993 sales
Block:				
Muscovite, stained and better	2,080	89	227	37
Phlogopite	8	52	—	—
Film: Muscovite, 1st and 2d qualities	496	([1])	68	33
Splittings:				
Muscovite	6,356	—	102	44
Phlogopite	598	—	113	51

[1]Less than 1/2 unit.

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[1] American Society for Testing and Materials. Standard Specification for Natural Muscovite Block Mica and Thins Based on Visual Quality. D351-77 in 1984 Annual Book of ASTM Standards: Volume 10.01, Electrical Insulation—Specifications: Solids, Liquids, and Gases; Test Methods: Liquids and Gases; Electrical Protective Equipment for Workers. Philadelphia, PA, 1984, pp. 136-143.

[2] Skow, M. L. Mica—A Materials Survey. BuMines IC 8125, 1962, 240 pp.

[3] Production of high-quality sericite is included in the totals; however, figures for low-quality sericite, used principally for brick manufacturing, are not included.

[4] Industrial Minerals (London). No. 320, May 1994, p. 23.

[5] ———. No. 304, Jan. 1993, p. 8.

[6] ———. No. 306, Mar. 1993, p. 9.

[7] Page 11 of work cited in footnote 6.

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
1989	119	6,273
1990	109	5,841
1991	103	5,542
1992	85	4,638
1993:		
North Carolina	51	2,696
Other States[2]	37	1,758
Total	88	[3]4,453

[1] Includes finely divided mica recovered from mica schist and high-quality sericite schist, and mica that is a byproduct of feldspar, kaolin, and lithium beneficiation.

[2] Includes Georgia, New Mexico, South Carolina, and South Dakota.

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

TABLE 4
GROUND MICA SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY END USE AND METHOD OF GRINDING[1]

(Thousand metric tons and thousand dollars)

	1992			1993		
	Quantity	Value	Unit value[2]	Quantity	Value	Unit value[2]
End use:						
Joint cement	43	6,819	157	49	7,549	155
Paint	16	5,227	323	16	5,416	348
Plastics	4	1,347	357	4	1,647	396
Well-drilling mud	2	281	123	4	560	209
Other[3]	19	8,082	432	19	11,814	616
Total	84	[4]21,755	258	92	26,986	293
Method of grinding:						
Dry	W	W	168	W	W	152
Wet	W	W	745	W	W	838

W Withheld to avoid disclosing company proprietary data.

[1] Domestic and some imported scrap. Low-quality sericite is not included.

[2] Based on unrounded dollars and thousand metric tons.

[3] Includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coatings, welding rods, and miscellaneous.

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

TABLE 5
FABRICATION OF MUSCOVITE BLOCK MICA IN THE UNITED STATES, BY QUALITY

(Kilograms)

Quality	1992	1993
Good stained or better	563	674
Stained or lower[1]	5,013	4,689
Total	5,576	5,363

[1] Includes punch mica.

TABLE 6
CONSUMPTION AND STOCKS OF MICA SPLITTINGS IN THE UNITED STATES

Year	Consumption		Stocks on Dec. 31 (metric tons)
	Quantity (metric tons)	Value (thousands)	
1989	1,108	$1,703	505
1990	842	1,414	632
1991	854	1,427	612
1992	836	1,388	427
1993	826	1,386	427

TABLE 7
BUILT-UP MICA[1] SOLD OR USED IN THE UNITED STATES, BY PRODUCT

Product	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Flexible (cold)	163	$794	104	$551
Heater plate	W	W	W	W
Molding plate	211	1,516	210	1,718
Segment plate	262	1,729	213	1,382
Tape	W	W	W	W
Other	216	2,036	124	1,074
Total	852	6,075	651	[2]4,724

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

[1] Consists of alternating layers of binder and irregularly arranged and partly overlapped splittings.

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

TABLE 8

U.S. EXPORTS OF CRUDE AND RIFTED MICA, MICA POWDER, AND MICA WASTE IN 1993, BY COUNTRY

Country	Crude and rifted				Powder		Waste	
	Less than $0.55 per kilogram		More than $0.55 per kilogram					
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	18	$6	—	—	18	$12	—	—
Australia	—	—	—	—	277	113	—	—
Barbados	—	—	—	—	25	20	—	—
Belgium	—	—	—	—	4	7	—	—
Belize	—	—	—	—	12	7	—	—
Brazil	16	6	44	$43	27	20	—	—
Canada	32	15	—	—	1,868	790	173	$34
Colombia	32	11	7	15	123	84	—	—
Dominican Republic	—	—	—	—	13	7	—	—
Ecuador	—	—	—	—	13	8	—	—
France	—	—	—	—	238	315	—	—
French Guiana	—	—	15	87	—	—	—	—
Germany	48	17	—	—	208	54	—	—
Guyana	—	—	—	—	12	3	—	—
Hong Kong	—	—	—	—	1	7	4	6
India	—	—	49	122	—	—	—	—
Ireland	—	—	—	—	16	3	—	—
Israel	—	—	—	—	5	3	—	—
Italy	—	—	19	15	82	14	—	—
Japan	—	—	153	204	409	243	—	—
Korea, Republic of	—	—	2	15	169	127	—	—
Mexico	—	—	(1)	7	413	198	—	—
Netherlands	—	—	2	3	—	—	—	—
Norway	—	—	—	—	25	15	—	—
Pakistan	—	—	—	—	5	4	—	—
Paraguay	—	—	—	—	42	25	—	—
Philippines	—	—	—	—	20	11	—	—
Saudi Arabia	—	—	—	—	51	22	—	—
Spain	—	—	—	—	15	14	—	—
Switzerland	—	—	—	—	9	8	—	—
Taiwan	—	—	—	—	140	101	—	—
Thailand	—	—	—	—	7	45	—	—
United Kingdom	11	4	—	—	289	287	—	—
Uruguay	—	—	—	—	4	3	—	—
Venezuela	—	—	—	—	77	36	—	—
Total[2]	158	59	292	511	4,614	2,604	177	40

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF WORKED MICA IN 1993, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Aruba	3	$24	—	—
Australia	11	150	11	$44
Austria	1	21	—	—
Bahamas, The	43	99	10	42
Belgium	22	518	—	—
Belize	—	—	1	5
Brazil	34	675	2	41
Bulgaria	(1)	10	—	—
Canada	116	2,554	68	1,427
Cayman Islands	—	—	1	5
Chile	—	—	(1)	11
Colombia	(1)	15	11	20
Costa Rica	17	56	1	5
Ecuador	4	18	—	—
Egypt	79	384	—	—
France	13	121	1	30
Germany	3	83	4	24
Guatemala	—	—	3	5
Honduras	1	18	5	16
Hong Kong	(1)	3	1	28
Hungary	(1)	11	—	—
India	(1)	24	—	—
Indonesia	—	—	2	34
Israel	—	—	1	15
Italy	41	463	—	—
Japan	9	377	1	3
Korea, Republic of	5	155	3	48
Mexico	24	617	14	186
Netherlands	—	—	(1)	15
Netherlands Antilles	(1)	10	4	15
New Zealand	11	38	—	—
Pakistan	—	—	(1)	4
Panama	—	—	3	74
Philippines	—	—	2	3
Saudi Arabia	—	—	(1)	12
Singapore	(1)	4	(1)	6
South Africa, Republic of	(1)	11	1	12
Switzerland	2	49	—	3
Taiwan	2	34	5	109
Thailand	5	16	—	—
Trinidad and Tobago	—	—	5	14
Turkey	1	7	—	—
Turks and Caicos Islands	1	4	—	—
United Kingdom	7	142	1	32
Venezuela	(1)	10	1	9
Total[2]	457	6,721	160	2,298

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

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND RIFTED MICA IN 1993, BY COUNTRY

Country	Split block		Splittings		Other			
					Less than $0.55 per kilogram		More than $0.55 per kilogram	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Brazil	—	—	—	—	315	$111	—	—
Canada	—	—	22	$2	—	—	(1)	$6
China	—	—	9	25	—	—	80	203
Germany	—	—	—	—	120	23	35	57
Hong Kong	—	—	—	—	100	16	1	10
India	184	$333	2,594	1,728	2,920	545	16	65
Indonesia	—	—	—	—	201	45	—	—
Japan	—	—	—	—	—	—	14	90
Tanzania	(1)	4	—	—	—	—	—	—
United Kingdom	—	—	—	—	—	—	(1)	3
Total[2]	184	337	2,625	1,754	3,656	739	147	433

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

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF MICA POWDER AND WASTE IN 1993, BY COUNTRY

Country	Powder		Waste	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Canada	12,721	$5,994	122	$14
China	5	8	—	—
France	16	57	—	—
Germany	14	44	—	—
India	—	—	937	482
Japan	152	1,840	(1)	7
Madagascar	—	—	36	36
Mexico	—	—	14	30
Netherlands	1	2	—	—
Norway	182	121	—	—
Russia	8	5	—	—
Total[2]	13,098	8,070	1,109	568

[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. IMPORTS FOR CONSUMPTION OF WORKED MICA IN 1993, BY COUNTRY

Country	Plates, sheets		Other	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	214	$519
Austria	—	—	(1)	10
Belgium	575	$4,574	—	—
Brazil	39	153	105	252
Canada	(1)	5	—	—
China	104	269	1	17
France	16	127	—	—
Germany	4	261	14	183
India	24	368	75	711
Italy	—	—	(1)	6
Japan	17	144	13	184
Korea, Republic of	12	77	14	28
Netherlands	—	—	(1)	2
Portugal	—	—	31	63
Russia	—	—	4	17
South Africa, Republic of	(1)	6	—	—
Spain	—	—	8	8
Switzerland	63	1,242	(1)	10
Taiwan	1	6	—	—
United Kingdom	2	35	(1)	19
Venezuela	—	—	13	41
Total[2]	859	7,269	493	2,069

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13
SUMMATION OF U.S. MICA TRADE DATA

	Scrap and flake mica				Sheet mica			
	Powder		Waste		Unworked		Worked	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Exports:								
1989	3,628	$1,634	1,224	$555	60	$156	415	$7,227
1990	4,319	2,050	580	646	148	272	612	7,568
1991	3,420	1,717	874	331	205	309	411	7,454
1992	3,954	2,054	475	204	170	307	436	7,180
1993	4,614	2,604	335	99	292	511	617	9,019
Imports for consumption:								
1989	8,902	4,971	4,185	1,256	1,616	2,054	1,129	6,711
1990	9,142	5,133	4,034	987	1,615	2,051	1,085	7,431
1991	9,725	5,219	3,630	996	1,422	1,608	918	6,835
1992	11,568	7,479	3,786	974	2,054	2,011	1,407	9,011
1993	13,098	8,070	4,765	1,307	2,956	2,524	1,352	9,338

Source: Bureau of the Census.

TABLE 14
MICA: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Argentina:					
Sheet	327	[r]243	[r]313	[r,e]290	300
Waste, scrap, etc.	[e]500	[r]684	[r]533	[e]450	450
Brazil[e]	3,700	5,000	[3]5,080	5,000	5,000
Canada[e]	12,000	16,000	17,000	17,500	17,500
France[e]	8,000	7,000	6,000	[r,3]12,000	8,000
India:					
Crude	[r]4,195	3,860	3,607	[e]3,500	3,000
Scrap and waste	[r]3,108	2,822	1,922	[e]2,000	1,600
Total	[r]7,303	6,682	5,529	[e]5,500	4,600
Iran[4]	2,294	1,352	4,135	[r]7,846	8,000
Korea, Republic of (all grades)	7,888	4,765	5,127	[r]7,732	7,500
Madagascar (phlogopite)	1,068	721	680	[r]798	774
Mexico (all grades)	4,510	5,863	[r]5,587	[r]5,866	[3]6,159
Morocco[e]	1,500	1,500	1,500	1,500	1,500
Peru[e]	100	100	100	100	100
Russia[5]	—	—	—	[e]35,000	30,000
Serbia and Montenegro[6]	—	—	—	[r,e]500	500
South Africa, Republic of (scrap)	1,708	1,765	1,883	[r]2,099	1,050
Spain	[r]951	[r]913	[e]300	[e]250	250
Sri Lanka (scrap)[e]	[r]200	[r]200	[r]200	[r]200	200
Taiwan	4,290	4,946	8,596	[r]11,038	10,000
Tanzania (sheet)	(7)	(7)	(7)	(7)	(7)
U.S.S.R. (all grades)[e,5,8]	50,000	45,000	40,000	—	—
United States (scrap and flake)[9]	119,142	108,845	102,830	85,338	[3]87,931
Yugoslavia[6,10]	794	802	800	—	—
Zimbabwe	1,471	1,301	506	[r]495	500
Total	[r]227,746	[r]213,682	[r]206,699	[r]199,502	190,314

[e]Estimated. [r]Revised.

[1] Table includes data available through July 13, 1994.

[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] Reported figure.

[4] Data are for year beginning Mar. 21 of that stated.

[5] All production in the U.S.S.R. from 1989-91 came from Russia.

[6] All production in Yugoslavia from 1989-91 came from Serbia and Montenegro.

[7] Less than 1/2 unit.

[8] Dissolved in Dec. 1991.

[9] Excludes U.S. production of low-quality sericite and sheet mica, if any.

[10] Dissolved in Apr. 1992.

MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 46 years of industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Sherwood C. Jordan, statistical assistant; and the world production tables were prepared by Harold D. Willis, international data coordinator.

Molybdenum is a refractory metallic element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has ensured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments. The variety of uses for molybdenum materials, few of which afford acceptable substitutions, has resulted in a demand that is expected to grow at a greater rate than most other ferrous metals.

Distribution of molybdenum reserves and productive capacity are concentrated in a few countries of the world. World mine output was an estimated 95,000 metric tons (molybdenum contained in concentrate) in 1993, of which Canada, Chile, China, and the United States provided 82%. These four countries, led by the United States, are expected to continue as the principal mine producers for the rest of this century. These countries also possess about 90% of the estimated 12 million metric tons of molybdenum in world reserve base.

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on molybdenum that are consistent with international usage, reports data in kilograms and metric tons.

DOMESTIC DATA COVERAGE

Domestic production data for molybdenum are developed by the U.S. Bureau of Mines by means of three separate, voluntary surveys. These surveys are Molybdenum Ore and Concentrate, Molybdenum Concentrate and Molybdenum Products, and Molybdenum Concentrates. Surveys are sent to all operations that produce molybdenum ore and products. Out of 12 operations to which surveys were sent, all responded, representing 100% of the total U.S. production shown in table 1.

BACKGROUND

From the period of the Greek and Roman civilizations to the late 18th century, terms such as "molybdous" or "molybdaena" were applied to minerals that were soft and "leadlike" in character, probably including minerals now known as galena, graphite, and molybdenite. This confusion was resolved in 1778 when the Swedish chemist, Karl Scheele, demonstrated that molybdenite, the principal molybdenum mineral, was a discrete mineral sulfide. Four years later, P. J. Hjelm of Sweden reduced the acid-forming oxide of the element by heating with charcoal, thereby producing an impure powder of the metal, which he named "molybdenum." Various properties of the element and its compounds were determined during the 19th century, and in 1893, German chemists produced a 96%-pure metal by reducing calcium molybdate. The impure metal was reported to have been used experimentally as a substitute for tungsten in tool steels.

Molybdenum-bearing armorplate was produced in France in 1894; this was the first recorded use of the metal as an alloying element in steel. Soon thereafter, Henri Mossiam, a French chemist, succeeded in producing a 99.98%-pure metal by reduction of molybdenum in an electric furnace. Mossiam then conducted studies to establish the element's atomic weight and to determine its physical and chemical properties. These studies stimulated interest in the metal and its compounds and investigations of commercial applications. By the late 1890's, molybdenum was used in certain chemicals and dyes, and in 1898, a self-hardening molybdenum tool steel was marketed.

The first mine production of molybdenite was probably from the Knaben Mine in southern Norway in the late 18th or early 19th century. Because essentially no commercial use for the metal existed, output from the mine remained insignificant until about 1880. By the end of the century, molybdenum ore was also mined intermittently in Australia and the United States. Molybdenite and wulfenite concentrates were produced from ores in Arizona and New Mexico, but U.S. output was small and ceased entirely in 1906 owing to lack of demand.

World War I generated the first appreciable utilizations of molybdenum, when it was substituted for tungsten in high-speed steels and used as an alloying element in certain steels for military armament. From 1912 to 1920, small output was recorded from several additional countries, and U.S. production was resumed. The flotation process for separating molybdenite from its ores was developed during these years. The Climax deposit in Colorado and the Questa deposit in New Mexico were initially exploited from 1917 to 1919. Development of the Climax deposit, the world's largest, later proved the viability of high-tonnage extraction of relatively low-grade ore and established the United States as the leading producer of molybdenum.

Output terminated in 1920 in the United States and most other countries because nonmilitary consumption of molybdenum was insufficient to support continued production. However, industrial efforts to develop peacetime applications, primarily as an alloy in steels and cast irons, were successful, and by the mid-1920's, demand exceeded that of the war years. Operations resumed at the Climax deposit in 1924. By 1930, world output of molybdenum totaled 4.2 million pounds, of which the United States and the Climax Mine accounted for about 89% and 73%, respectively.

In 1933, the Greene Cananea Copper Co., a Mexican subsidiary of the Anaconda Co., initiated the recovery of molybdenite as a byproduct of copper mining operations. Three years later, Kennecott Corp. began byproduct recovery at its Bingham open pit in Utah. Since that time, molybdenite recovery circuits have been installed at numerous copper concentrating plants, notably in Canada, Chile, and the United States. These sources have supplied 40% to 50% of the world molybdenum output in recent years.

Since the early 1930's, industrial research and marketing programs have considerably expanded the range of metallurgical materials in which molybdenum is a preferred or essential alloy ingredient. The use of molybdenum as a refractory metal and in a variety of chemical applications also has experienced significant growth.

Definitions, Grades, and Specifications

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of 95.95, and a density of 10.2 grams per cubic centimeter. The chemistry of molybdenum is complex; molybdenum exhibits oxidation states from -2 to 6, coordination numbers from 4 to 8, and forms compounds with most inorganic and organic liquids. Molybdenum is a strong carbide-forming element, and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610° C; among the metallic elements, only osmium, rhenium, tantalum, and tungsten have higher melting points. Other significant physical properties of molybdenum metal are good thermal conductivity (about one-half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures, and resistance to corrosion in a wide variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures, but above 500° C it oxidizes readily.

Molybdenite is the principal mineral from which molybdenum is obtained. Crude ore containing molybdenite is beneficiated to produce molybdenite concentrate. The concentrate generally contains about 90% molybdenite; the grade may be somewhat lower, particularly if produced at copper byproduct concentrating plants. Technical-grade molybdic oxide is produced by the roasting of molybdenite concentrate. Typically, the oxide has a content of 85% to 90%, or a minimum of 57% contained molybdenum. Other raw materials, including ferromolybdenum, purified molybdic oxide, ammonium, and sodium molybdate, and molybdenum metal powder are produced from technical-grade oxide. The production of these materials is described in the section entitled "Products for Trade and Industry."

The American Society for Testing and Materials (ASTM) has developed standards for the chemical composition of molybdenum oxide products (Specification A 146-64, reapproved 1979) and ferromolybdenum (Specification A 132-74, reapproved 1979). These standards specify minimums for molybdenum content and maximums for impurity content as an aid to producers and purchasers. Material marketed by the major domestic producers generally meet or exceed ASTM standards.

Products for Trade and Industry

Some commercial-grade molybdenite concentrate is treated in additional grinding and flotation steps to produce lubricant-grade molybdenum disulfide. Oil and water are volatilized by passing an upgraded concentrate through an inert-gas-swept kiln. The oil-free product is about 99% molybdenum disulfide and suitable for use in lubricant applications.

Molybdenite concentrate is converted to technical-grade molybdic oxide, the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals, and molybdenum metal powder. The technical-grade oxide is produced by roasting molybdenite concentrate in the multiple-hearth furnace at temperatures of up to 650° C. Typically, the roasted product contains 90% molybdic oxide and a maximum of 0.1% sulfur. Technical-grade oxide is used to add molybdenum to steels, cast irons, and other alloys.

Ferromolybdenum is typically produced by reduction of technical-grade oxide and iron oxide with a conventional metallothermic process, using silicon and/or aluminum as the reductant. The molybdenum content ranges from 58% to 64%. Ferromolybdenum is used as an alternative additive in producing alloy steels, cast irons, and nonferrous alloys.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made in a similar manner using sodium hydroxide and calcium chloride.

Molybdenum metal powder is manufactured by reducing pure molybdic oxide or ammonium molybdate with hydrogen. The purest metal powder (99.95% molybdenum minimum) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots, which are converted into rod, wire, or sheet by hot rolling, swaging, or forging. Large ingots are produced by arc-casting powder under a vacuum or inert gas atmosphere.

Industry Structure

Four countries, Canada, Chile, China, and the United States, mine 82% of world output of molybdenum ore. Plants to convert ore concentrates to technical-grade oxide and other molybdenum products are in Chile, China, Russia, the United States, and Western Europe.

Geology-Resources

Almost all molybdenum is recovered from low-grade deposits of the mineral molybdenite. Two types of deposits, primary and byproduct porphyry copper, provided the United States and world output of molybdenite. Primary molybdenum deposits generally grade 0.2% to 0.5% molybdenite; copper ores from which byproduct molybdenum is recovered contain 0.02% to 0.08% molybdenite.

The average crustal abundance of molybdenum is 1 to 2 parts per million (ppm). The molybdenum content of igneous rocks tends to increase with increasing silica content. Molybdenum does not occur in nature in its free or native state, but is found only chemically combined with other elements. Small deposits of molybdenum-bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite, and ferrimolybdite are common but have supplied very little molybdenum.

Molybdenite (MoS_2) is a lead-gray metallic mineral that characteristically occurs in thin, tabular, commonly hexagonal plates and also disseminated as fine specks. It has a specific gravity of 4.6 to 4.7, a hardness of 1 to 1.5, a greasy feel, and it soils the fingers. Superficially, it resembles graphite, for which it commonly has been mistaken.

Molybdenum deposits are of five geological types: (1) porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks.

The first three genetic-type deposits are hydrothermal in origin and as such represent nearly all the known molybdenum resources currently mined in the world. The remaining types do not represent a great volume of molybdenum but are of certain economic importance only when molybdenum is associated with other minerals.

In the hydrothermal deposits, metallic minerals are precipitated from high-temperature aqueous solutions either by changes in temperature and pressure or by evaporation of the liquid. Minerals are deposited in the cavities, cracks, or interstices of the matrix rock.

Most of the porphyry coppers contain small quantities of molybdenite disseminated with the copper minerals through large bodies of granitic rock. The chief minerals are chalcopyrite and chalcocite, with pyrite and small amounts of other sulfides, including molybdenite.

Available information on world reserves and reserve base of molybdenum varies widely in reliability. For certain countries such as Canada, Chile, and the United States, company annual reports or other published materials enable inventorying minable ore reserves. For most other countries, reserves must be estimated from fragmentary or preliminary data on ore tonnage and grade of known or anticipated sources. In particular, the reserve figures for China and the former U.S.S.R. should be considered order-of-magnitude estimates.

It should be noted that the reserve data refer to molybdenum contained in ore. The recovery of molybdenum after milling approximates 75% to 90% of the in-place ore content at primary molybdenum sources. Recoveries achieved at byproduct sources vary markedly from mine to mine, but average an estimated 55% of the molybdenum in ore processed. Overall, an estimated 65% of the total world molybdenum reserves can be considered as recoverable.

Most of the world reserves of molybdenum occur in the western mountain regions of North and South America, extending from Alaska and British Columbia through the United States and Central America to the Andes Mountains of Chile. These regions, roughly bordering the eastern margin of the Pacific Basin, are also regarded as most promising for future discoveries and additions to reserves.

Technology

Exploration.—Prospecting and exploration for molybdenum is basically the same as that for deposits of other metals. Areas generally considered favorable for molybdenite mineralization are those metallogenic provinces that encompass known occurrences of molybdenum stockworked deposits and copper-molybdenum porphyry deposits. An understanding of regional geology, mineral associations, and known patterns of molybdenite mineralization is essential to identify potential sites for field investigation. Sites for detailed study may be selected on the basis of geologic mapping of rock units and structures, geochemical analyses of sediments and soils, and ground geophysical surveys. An intensive drilling and sampling program is then required to estimate the size, grade, and continuity of the discovery. Exploration drifts may be driven into the ore body to provide more specific geologic information and bulk samples for metallurgical testing.

The evaluation of a deposit may require 2 to 5 years from the time of discovery. During this time, the technical, economic, and environmental aspects of mine development must be evaluated. An additional 3 to 8 years may be required to prepare the deposit for production. Long development times are indicative of the complex planning and considerable capital needed to develop the large, low-grade stockwork and porphyry deposits that are expected to remain the significant sources of molybdenum. As a general rule, development of underground molybdenum deposits would require more time and capital than that of surface deposits.

Mining.—Molybdenum ore is mined by underground and open pit methods, the choice of method determined by the size, configuration, grade, and depth of the ore body. Underground and surface operations accounted for about 40% and 60%, respectively, of the domestic molybdenum output.

Underground deposits of molybdenum ore are mined by block or panel caving methods modified to suit the characteristics of the particular ore body being worked. In these methods, large masses of ore are undercut and blasted at the base to induce the collapse and fragmentation of the ore under its own weight. The broken ore may be drawn off from the caved mass by gravity through finger raises into slusher drifts. The ore is then scraped to draw holes where it falls into ore cars on a haulage level beneath the slusher drifts. Alternatively, the broken ore may be funneled by gravity to crosscut drifts at intervals between production drifts. Ore is moved from the ends of the crosscuts along the production drifts to ore passes where it is dumped and collected in loading pockets on a deeper main haulage level. Ore is then transported from the main haulage level to the site of the initial milling operations. Caving methods are used to mine underground deposits of molybdenum because the low grade of the ore necessitates extraction of large tonnages of rock at a minimum of cost. However, caving of the ore must be carefully controlled to avoid ore dilution and excessive ground stresses to mine openings.

In open pit mining operations, the ore is exposed by removal of waste rock. The cut in the ore takes the form of benches, which vary in height and width from mine to mine. The cycle of open pit extraction consists of drilling, blasting, loading, and haulage. Primary drilling consists of driving a vertical blasting hole into the ore. Secondary drilling and blasting may be required to break large boulders. Ore is loaded by mechanical shovels into rail cars or trucks and hauled by large trucks for short distances or by train for long distances. Skipways and belt conveyors are used at some mines for transporting ore to the mill site.

Beneficiation.—Because of their low molybdenum content, all molybdenum-bearing ores require beneficiation. After crushing and grinding to a suitable size, both primary molybdenite and copper sulfide ore containing molybdenite are beneficiated by flotation. With primary ores, a final concentrate of 90% to 95% molybdenite is produced by subjecting the ore to several stages of grinding and reflotation. Copper, iron, and lead minerals are generally the critical impurities that must be minimized in the final concentrate product. Overall recovery of molybdenite at primary-ore concentrating plants ranges from 75% to 90% of the in-place ore content.

Production of molybdenite concentrate from copper ores is more difficult, however, because molybdenite constitutes less than 0.1% of the ore. As a byproduct value, molybdenite recovery is generally given less priority than recovery of copper values. In some cases, improved molybdenite recovery may be attained only at the expense of reduced copper recovery or lower grade of copper concentrate produced.

Recovery from copper ores begins with the bulk flotation of copper minerals and molybdenite as the first separation from gangue materials. Molybdenite in the bulk flotation product is then separated from the copper minerals in a selective flotation process, which usually involves the flotation of molybdenite and depression of copper minerals. The separatory flotation requires close control of pH, reagent mix, and several flotation steps. Processing of copper-molybdenum ore varies from plant to plant depending on the grade of mineralization and impurities in the ore. Concentrate produced as a byproduct contains 70% to 90% molybdenite, although most approaches the higher end of the range in content.

Recycling.—Some secondary molybdenum is recovered in the production of alloy steels, superalloys, and the metal, but data on quantities are incomplete and inconclusive. Most of this recycled material is generated and reused directly at metal-forming or fabricating plants (runaround scrap) or shipped to plants that reclaim it (prompt industrial scrap). A small amount of molybdenum-containing obsolete scrap is processed for its molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on its molybdenum content. An increasing quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

Byproducts and Coproducts

Rhenium is extracted from flue gases and dust produced during the roasting of molybdenite concentrate that has been produced as a byproduct of copper mining.

Molybdenum is recovered as a byproduct primarily from copper ores. A very small amount is obtained from tungsten and uranium ores. At the Sierrita Mine in Arizona, copper and molybdenum are considered coproduct values.

Substitutes

Historically, molybdenum has been a relatively inexpensive alloying agent used primarily in specialty steels and alloys, and in the United States, it has been readily available. As a result, metallurgical applications for molybdenum were broadened, and its utility as an alloy ingredient became well recognized. The substitution for molybdenum by other alloy metals has had little impetus.

Several factors mitigate the possible replacement of molybdenum to the degree that its overall demand would be significantly affected. First, there is no acceptable substitute in numerous metallurgical and chemical uses. Second, it is commonly added to steels and alloys to enhance several desired properties (such as hardenability, strength, corrosion resistance, etc.), often in synergistic effect with other alloy metals. In such cases, molybdenum could be replaced for particular effects, but at a sacrifice in overall performance. Moreover, the molybdenum content of alloy and specialty steels ranges from less than 1% to a few percent. Therefore, costs of molybdenum raw materials have to increase substantially to appreciably affect the cost of the finished product, thereby stimulating substitution. Finally, the United States is self-sufficient in molybdenum, a situation unlike that of many other ferrous metals. Significant replacement would entail increases in the imports of substituted metals.

Nevertheless, possible alternatives exist in most applications of molybdenum. Steels and alloys containing little or no molybdenum might be used in place of those with higher molybdenum content. In most cases, such substitution would result in lowered or unacceptable performance. Boron, chromium, and manganese can replace molybdenum in steels where hardenability is the only desired effect. In certain low-alloy steels, columbium, manganese, and vanadium act in similar fashion to molybdenum. Chromium, nickel, and tungsten are possible substitutes in steels and other alloys. Molybdenum has substantially replaced tungsten in high-speed tool steels; a return to tungsten grades is possible, but with a reduction in economy and performance. Nonmetallurgical materials, such as plastics and ceramics, can replace steels and alloys containing molybdenum in certain applications.

Tungsten and tantalum can be substituted for molybdenum in certain refractory metal uses, but as a cost disadvantage. Molybdenum can be replaced by graphite for refractory elements in electric furnaces in the range of 1,000° to 1,600° C, but at the expense of slightly greater difficulty in operation and control. Chrome orange, cadmium red, and organic orange pigments are possible substitutes for molybdenum orange. Acceptable substitutes for molybdenum are not found in most of its major catalytic applications. Graphite and other solid lubricants generally do not perform as well as molybdenum disulfide, especially under high-pressure and high-temperature conditions.

Economic Factors

The prices of molybdenum products are quoted on a contained-molybdenum basis and reflect, at least partially, the cost of conversion. Technical-grade oxide, the major form of molybdenum sold commercially, varies slightly in price depending on purity, type of packaging, and whether it is briquetted.

Price quotations generally fall under two groups, the producer-marketer and the merchant. The producer-marketer mines and concentrates the ore, converts the concentrates into consumer products, and markets these products, while a merchant buys and sells concentrates and may convert concentrates into products that are marketed. The source for the merchant to buy concentrates is the byproduct producer. The byproduct producer prices the byproduct as one that provides extra credit. Therefore, this type of a producer is not likely to hold back concentrates from sale. The producer-marketer tries to keep the market balanced by setting a price-based cost plus profit and varying the output to maintain a balance.

Operating Factors

Environmental Requirements.—The mining of molybdenum ore and disposal of ore tailings disturb land areas. Land reclamation is part of the ongoing mining operation. Development of new mining and milling complexes present local socioeconomic and land-use problems. Because new potentially economic sources are likely to be found in relatively unpopulated regions with little other industry, development of a major mine can have significant impact on established occupational patterns. Interaction between mining firms and local, State, and Federal agencies are required to ensure that mine development proceeds in as orderly and environmentally sound manner as possible. The conversion of molybdenite concentrate to technical-grade molybdic oxide involves roasting. Roasting facilities have been modified with sulfuric acid recovery equipment to reduce emissions and thereby comply with stringent environmental restrictions.

Toxicity.—Compared to other industrial metals, molybdenum exhibits very low, negligible toxicity. No significant toxic effects in human beings have been identified in mining or processing molybdenum materials. As an environmental trace element, molybdenum is an essential micronutrient. Deficiencies of molybdenum can affect the normal growth and development of plant and animal species.

Employment.—Employment in the past decade has been reduced by a factor of five with about the same tonnage of production. This improvement in productivity was due to changes in mining and milling equipment and methodologies.

ANNUAL REVIEW

Domestic and foreign molybdenum markets for concentrates did not change in 1993. Total domestic stock levels decreased 11% compared with those of 1992. U.S. mine output of molybdenum was about 40% of world production. Reported end-use consumption of molybdenum in raw materials increased about 3% from that of the previous year. Exports of all forms of molybdenum from the United States decreased, while imports of molybdenum increased. Domestic producer stocks of molybdenum products decreased about 18% from those of the previous year. Domestic mine production of molybdenum concentrate decreased to a total of 37,000 tons of contained molybdenum compared with 50,000 tons in 1992. World mine production of molybdenum concentrate also decreased from a total of 108,000 tons in 1992 to 95,000 tons in 1993. Canada, Chile, China, Russia, and the United States accounted for an estimated 87% of the molybdenum produced worldwide. *(See tables 1, 2, and 3.)*

Consumption and Uses

Consumption of molybdenum concentrate decreased 1,500 tons in 1993. Domestic mine production of molybdenum concentrate was either roasted, exported for conversion, or purified to lubrication-grade molybdenum disulfide. The consumption in 1993 of technical-grade molybdic oxide increased about 6% from that of the previous year. Oxide is the chief form of molybdenum utilized by industry, particularly in steel, cast iron, and superalloys. However, some of the material is also converted to other molybdenum products, such as ferromolybdenum, high-purity oxide, ammonium, and sodium molybdate, and metal powder. Apparent U.S. consumption (defined as U.S. primary plus secondary production plus imports minus exports plus adjustments for Government and industry stock changes) was about 13,000 tons of molybdenum. *(See table 4.)*

Stocks

Total industry stocks, which include those of producers and consumers, decreased about 2,500 tons of contained molybdenum. Inventories of molybdenum in concentrate at producer locations decreased about 1,200 tons. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 1,300 tons. Compared with apparent consumption, yearend producer stocks of these materials represented about a 16-month supply. Domestic consumer inventories of about 2,500 tons, the same amount as at yearend 1992, represented approximately a 2-month supply as measured by average monthly reported consumption. *(See table 5.)*

Prices

The average 1993 Metals Week Dealer (MWD) price of concentrate (per kilogram of contained molybdenum) was $3.752. The average MWD price of oxide was $5.130 and the average MWD price of ferromolybdenum was $7.092.

Foreign Trade

Exports of molybdenum in concentrate and of oxide decreased about 15% when compared with those of 1992. Molybdenum concentrate exports were about 67% of domestic mine production. Approximately 97% of reported shipments of concentrate and oxides were made to Belgium, Chile, France, Germany, Japan, the Netherlands, Sweden, and the United Kingdom. The calculated molybdenum content of all exports was about 31,000 tons in 1993. Total value of exports decreased from $165 million in 1992 to $108 million in 1993.

Approximately 7,200 tons of molybdenum in various forms was imported into the United States, about 4,200 tons more than that in 1992. Total value of all forms of molybdenum imported increased from $27 million in 1992 to $48 million in 1993. In terms of both value and quantity, the major form imported was ore and concentrates. *(See tables 6, 7, 8, and 9.)*

World Review

Capacity.—The rated capacity for mines and mills as of December 31, 1993, was 125,000 tons per year of contained metal. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Mine capacity for molybdenum is based on published reports, production statistics, and estimates.

Reserves.—The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification For Minerals," which is reprinted in the U.S. Bureau of Mines Mineral Commodity Summaries, 1991.

Estimated world reserves and reserve base of molybdenum appear in table 10. The United States, with a reserve base of molybdenum estimated at 11.8 million tons, has 45% of the world molybdenum reserve base. About 90% of U.S. reserves occur in large porphyry or disseminated deposits mined, or anticipated to be mined, primarily for molybdenum. These deposits are in Alaska, Colorado, Idaho, Nevada, New Mexico, and Utah. Other molybdenum sources contribute insignificantly to U.S. reserves.

Canadian reserves of primary molybdenum are in British Columbia, including 30% of the total in the Endako primary deposit. Other Canadian reserves are associated with molybdenum and copper-molybdenum porphyry deposits in British Columbia and in relatively minor sources in Quebec and New Brunswick.

Molybdenum reserves in Central and South America are mainly in large copper porphyry deposits. Of several such deposits in Chile, the Chuquicamata and El Teniente deposits are among the world's largest and account for 85% of total molybdenum reserves in Chile. Mexico and Peru have substantial reserves. The La Caridad deposit in Mexico is a large producer. Numerous other copper porphyries that may contain recoverable quantities of molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in China and the former U.S.S.R. are estimated to be substantial, but definitive information about the current sources of supply or prospects for future development in the two countries is lacking. Copper ores are being investigated on the islands of New Guinea and Bougainville in the southwest Pacific, but it is not known whether these contain economically recoverable molybdenum.

OUTLOOK

The demand for molybdenum for alloy and stainless steel decreased in 1993 but is expected to remain level for the remainder of 1994 and into 1995. The demand for molybdenum for catalysts also will remain level during 1994, but will increase with the future increases in catalysts manufacturing capacity. The long-term demand depends on developments in the steel market and the ability to meet the needs of capital expenditures for environmental controls and to expand the manufacturing capacity.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Molybdenum. Ch. in Minerals Commodity Summaries, annual.
Molybdenum. Ch. in Minerals Yearbook, annual.
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Other Sources

American Bureau of Metal Statistics. Nonferrous Metal Data.
American Metal Market (daily paper).
Canadian Mining Journal (Canada). Annual reports of various companies.
Engineering and Mining Journal.
Metal Bulletin (London).
Metals Week.
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Mining Engineering.
Mining Journal (London).
Skillings' Mining Review.
The Northern Miner (Canada).

TABLE 1
SALIENT MOLYBDENUM STATISTICS

(Metric tons of contained molybdenum unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Concentrate:						
Production		63,105	61,611	53,364	49,725	36,803
Shipments		61,733	61,580	53,607	45,098	39,209
Value	thousands	$421,427	$346,262	$249,909	$189,895	$165,096
Reported consumption		41,877	35,455	32,998	[r]15,243	13,794
Imports for consumption		238	478	161	831	3,398
Stocks, Dec. 31: Mine and plant		6,969	7,672	5,291	11,905	10,762
Primary products:						
Production		27,985	28,764	33,714	26,009	22,703
Shipments		18,277	17,983	19,105	17,305	15,981
Stocks, Dec. 31:		6,675	[r]5,919	[r]9,422	[r]7,480	6,149
Reported consumption, by end use		17,204	18,060	16,901	[r]17,168	17,715
World: Mine production		[r]136,494	[r]127,028	[r]115,459	[r]107,610	[e]95,286

[e]Estimated. [r]Revised.

TABLE 2
PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM PRODUCTS IN THE UNITED STATES

(Metric tons of contained molybdenum)

	Metal powder		Other[1]		Total	
	1992	1993	1992	1993	1992[2]	1993
Received from other producers	233	—	2,953	4,321	3,186	4,321
Gross production during year	2,355	1,578	23,653	21,125	26,009	22,703
Molybdenum products used to make other products	391	286	11,738	10,428	12,129	10,714
Net production	1,964	1,292	11,916	10,697	[r]13,880	11,989
Shipments	572	419	16,734	15,562	17,305	15,981
Producer stocks, Dec. 31	143	101	7,336	6,048	[r]7,480	6,149

[r] Revised.

[1] Includes ferromolybdenum, molybdic oxides, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl.

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

TABLE 3
MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of contained molybdenum)

Country[2]	1989	1990	1991	1992	1993[e]
Armenia[3]	—	—	—	[e]1,000	500
Bulgaria[e]	190	[r]150	[r]120	[r]120	120
Canada	[r]14,073	[r]11,994	11,329	[r]9,405	10,098
Chile	16,550	13,830	14,434	14,840	15,400
China[e]	15,700	15,700	[r]13,200	16,000	16,000
Iran[e]	785	542	[r]395	[r]1,320	1,500
Kazakhstan[3]	—	—	—	[e]3,000	3,000
Korea, Republic of	132	103	144	[r]—	—
Mexico	4,189	[r] [e]2,000	1,716	[r]1,458	1,705
Mongolia[e]	[r]1,580	[r]1,578	[r]1,716	[r]1,522	1,500
Niger[e]	13	10	10	[r]—	—
Peru	3,177	[r]2,510	[r]3,031	[r]3,220	2,860
Russia[3]	—	—	—	[e]5,000	4,800
U.S.S.R.[e] [4]	17,000	17,000	16,000	—	—
United States	63,105	61,611	53,364	49,725	[5]36,803
Uzbekistan[3]	—	—	—	[e]1,000	1,000
Total	[r]136,494	[r]127,028	[r]115,459	[r]107,610	95,286

[e] Estimated. [r] Revised.

[1] Table includes data available through July 5, 1994.

[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] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[4] Dissolved in Dec. 1991.

[5] Reported figure.

TABLE 4
U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Hundred kilograms contained molybdenum)

End use	Molybdic oxides	Ferro-molybdenum[1]	Ammonium and sodium molybdate	Other[2]	Total[3]
1992					
Steel:					
Carbon	6,930	1,196	—	357	8,483
Stainless and heat resisting	31,029	2,091	—	684	33,805
Full alloy	23,361	9,633	—	58	[r]33,051
High-strength low-alloy	4,040	3,675	—	—	7,715
Tool	6,979	2,801	—	184	9,964
Cast irons	866	6,347	—	132	7,345
Superalloys	W	523	—	8,211	8,734
Alloys:					
Welding materials (structural and hard-facing)	—	[r]835	—	38	[r]873
Other alloys[4]	W	W	—	507	507
Mill products made from metal powder	—	—	—	24,578	24,578
Chemical and ceramic uses:					
Pigments	18	—	W	—	18
Catalysts	9,459	—	W	1,793	11,252
Other	W	W	W	2,715	2,715
Miscellaneous and unspecified	8,769	871	[r]11,817	1,183	[r]22,640
Total[3]	91,450	27,972	[r]11,817	40,441	[r]171,681
1993					
Steel:					
Carbon	6,589	1,746	—	683	9,018
Stainless and heat resisting	28,364	2,096	—	576	31,036
Full alloy	23,773	11,170	—	131	35,074
High-strength low-alloy	4,513	3,463	—	—	7,976
Tool	5,969	W	—	82	6,051
Cast irons	830	7,391	—	146	8,367
Superalloys	W	W	—	8,885	8,885
Alloys:					
Welding materials (structural and hard-facing)	—	940	—	64	1,004
Other alloys[4]	W	W	—	552	552
Mill products made from metal powder	—	—	—	17,604	17,604
Chemical and ceramic uses:					
Pigments	W	—	W	—	W
Catalysts	16,495	—	W	1,793	18,288
Other	W	W	W	3,149	3,149
Miscellaneous and unspecified	10,828	4,151	14,202	966	30,147
Total[3]	97,361	30,956	14,202	34,631	177,150

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Miscellaneous and unspecified."

[1] Includes calcium molybdate.

[2] Includes purified molybdenum disulfide, molydenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

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

[4] Includes magnetic and nonferrous alloys.

TABLE 5
INDUSTRY STOCKS OF MOLYBDENUM MATERIALS, DECEMBER 31

(Metric tons of contained molybdenum)

	1989	1990	1991	1992	1993
Concentrate: Mine and plant	6,969	7,672	5,291	11,905	10,762
Producers:					
Molybdic oxides[1]	W	W	W	W	W
Metal powder	124	254	138	143	W
Other[2]	6,551	[r]5,665	[r]9,284	7,336	6,149
Total[3]	6,675	[r]5,919	[r]9,422	7,480	6,149
Consumers:					
Molybdic oxides[1]	1,624	1,559	1,570	1,487	1,434
Ferromolybdenum[4]	235	219	220	195	235
Ammonium and sodium molybdate	19	24	28	[r]28	32
Other[5]	703	786	771	791	815
Total	2,581	2,588	[r]2,589	[r]2,501	2,516
Grand total[3]	16,225	16,179	17,302	[r]21,885	19,427

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Producers: Other."

[1] Includes technical and purified molybdic oxide and briquets.

[2] Includes ferromolybdenum, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, sodium molybdate, calcium molybdate, molybdenum metal, pellets, molybdenum pentachloride, and molybdenum hexacarbonyl.

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

[4] Includes calcium molybdate.

[5] Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

TABLE 6
U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES (INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

Country	1992		1993	
	Quantity (contained molybdenum) (metric tons)	Value (thousands)	Quantity (contained molybdenum) (metric tons)	Value (thousands)
Australia	197	$43	61	$284
Belgium	6,188	23,563	6,927	6,623
Brazil	242	892	218	816
Canada	430	948	403	1,787
Chile	2,457	6,840	2,958	8,244
China	1	33	—	—
France	1,188	5,110	294	1,028
Germany	722	1,956	1,498	5,039
India	49	204	2	54
Japan	4,438	13,299	4,031	12,953
Mexico	61	126	12	112
Netherlands	13,722	48,895	9,994	28,236
Sweden	2,252	9,285	874	2,540
United Kingdom	1,435	5,937	976	5,580
Other	57	8,274	32	929
Total	[r]33,439	125,405	28,280	74,225

[r] Revised.

Source: Bureau of the Census.

TABLE 7
U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

Product and country	HTS No.	1992 Quantity (metric tons)	1992 Value (thousands)	1993 Quantity (metric tons)	1993 Value (thousands)
Oxides and hydroxides, gross weight:	2825.70.0000				
Belgium		6	$34	154	$720
Canada		249	1,378	199	1,328
Japan		186	1,102	525	2,854
Korea, Republic of		10	34	17	77
Netherlands		33	129	77	353
United Kingdom		—	—	47	155
Venezuela		—	—	23	124
Other		71	212	—	—
Total[1]		^{r}557	^{r}2,890	1,042	5,611
Molybdates—all, contained weight:	2841.70.0000				
Canada		^{r}530	2,497	525	2,464
Japan		279	1,321	152	726
Korea, Republic of		^{r}59	^{r}341	110	512
Mexico		75	^{r}345	73	315
Taiwan		^{r}22	95	38	176
Other		^{r}63	376	60	590
Total[1]		1,030	4,976	958	4,783
Ferromolybdenum, contained weight:[2]	7202.70.0000				
Canada		85	954	60	593
Japan		101	1,937	41	616
Malaysia		65	951	76	1,117
Mexico		20	156	20	239
Singapore		3	30	16	232
Venezuela		19	176	3	32
Other		27	200	7	129
Total[1]		^{r}320	^{r}4,404	224	2,958
Powder, gross weight:	8102.10.0000				
Belgium		1	39	1	5
Brazil		4	162	8	118
Canada		4	110	5	189
France		14	203	4	145
Germany		18	331	5	249
India		23	364	15	247
Italy		2	48	1	51
Japan		28	1,068	11	324
Mexico		6	133	16	399
Netherlands		137	1,041	1	32
Sweden		10	150	18	286
Taiwan		88	1,663	72	1,347
United Kingdom		10	246	45	210
Other		8	253	24	589
Total[1]		350	5,811	226	4,191
Molybdenum unwrought, gross weight:	8102.91.0000				
Canada		3	67	7	87
France		3	67	8	163

See footnotes at end of table.

TABLE 7—Continued
U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

Product and country	HTS No.	1992 Quantity (metric tons)	1992 Value (thousands)	1993 Quantity (metric tons)	1993 Value (thousands)
Molybdenum unwrought, gross weight—Continued:	8102.91.0000				
India		4	$55	3	$56
Japan		21	224	1	12
Netherlands		41	188	25	423
Other		2	[r]40	8	60
Total[1]		74	640	52	801
Molybdenum wrought, gross weight:	8102.92.0000				
Canada		7	293	7	393
France		24	1,170	23	975
Germany		10	677	6	483
Japan		39	1,379	14	1,275
United Kingdom		44	1,414	31	1,062
Other		[r]20	[r]841	12	603
Total[1]		144	5,772	93	4,791
Wire, gross weight:	8102.93.0000				
Belgium		62	1,865	(3)	52
Brazil		30	1,004	23	947
Canada		10	335	4	175
France		23	1,025	16	605
Germany		90	2,408	60	1,986
India		22	956	14	720
Italy		13	489	14	526
Japan		40	1,576	37	1,512
Korea, Republic of		18	846	16	736
Mexico		12	432	10	519
Spain		5	163	3	109
Sweden		5	217	2	111
Taiwan		5	214	4	235
United Kingdom		2	132	4	168
Other		[r]19	[r]3,310	53	1,865
Total[1]		[r]356	14,972	260	10,266

[r] Revised.

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

[2] Ferromolybdenum contains about 60% to 65% molybdenum.

[3] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

Item	HTS No.	1992			1993		
		Gross weight (metric tons)	Contained molybdenum	Value (thousands)	Gross weight (metric tons)	Contained molybdenum	Value (thousands)
Molybdenum ore and concentrates, roasted	2613.10.0000	1,022	585	$2,884	5,796	3,373	$16,804
Molybdenum ore and concentrates, other	2613.90.0000	403	246	1,197	41	25	172
Molybdenum oxides and hydroxides	2825.70.0000	1,032	NA	3,928	622	NA	2,875
Molydates of ammonium	2841.70.0000	154	86	757	538	300	2,606
Molybdates—all others	2841.70.5000	(1)	(1)	6	19	17	28
Molybdenum orange	3206.20.0000	894	NA	2,566	680	NA	2,041
Mixtures of inorganic compounds	3823.90.3400	5	2	104	19	(1)	154
Ferromolybdenum	7202.70.0000	1,722	1,096	6,974	3,480	2,190	12,725
Molybdenum powders	8102.10.0000	68	52	1,784	66	52	2,086
Molybdenum unwrought	8102.91.1000	71	46	1,437	164	136	1,753
Molybdenum waste and scrap	8102.91.5000	128	125	1,000	380	363	2,595
Molybdenum wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	46	NA	3,004	49	NA	3,426
Molybdenum wire	8102.93.0000	1	NA	177	3	NA	308
Molybdenum other	8102.99.0000	2	NA	800	1	NA	759
Total[2]		5,548	2,238	26,618	11,856	6,457	48,332

NA Not available.

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9

HARMONIZED TARIFF SYSTEM ON U.S. MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	General most favored nation	Rates of duty during 1993	
					Special[1]	Non-most favored nation
Molybdenum ore and concentrates:						
Import	2613.10.0000	Molybdenum ore and concentrates, roasted	Contained	13.2 cents/kg on molybdenum content + 1.9% ad valorem	Free (E,IL,J) 7.9 cents kg on molybdenum content + 1.1% ad valorem (CA)	$1.10/kg on molybdenum content + 15% ad valorem.
Export	2613.10.0000	do.	do.	—	—	—
Import	2613.90.0000	Molybdenum ore and concentrates, other	do.	19.8 cents/kg on molybdenum content	Free (E,IL,J) 3.9 cents/kg on molybdenum content (CA)	77.2 cents/kg on molybdenum content.
Export	2613.90.0000	do.	do.	—	—	—
Molybdenum chemicals:						
Import	2825.70.0000	Molybdenum oxides and hydroxides	Gross	3.2% ad valorem	Free (A, E, IL, J) 0.6% (CA)	20.5% ad valorem.
Export	2825.70.0000	do.	do.	—	—	—
Export	2841.70.0000	Molybdates—all	Contained	—	—	—
Import	2841.70.1000	Molybdates of ammonium	do.	4.3% ad valorem	Free (A, E, IL, J) 0.8% (CA)	29% ad valorem.
Import	2841.70.5000	Molybdates—all others	do.	3.7% ad valorem	Free (A, E, IL, J) 0.7% (CA)	25% ad valorem.
Export	3206.20.0000	Pigments based on chromium (molybdenum orange, etc.)	Gross	—	—	—
Import	3206.20.0020	Molybdenum orange	do.	3.7% ad valorem	Free (A, E, IL, J) 0.7% (CA)	25% ad valorem.
Export	3823.30.0000	Nonagglomerated metal binders, molybdenum, etc.	do.	—	—	—
Import	3823.90.3400	Mix of two or more inorganic compounds of molybdenum	Contained	2.8% ad valorem	Free (A, E, IL, J) 0.5% (CA)	18% ad valorem.
Ferroalloys:						
Export	7202.70.0000	Ferromolybdenum	do.	—	—	—
Import	7202.70.0000	do.	do.	4.5% ad valorem	Free (E, IL, J) 0.9% (CA)	31.5% ad valorem.
Import	8102.10.0000	Powders	do.	13.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E, IL, J) 2.7 cents kg on molybdenum content 0.3% (CA)	$1.10/kg on molybdenum content + 15% ad valorem.
Export	8102.10.0000	do.	Gross	—	—	—
Export	8102.91.0000	Unwrought, waste and scrap	do.	—	—	—
Import	8102.91.1000	Unwrought	Contained	13.9 cents/kg on molybdenum content + 1.9% ad valorem	Free (E, IL, J) 2.7 cents kg on molybdenum content 0.3% (CA)	$1.10/kg on molybdenum content + 15% ad valorem.
Import	8102.91.5000	Waste and scrap	do.	Free	—	Free.

See footnotes at end of table.

TABLE 9—Continued

HARMONIZED TARIFF SYSTEM ON U.S. MOLYBDENUM IN THE UNITED STATES

Type trade	HTS No.	Commodity description	Quantity (kilograms)	General most favored nation	Rates of duty during 1993 Special[1]	Rates of duty during 1993 Non-most favored nation
Ferroalloys—Continued:						
Import	8102.92.0000	Wrought	Gross	6.6% ad valorem	Free (A, E, IL, J) 1.3% (CA)	60% ad valorem.
Export	8102.92.0000	do.	do.	—	—	—
Import	8102.93.0000	Wire	do.	6.6% ad valorem	Free (A, E, IL, J) 1.3% (CA)	60% ad valorem.
Export	8102.93.0000	do.	do.	—	—	—
Import	8102.99.0000	Other	do.	5.5% ad valorem	Free (A, E, IL, J) 1.1% (CA)	45% ad valorem.
Export	8102.99.0000	do.	do.	—	—	—

[1] Symbols for programs are as follows: A Generalized System of Preferences; CA United States-Canada Free-Trade Agreement; E Caribbean Basin Economic Recovery Act; IL United States-Israel Free Trade Area, J Andean Trade Preference Act.

Source: U.S. International Trade Commission.

TABLE 10

MOLYBDENUM RESERVES AND RESERVE BASE[p]

(Thousand metric tons of contained molybdenum)

	Reserves	Reserve base
North America:		
Canada	450	910
Mexico	90	230
United States	2,720	5,350
Other	—	90
South America:		
Chile	1,130	2,450
Peru	140	230
Other	—	90
Europe:		
Bulgaria	(1)	10
U.S.S.R.[2]	450	680
Other	—	270
Asia:		
China	500	1,220
Iran	50	140
Other	—	140
Total	5,530	11,810

[p] Preliminary.

[1] Less than 1/2 unit.

[2] Dissolved in Dec. 1991.

NICKEL

By Peter H. Kuck

Dr. Kuck has been a physical scientist with the U.S. Bureau of Mines since 1979 and was previously responsible for iron ore, silicon, and vanadium. Domestic survey data were prepared by Barbara J. McNair, Ferrous Data Section. International data tables were prepared by Ivette E. Torres, Chief, Jeremy Tidwell, and Ronald L. Hatch, Section of International Data.

Nickel is vital to the stainless steel industry and has played a key role since the beginning of the 20th century in the development of the chemical and aerospace industries. The element (symbolized by Ni) is critical in a highly industrialized and technological society because of its myriad of applications. Nickel's greatest value is as an alloying agent with other metallic elements, adding strength and corrosion resistance over a wide range of temperatures.

Demand for nickel in the Western World recovered substantially in 1993 despite lingering recessionary forces in Japan, the United States, and Western Europe. Total demand for primary nickel in the West was about 685,000 metric tons—an all-time high, breaking the previous record of 673,000 tons set in 1990.[1] Much of the recovery was being driven by growing production and consumption of nickel-bearing stainless steel in the newly industrialized countries of Asia. Brazil and the Republic of South Africa also have become important producers of stainless steel since 1984.

Although nickel demand was strong in the West, world prices remained weak because of global oversupply and plummeting consumption in the Russian Federation. Because of the economic turmoil in Russia and the country's need for hard currencies to convert to a market economy, large tonnages of Russian nickel have been flooding Western markets since 1989. The bulk of the material is cathode produced from nickel-copper sulfide ores mined in the West Siberian Arctic or on the Kola Peninsula. The influx of Russian material accelerated in mid-1993, after slackening somewhat in 1992. This new surge of exports, coming on the back of a global recession, caused the London Metal Exchange (LME) cash price to drop below the $5,500-per-ton mark (about $2.50 per pound) in June 1993. At that point, North American producers began idling less profitable operations because of the poor price situation. Outokumpu Oy of Finland and Western Mining Corp., however, were more sanguine about the future of the nickel industry and proceeded to bring two new mines in Western Australia on-stream. On September 30, 1993, the LME cash price hit a 6-year low of $4,012 per ton ($1.820 per pound).

The nickel market improved considerably after September 1993, but prices continue to be kept in check by the large exports of Russian cathode and record-high stocks in the LME warehouse at Rotterdam. On December 31, 1993, the LME settlement price was still only $5,295 per ton ($2.402 per pound). At the end of 1993, recessionary forces in Japan and Western Europe began to weaken.

The United States produced 1.77 million metric tons of crude stainless steel in 1993, an amount slightly lower than that of 1992. Almost 67%, or 1.18 million tons, were nickel-bearing grades.[2] Production of austenitic stainless and other nickel-bearing grades was down 7% from the previous year, while ferritic production was up 9%. In contrast, U.S. imports of all grades of stainless steel jumped more than 50% between 1992 and 1993. Most of the increased tonnage came from Canada, Japan, Mexico, and Western Europe. Japan has been the largest stainless steel producer in the Western World for more than a decade. Japan produced 2.65 million tons of crude stainless in 1993, almost the same as in 1992.[3] Almost 71%, or 1.88 million tons, were hot-rolled, nickel-bearing grades.

Data reported to the U.S. Bureau of Mines (USBM) indicated that overall demand for nickel in the United States was little changed from that of 1992. Reported domestic consumption of nickel for all end uses was up about 4%.*(See table 1.)*

DOMESTIC DATA COVERAGE

The USBM tries to identify and canvass every nickel consumer who uses 2 tons or more per year. Most of the larger companies report on a monthly basis. Reports were received from 55 of the 64 facilities on the 1993 monthly canvass. An additional 148 facilities were canvassed at the end of the year. Of the 148 facilities, 125 responded, or about 84% of the second canvass. Estimates for nonrespondents were made by comparing data reported in prior years with current consumption trends. Reported primary consumption, based on data from monthly and annual canvass forms and estimates, was 86% of apparent primary consumption. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Primary nickel is normally marketed as either nickel metal, nickel oxide sinter, or ferronickel (FeNi). Commercial nickel metal is more than 99.5% pure and may be in the form of square plates, powder, briquets, pellets, ingots, disks, or shot. The square plates are referred to as "cathode" because they are cut from an electrolytic cathode sheet at the end of the refining process. The ferronickel produced in the United States contains 48% to 52% Ni and was being sold as shot or in 28-pound ingots; material produced in other countries may contain anywhere from 19% to 55% Ni. Several customers prefer the shot over the ingot because the shot is more amenable to computerized, bulk loading systems than the ingot. Commercial grades of nickel oxide sinter typically contain either 77% or 85%+ Ni. Almost all of the 85%+ grade imported into the United States comes from the Yabulu refinery of the Queensland Nickel Joint Venture (QNJV) in Australia. In 1992, Queensland Nickel improved its extraction process and is now making a new high purity product that assays 99.5% Ni.

Industry Structure

At least 23 countries mined some type of nickel ore in 1993. All but three of the 23 also had active smelters and/or refineries. An additional six countries (Austria, metropolitan France, Japan, the Republic of Korea, Taiwan, and the United Kingdom) had smelters and/or refineries that were totally dependent on imported feed.

In almost every case, the nickel came from either a laterite deposit or a sulfide deposit. Most producing companies tend to favor one of the two deposit types at the expense of the other because of significant differences in how the ores are processed. Inco Ltd. is an exception owing to the global nature of its operations. Because laterites are formed by surface water percolating downward through ultramafic rock, most laterite deposits are either in the tropics or in subtropical-to-temperate coastal regions that have a long geologic history of heavy rainfall. Sulfide deposits, on the other hand, can occur almost anywhere, ranging from central Africa to the high Arctic.

The nickel in laterite ores is usually processed into ferronickel for two reasons. First, the ores have a high iron content. Second, the ores are more easily smelted than concentrated. Sulfide ores are more amenable to concentration and hydrometallurgical refining. During the 5-year period from 1989 through 1993, laterite operations accounted for about 37% of world mine production, with the balance coming from sulfide operations. The Norilsk Nickel Combine of Russia is currently the largest producing company in the world, followed by Inco Ltd. of Canada. For 1989 through 1993, the six largest producing countries and their share of world mine production were as follows: the Commonwealth of Independent States, 29%; Canada, 20%; New Caledonia, 11%; Indonesia, 7%; Australia, 7%; and Cuba, 4%.

The Sudbury district of Ontario continues to be one of the principal sources of nickel for the world. Falconbridge Ltd. and Inco operate most of the mines in the Sudbury Basin. The bulk of the nickel at Sudbury is tied up in iron sulfides, which are intergrown, in turn, with copper sulfides. Other important nickel mining regions are the Norilsk district of central Siberia, the western half of the Kola Peninsula, and the Kambalda district of Western Australia. Like Sudbury, all three have numerous deposits of sulfide ores averaging more than 2% Ni and 1% copper (Cu).

Cuba and New Caledonia have the largest reserves of laterite. Laterites also are currently mined in Australia, Brazil, Colombia, the Dominican Republic, Greece, Indonesia, Macedonia, the Philippines, Russia, and Ukraine. The only U.S. producer in recent years has been the Glenbrook Nickel Co., which was forced to idle its laterite mine and ferronickel smelter at Riddle, OR, in August 1993. Some nickel is also produced in the United States as a byproduct of copper refining and recycling.

Geology-Resources

Nickel laterites are formed by the weathering of ultramafic rocks. As the rocks weather, nickel, iron, and sometimes cobalt, are taken into solution by descending meteoric water and redeposited at greater depth, producing a zone of enrichment. The water is initially acidic because of the presence of organic acids and dissolved carbon dioxide. As the metal-bearing water descends, it reacts with the bedrock and becomes more basic. The cobalt and iron tend to precipitate out first, forming a limonite zone that averages 0.8% to 1.5% Ni and is rich in nickeliferous goethite [(Fe,Ni)OOH]. Further down, a point is reached where the bulk of the nickel precipitates out, together with the accompanying magnesium and silica. This second zone of enrichment typically contains 1.8% to 3.5% Ni. Here, the principal ore mineral is garnierite [$(Mg>>Fe,Ni)_3Si_2O_5(OH)_4$].

Nickel sulfide deposits, on the other hand, are formed by some type of igneous or metamorphic activity, such as the intrusion of molten ultramafic rock or the alteration of the host rock by hydrothermal solutions. The principal ore minerals are pentlandite [$(Fe,Ni)_9S_8$] and nickeliferous pyrrhotite ($Fe_{1-x}S$). Millerite (NiS) is regarded as a secondary, supergene mineral at Sudbury, but also can occur as a primary mineral in some lower temperature types of deposits. Heazlewoodite (Ni_3S_2), niccolite/nickeline (NiAs), and the various linnaeite end members [$(Fe,Co,Ni)_3S_4$] are normally present in only minor amounts. At Sudbury, pentlandite and pyrrhotite are frequently associated with chalcopyrite ($CuFeS_2$) and, to a lesser degree, cubanite ($CuFe_2S_3$). As a result, copper is an important byproduct for both Falconbridge and Inco. Cobalt and platinum-group metals also are being recovered from the sulfide concentrate.

Recycling

The International Metals Reclamation Co., Inc. (INMETCO), a subsidiary of Inco United States Inc., has been operating a recycling plant for chromium and nickel at Ellwood City, PA, since 1978. Baghouse dust, mill scale, grinding swarf, and other particulate waste from stainless steel plants are blended, pelletized, mixed with a reductant, reduced in a rotary hearth furnace, and then smelted in an electric furnace. The nickel and chromium are recovered as a remelt alloy and sold back to the stainless producers.

The Pennsylvania plant was modified several years ago so that a wider variety of waste materials could be treated. INMETCO now accepts spent pickling solutions, pickling and wastewater treatment filter cakes, and chromium-bearing refractories. Spent nickel-cadmium (Ni-Cd) batteries are also processed on-site. Up until 1994, the cadmium had been recovered as a dust and sent for further treatment across the State to the zinc recycling plant operated by Horsehead Resource Development Co., Inc. at Palmerton, PA. In 1994, INMETCO began construction of its own cadmium recovery circuit and expects the facility to be operational by mid-1995.

A completely different type of plant is operated by the U.S. Filter Recovery Services, Inc. at Roseville, MN. The Minnesota plant uses a variety of hydrometallurgical and electrowinning processes to recover nickel, cadmium, and copper from scrap and ion exchange resins.

Economic Factors

Prices.—Nickel prices traditionally have been quite volatile. The time-price relationship for the metal over a 150-year span is given in the metal prices handbook published by the USBM in 1993.[4] The annual LME price has been extremely volatile since 1985, skyrocketing to $6.250 per pound in 1988 when demand for stainless was strong, and then collapsing to $2.401 in 1993 after large amounts of Russian cathode began appearing in Western warehouses. *(See figure 1.)*

Costs.—Several significant factors determine the cost of producing nickel. They include the type and nickel content of the ore, the mining method, transportation, infrastructure, energy prices, labor and materials, regulatory compliance, and credits from recoverable byproducts.

Generally, nickel can be recovered from sulfide ores at a lower cost than from laterite ores because sulfides are more readily concentrated using established mineral dressing methods. On the other hand, virtually all of the laterite deposits are open pit operations and, therefore, less costly to mine. Most sulfide deposits occur at considerable depth and have to be mined from underground drifts. Shaft sinking, timbering, roof bolting, lighting, ventilation, and pumping all drive up costs.

Exploration and initial development costs for the two types of deposits are also quite different. Exploring and drilling for sulfides is much more expensive than for laterites. Subsurface samples can be obtained from most laterite deposits using an auger because the rock formations are extensively weathered. Sulfide deposits occur in much harder rock and must be diamond- or rotary-drilled, a more costly and time consuming operation.

Sulfide deposits are also harder to locate, driving up drilling costs even more. The sparsity of massive, primary sulfide deposits at the surface is understandable. Many sulfide minerals readily oxidize to sulfates when exposed to air for an extended period of time. Sulfuric acid forms when copious amounts of water are present, accelerating the oxidation process. Discovery of a near-surface nickel sulfide deposit can be difficult because a subeconomic laterite deposit can be mistaken for the leached and heavily oxidized gossan capping a sulfide target. A limited outcrop of gossan created by the oxidation of sulfides can be easily mistaken for other types of gossan, and vice versa. The presence of a gossan does not necessarily mean unaltered sulfides exist at depth. Even if the gossan is correctly identified, it may only overlie a much poorer fringe of the ore body.

Energy consumption is the most significant cost in recovering nickel from laterite ores. Estimates indicate that for every $1 increase in the price of a barrel of crude oil, there is a corresponding increase of $0.05 per pound of nickel produced at operations that are dependent on oil for both drying and smelting. It does not seem to matter much whether the laterite ore is converted to ferronickel or to matte. Sulfide ores, on the other hand, do not have to be dried, and, unlike laterite ores, are more amenable to concentration.

Byproduct revenues can significantly reduce net production costs. Smelters that convert laterite ores to ferronickel produce only slag, iron, and occasionally electrical power as byproducts. The few plants that chemically leach laterite ores typically recover significant amounts of cobalt along with the nickel. In contrast, sulfide operations generate revenues not only from the recovery of byproduct cobalt, but also copper and precious metals. The Sudbury nickel deposits are an important source of both platinum and palladium. The principal platinum mineral is sperrylite, $PtAs_2$, while much of the palladium is tied up in bismuthides and bismuth tellurides. Some sulfide facilities also profit from the sale of byproduct liquid sulfur dioxide and sulfuric acid.

The costs of complying with air pollution control regulations can be significant. Dust generated in the processing of laterite ores can be controlled using relatively inexpensive equipment. In contrast, a large capital investment is required to reduce sulfur dioxide emissions from a smelter processing nickel-copper sulfide concentrates. Nickel smelters have a much higher sulfur burden than their copper and zinc counterparts. As a rule of thumb, 1 ton of sulfur is generated for each ton of copper produced. In contrast, 8 tons of sulfur is generated for each ton of nickel. During the past 10 years, Inco has allocated 12% of its total capital expenditures to attain compliance with Canadian regulations limiting sulfur dioxide emissions.

Operating Factors

Environmental Issues.—The principal environmental problem associated with nickel production is the emission of sulfur dioxide (SO_2) from smelters that process sulfide ores. The SO_2 emitted from smelter smokestacks combines with water in the atmosphere to form droplets of sulfuric acid (H_2SO_4), a major component of acid rain. In 1985, the Provincial Government of Ontario ordered Inco to reduce SO_2 emissions at its Sudbury complex from 685,000 tons per year to no more than 265,000 tons per year. Since then, the company has spent $530 million on state-of-the-art pollution control equipment to meet the new limit. The sulfur dioxide abatement project was completed in late 1993, in time to meet the Provincial Government's deadline of January 1, 1994. Inco now captures more than 90% of the sulfur in its Sudbury ores. *(See Canada section of this report.)*

The Provincial Government gave Falconbridge a similar ultimatum. Falconbridge had to reduce its SO_2 emissions from 154,000 tons per year to 100,000 tons per year by 1994. Like Inco, the company spent millions of dollars complying with the Provincial order. In 1993, Falconbridge succeeded in lowering its emission rate to 57,000 tons per year.

Recent environmental legislation and other responses to environmental concerns are expected to significantly affect future nickel consumption. In some cases, the effect will be positive; in others, negative.

In November 1990, the Congress amended the Clean Air Act (CAA), updating Federal air pollution standards for the first time since 1977 and completely overhauling the hazardous air pollutants program. The amendments (Public Law 101-549), among other things, put controls on airborne emissions of nickel metal, its compounds, and alloys. Nickel compounds were specifically included in the new list of 189 hazardous air pollutants to be regulated.

The law also directed the U.S. Environmental Protection Agency (EPA) to develop an initial list of pollution source categories that warranted regulation. Because of the magnitude and complexity of the problem, it took EPA more than 2 years to develop the list and reply to the 140 comments received from public and private interests. The list was finally published in the Federal Register on July 16, 1992.[5] A number of nickel consumers appeared on the July list, including integrated steel mills, electric arc furnace operations, iron and steel foundries, and ferroalloy production facilities. A draft schedule for promulgating emission standards for each of the initial 174 source categories was published in the Federal Register on September 24, 1992, as part of the 10-year phase-in of CAA regulations.

Because many facilities will need new pollution control equipment to comply with these standards, the enactment of the Clean Air Act Amendments is expected to increase demand for stainless steel and other alloys of nickel. Under the new law, 111 fossil fuel-fired powerplants must reduce their SO_2 emissions by 1995. This particular section of the law was enacted to help control acid rain. The 111 plants—a total of 251 generating units—were specifically targeted because each emits more than 2.5 pounds of SO_2 per million British thermal units. Some plants will be able to reduce SO_2 emissions by simply switching to fuels that contain lower levels of sulfur; others, though, will be forced to install scrubbers (flue gas desulfurization units).

Because it is far cheaper and easier to include scrubbers in the design of a new powerplant than to retrofit an existing facility, most plants in the near-future will be equipped with some type of scrubbing system. Roughly 100 tons of corrosion-resistant alloy will be required for each scrubber. Although it is not clear which alloy will be used, many of the more promising candidates contain significant amounts of nickel, which improves the resistance of the alloy to corrosion and heat. A significant amount of stainless will also go into turbines for the new powerplants.

Toxicity.—Zero exposure to nickel is impossible and undesirable. Studies have shown that nickel is an essential element in a variety of cellular organisms, animals, and plants.[6] Nickel may also be an essential element for humans, but more research is needed on the subject. Some non-prescription multivitamins contain as much as 5 micrograms of nickel per tablet. Studies to date indicate that inhalation is the most important route of nickel intake in the workplace. Dermal exposure and ingestion are also important, but of lesser concern.

The American Conference of Governmental Industrial Hygienists (ACGIH) postponed action until 1995 on a proposal to set more stringent workplace limits for nickel and its compounds. The ACGIH had proposed reducing its recommended workplace limits, or threshold limit values (TLV's), for nickel metal and all nickel compounds to 0.05 milligrams per cubic meter (mg/m^3) of air . The proposal also called for nickel metal and all inorganic nickel compounds to be designated "confirmed human carcinogens." The Nickel Producers Environmental Research Association (NiPERA), among others, had urged the ACGIH not to reduce the existing TLV's until new evidence, now being gathered, could be properly evaluated. The 8-hour TLV is currently set at 1.0 mg/m^3 for insoluble forms of nickel (e.g., NiO) and 0.1 mg/m^3 for water-soluble forms of nickel (e.g., $NiSO_4$). ACGIH guidelines are important because the U.S. Occupational Safety and Health Administration (OSHA) and regulatory agencies in other countries weigh them carefully in determining mandatory permissible exposure limits for the workplace.

OSHA has specified eight-hour Time Weighted Average Permissible Exposure Limits (PELs) for more than 400 substances, including nickel and its compounds. In March 1993, after almost 4 years of litigation that involved reviews by both the U.S. Eleventh Circuit Court of Appeals and the U.S. Supreme Court, the PEL for water-soluble nickel compounds was set at 1.0 mg Ni/m^3. Nickel metal and insoluble nickel compounds also have a PEL of 1.0 mg Ni/m^3. Nickel carbonyl was singled out because of its extreme toxicity and has a

PEL of only 0.007 mg Ni/m^3.

In 1991, the United Nations published indepth environmental health criteria for nickel, together with a companion health and safety guide on nickel metal, nickel carbonyl, and selected nickel compounds.[7] The 383-page report was prepared as part of the International Program on Chemical Safety (IPCS). The principal conclusions are summarized below:

> "Although some, and perhaps all, forms of nickel may be carcinogenic, there is little or no detectable risk in most sectors of the nickel industry at current exposure levels; this includes some processes that were associated, in the past, with very high lung and nasal cancer risks. Long-term exposure to soluble nickel at concentrations of the order of 1 mg/m^3 may cause a marked increase in the relative risk of lung cancer, but the relative risk among workers exposed to average metallic nickel levels of about 0.5 mg/m^3 is approximately 1...."

In May 1994, NiPERA and the Nickel Development Institute (NiDI) published their own health guide, entitled "Safe Use of Nickel in the Workplace."[8] The 65-page report was written primarily for plant managers and individuals in the medical community who are responsible for the health and safety of personnel exposed routinely in the workplace to nickel or nickel-containing substances. A variety of topics are covered, including pharmacokinetics, toxicity, biological monitoring, air monitoring, and control measures that can be taken to prevent overexposure. The guide also compares occupational exposure limits established by the United States with those of Canada, Germany, and the United Kingdom.

Energy Requirements.—As mentioned earlier, energy costs are much more critical for laterite operations than for sulfide operations. Laterite ores are typically smelted in direct-arc furnaces having power ratings on the order of 20 to 40 megawatts (MW). Glenbrook Nickel, for example, has four 24-MW furnaces. Power is provided by the Bonneville Power Administration, a hydroelectric-based utility.

Glenbrook has been smelting the laterite by the Ugine Process. The process is not only power intensive, but also requires the addition of ferrosilicon—a source of chemical energy. This chemical energy is transferred to the molten ferronickel when the ferrosilicon is converted to slag.

The ferrosilicon can be produced onsite in a similar submerged arc furnace by reacting lumps of quartzite with shredded steel scrap and a carbon-rich reductant, such as coke. Electrical power consumption is the principal cost in producing ferrosilicon. Ferrosilicon and silicon metal are the most power intensive of the bulk ferroalloys, requiring 8,500 to 14,000 kilowatt hours of electrical energy per ton of contained silicon.

ANNUAL REVIEW

Legislation and Government Programs

On March 24, 1993, the Defense Logistics Agency (DLA) began selling nickel from the National Defense Stockpile (NDS). The Government had 33,760 tons of nickel in inventory when the sales started. The bulk of the material was purchased during the Korean War or the 5-year period immediately following the war. All 33,760 tons was cathode except for 399 tons contained in 520 tons of oxide of Cuban origin. The cathode sheets ranged in size from 30 by 64 centimeters to 64 by 91 centimeters. The fine-grained oxide powder averaged about 76% Ni with less than 0.74% cobalt and 0.21% iron. Until the end of 1992, the Federal Government had a stockpile goal of 181,437 tons.

Legislation supporting the disposal was signed into law by the President on October 23, 1992. (Title XXXIII of Public Law 102-484: The Defense Authorization Act of 1992). The current annual materials plan allows the Defense National Stockpile Center (DNSC) to continue selling a maximum of 9,072 tons per year (10,000 short tons) of nickel through September 30, 1995. When the disposal program was presented for comment at the beginning of 1993, several nickel producers were concerned that the long-term selloff would unduly disrupt an already weakened North American market. A twice-monthly auction schedule was adopted to ease their concerns, with only about 270 tons (300 short tons) being offered at each auction. Sealed bids were being solicited on the second and fourth Thursdays of each month. The auctions are scheduled to run for at least 4 more years. All of the nickel is being sold on an as-is basis.

The DNSC sold 2,209 tons of cathode in 1993, leaving a total of 31,551 tons of nickel in inventory at yearend. An additional 4,325 tons of cathode was auctioned off during the first 9 months of 1994.

On February 8, 1994, the U.S. Department of the Treasury lifted all restrictions on the importation of unfabricated nickel and nickel-bearing materials from the former Union of Soviet Socialist Republics. The restrictions had been in effect since 1983 to prevent Cuban nickel from reaching the United States in violation of the U.S. embargo on trade with the island republic. A complete ban was originally imposed on November 23, 1983, after the U.S. Government received information indicating that nickel feedstocks of Cuban origin were being processed in the Urals together with local material and later exported as Russian metal. Enforcement of the 1983 ban was tempered in 1990 following an exchange of letters between the U.S. and Soviet Governments.

The Treasury action also terminated administrative procedures established in 1990 that permitted some nickel refined at Norilsk and Monchegorsk to enter the United States. Under the terms of the 1990 agreement, the nickel had to be produced solely from Russian ores. In addition, each shipment had to be accompanied by a special certificate of origin issued by VVO Raznoimport, the former Soviet state trading organization.[9] Importation of Cuban nickel into the United States is still prohibited under the Cuban Assets Control Regulations, 31

CFR part 515. *(See Issues section of this report.)*

For the first time, the U.S. Mint began using small quantities of recycled nickel that had been toll processed in Russia. In November 1993, the Mint bought 36 tons of the recycled metal from Sovereign Recycling International, Inc. of Bettendorf, IA, for about $167,000. The material was recovered from superalloy scrap exported from the United States earlier in the year. The scrap was shipped from Norfolk, VA, through Murmansk to the Severonikel Refinery at Monchegorsk.

Strategic Considerations

Nickel is an essential ingredient in austenitic stainless steel and superalloys. As such, its availability is important to the national security. Domestic mine capacity was less than 13% of primary apparent consumption in 1993. Canada, however, a close ally and a geographically secure source, is capable of supplying U.S. needs under normal circumstances.

Issues

The U.S. Department of the Treasury continued to ban the importation of nickel and nickel-containing materials from Cuba. The ban has been in effect since 1962. In the past, more than two-thirds of the mixed nickel-cobalt oxide sinter from the Nicaro and Punta Gorda plants was exported to Europe. The mixed nickel-cobalt sulfide precipitate from the Pedro Sotto Alta smelter at Moa was shipped directly to refineries in the Ural Mountains of the former U.S.S.R.

Since 1991, however, a significant amount of Cuban material has been going to Sherritt's refinery in Alberta, Canada. Canadian import statistics show that Sherritt received 22,366 tons (gross weight) of nickel oxide sinter from Cuba in 1993, significantly more than the 19,957 tons shipped in 1992. In recent months, the Government of Cuba has strengthened its ties with Sherritt and agreed in principle to form a joint venture with the Canadian producer. *(See Cuba section of this report.)*

In June 1993, the Government of Cuba indicated that it might consider compensating the former owners of the nickel mines and plants that were nationalized in October 1960. The Cuban proposal, if followed up, would remove a major stumbling block to improving United States-Cuban relations. The original nickel plant at Nicaro was built by the United States Government in 1943 to obtain nickel oxide for the war against Germany and Japan. The plant was upgraded by the General Services Administration in 1951-52 as part of the Korean War effort. The plant built at Moa Bay by the Freeport Nickel Co. between 1957 and 1959 also was partly financed by the U.S. Government.

Production

Glenbrook Nickel Co., the only domestic nickel producer, halted mining and smelting operations at its Riddle, OR, complex because of low nickel prices and higher operating costs. On August 10, 1993, Glenbrook shut down both its Riddle smelter and Coos Bay port facility for an indefinite period. The action was taken primarily in response to weakening ferronickel prices and large exports of cathode from Russia to the West. However, the sharp rate increase proposed by the Bonneville Power Administration also influenced the company's decision. The proposed power rate increase would have significantly raised Glenbrook's production costs. The company was hurt further by a U.S. International Trade Commission antidumping ruling in March 1993 that made the importation of ferrosilicon more expensive.

In 1992, Glenbrook upgraded the capacity of the Riddle smelter from 11,000 tons per year of contained Ni in FeNi to 16,300 tons per year. The additional feed requirements were met by importing garnierite ore averaging 2.2% to 2.4% Ni from New Caledonia. The ore was being supplied by Société Minière du Sud Pacifique, which has mines on the main island at Ouaco, Nakety, and Boakaine. Feasibility studies had shown that it was cheaper to buy and ship ore from New Caledonia than to expand the mine on Nickel Mountain. The ore from Nickel Mountain had been averaging only 1.18% Ni. A little-used dock area at Coos Bay was purchased and rehabilitated to receive and temporarily store the imported laterite before trucking it to Riddle. Ore handling facilities, a crushing plant, and a dryer were constructed at dockside to remove the bulk of the water in the crude ore prior to transshipment.

In 1993, Glenbrook mined only 187,000 tons (dry basis) of usable ore containing 2,464 tons of Ni. The ore received from New Caledonia contained an additional 2,966 tons of Ni. From the two feedstocks, the company was able to produce 4,878 tons of Ni contained in ferronickel.[10] Because new shot casting equipment was purchased when the smelter was upgraded, Glenbrook can now make 6-millimeter (1/4-inch) shot in addition to the 28-pound ingots already being produced.

More than 250 employees were affected by the August 1993 shutdown. The company had been forced to take similar action only a few months earlier, idling operations from December 20, 1992, to February 22, 1993. At that time, the LME cash price ranged between $2.60 and $2.87 per pound. When Glenbrook resumed production in March, the price was still averaging about $2.70 per pound but was under intense pressure because of the global oversupply situation. By the end of June, the price had fallen below $2.50 and was rapidly collapsing. When Glenbrook shut down, it had sufficient stocks of ferronickel on hand to meet sales commitments for the remainder of 1993.

Consumption and Uses

Demand for primary nickel in the Western World recovered substantially in 1993 and was estimated to be about 685,000 tons—an all time high. The tonnage was about 2% more than the previous record of 673,000 tons set in 1990. U.S. apparent consumption of primary nickel was 122,000 tons, or about 18% of Western demand. U.S. industry consumed an additional 55,000 tons of nickel in scrap. Both U.S. and world demand continued to be driven by the stainless steel industry, which accounted for 44% of primary nickel demand in the United States and almost 60% of equivalent world demand. *(See tables 2 through 4 and figure 2.)*

Production of raw stainless and heat-resisting steel in the United States slipped slightly to 1.77 million metric tons and was 3% less than the corresponding figure for 1992.[11] Nickel-bearing grades accounted for 67% of the production tonnage. Net shipments of all types of stainless totaled 1.391 million tons. Shipments of sheets and strip rose 3% to 981,677 tons, breaking the record of 954,483 tons just set in 1992. This category has been steadily increasing since 1989. The next largest category was plate (flat product 4.8 millimeter [3/16 inch] or more in thickness). Shipments of plate were 176,623 tons, a 12% jump from that of 1992. Together, plate and sheet accounted for 83% of total net shipments, compared with 81% in 1992.

Stainless steel sheet is used in the manufacture of a wide range of consumer products, including household appliances, kitchen facilities, machinery, and medical equipment. In the past, automotive trim was an important end use for sheet, but aluminum and plastics have captured much of that market. Plate is primarily used in the fabrication of chemical reaction vessels and similar heavy-duty industrial equipment. The chemical, food and beverage, petrochemical, pharmaceutical, pulp and paper, and textile industries are all large consumers of stainless plate.

Since 1991, major restructuring, adoption of more efficient work practices, and the introduction of new technology have improved the competitiveness of the U.S. stainless and specialty steel industry. Three key mergers of stainless steel producers occurred between early 1992 and yearend 1993. In April 1992, Armco, Inc. acquired Cyclops Industries, Inc., dramatically increasing Armco's stainless steel finishing capabilities. That same month, Lukens, Inc. bought Washington Steel Corp., a major producer of stainless steel sheet. Finally, on November 10, 1993, Allegheny Ludlum Corp. bought Athlone Industries, Inc., the parent of Jessop Steel Co., for about $107 million. Jessop Steel is an important producer of stainless and alloy plate, with sizeable facilities at Washington, PA.[12]

Armco and Cyclops consolidated their melting operations shortly after merging and made Armco's state-of-the-art shop at Butler, PA, the principal melting and casting facility for the new company. The old Armco had already spent $13 million upgrading the Butler melt shop in 1991. This allowed management to close three older melt shops: one at the Cyclops plant in Bridgeville, PA; one at Armco's Baltimore Specialty Steels Corp. in Baltimore, MD; and one at Armco's Eastern Stainless subsidiary in Baltimore.

Shortly after Lukens acquired Washington Steel, Lukens announced that it would install a vacuum oxygen decarburization (VOD) unit at its melt shop in Coatesville, PA, and begin producing stainless steel. Although Lukens, a plate producer, has had a long history of rolling and finishing stainless on a tolling basis for other companies, it has not been a melter of stainless steel.

In 1993, U.S. consumption of primary nickel in superalloys increased 2%, despite problems in the aerospace industry. Sales by the aerospace industry fell 10% to $124 billion.[13] Combined aircraft and missile purchases by the U.S. Department of Defense declined for the sixth consecutive year. Purchases of civil aircraft, engines, and parts by commercial airlines and foreign governments were down 20%. Jet engine manufacturers, significant consumers of nickel-chromium-cobalt and nickel-chromium-iron alloys, were hard pressed and working aggressively to cut costs. The Boeing Co. and McDonnell Douglas Corp. continued to work off a backlog of orders received between 1988 and 1990 for civil jet transport. However, only 236 new orders for aircraft were received in 1993, compared with 670 in 1990 and 1,015 in 1989.

In August 1993, Eveready Battery Co., the world's largest manufacturer of household batteries, purchased the nickel-based rechargeable battery operations of Gates Energy Products Inc. Terms of the sale were not disclosed. The former Gates division offered a full line of nickel-cadmium (NiCd) batteries and was expanding its rechargeable nickel-metal hydride (NiMH) production facilities. The sale included Gates' main NiCd manufacturing plant at Gainesville, FL; a battery assembly plant in Juarez, Mexico; and at least three other facilities. Eveready's new division is now called Energizer Power Systems.[14]

This was Eveready's first serious entry into the NiCd market. Until then, Eveready had focused on the alkaline, carbon zinc, and zinc air segments of the battery business. Eveready is a wholly owned subsidiary of the Ralston Purina Co. and operates 43 plants worldwide. The St. Louis, MO-based food company bought Eveready from the Union Carbide Corp. in 1986 for $1.42 billion.

Reported nickel consumption statistics were revised for 1985 through 1992. The corrected annual data for 1989 through 1992 are shown in tables 1, 3, and 4.

Stocks

The combined stocks of primary nickel maintained in the United States by foreign producers and metal-trading companies with U.S. sales offices jumped 53% during the year. At yearend, these stocks represented 46 days of apparent primary consumption. *(See table 5.)*

Markets and Prices

Nickel supply exceeded demand in 1993, depressing world prices for the metal. The average LME cash price for the year was $5,293.419 per metric ton, which equates to $2.401 per pound. In terms of current dollars, this represented a drop of 24% from the 1992 average of $7,001.227 per ton ($3.166 per pound). The principal reasons for the weakening of the nickel price were associated with the deterioration of the Russian economy. Stainless steel production in Russia and the rest of the former Soviet Union had plummeted since 1991. The drop in Russian stainless production, coupled with the collapse of the ruble, encouraged the Norilsk Nickel Combine to export the bulk of its production to the West. This, in turn, led to a large buildup of stocks of nickel cathode and powder in the LME warehouses at Rotterdam. The price collapse would have been far worse if production of stainless steel in the Western World had not reached a record high of 11.6 million tons. Brazil, Canada, the Republic of Korea, the Republic of South Africa, and several countries in Western Europe all reported record production of stainless.

LME stocks continued their precipitous climb, rising from 67,914 tons on December 21, 1992, to 124,104 tons on December 31, 1993. Stocks kept growing until April 5, 1994, when they peaked at 137,010 tons. Of the 137,010 tons, 131,622 tons or 96% were in the form of cut cathodes. The remaining 4% consisted of briquettes and a limited amount of pellets. Most of the nickel was being stored in Rotterdam, even though the LME has 18 authorized warehouse sites scattered around the world.

Nickel prices lost considerable ground between early 1989 and yearend 1993. The weekly LME cash price began 1993 at $5,815 per ton ($2.638 per pound) and stayed at that level, with only minor fluctuations, until mid-May. On May 21, however, the weekly average dropped to $5,600 per ton ($2.540 per pound) and began to slowly deteriorate. On September 30, the daily cash price hit a 6-year low of $4,012 per ton ($1.820 per pound). Market conditions improved somewhat in the fourth quarter, causing prices to partially recover. The last weekly price (for the week ending December 31) was $5,328 per ton ($2.417 per pound).

Foreign Trade

U.S. net import reliance as a percentage of apparent consumption was 63% in 1993. The figure was slightly higher than the 1992 percentage because of decreased ferronickel production in Oregon and a 7% increase in imports of cathode. Imports accounted for about 98% of primary supply in 1993 if Government stockpile sales are excluded. Canada, as usual, supplied most of the imported material. A significant part of the nickel imported from Norway, the second largest source, was also of Canadian origin.

U.S. imports of Russian cathode jumped 96% between 1992 and 1993. According to the U.S. Bureau of the Census, the United States imported 6,629 tons of cathode and 36 tons of powder and/or flake directly from Russia in 1993. Importers also brought in 21 tons of Russian nickel contained in ferronickel and 30 tons contained in primary chemicals. These figures do not include material that may have been recovered in Norway from Russian matte and later exported to the United States. No primary material was reported from the Ukraine—only stainless steel scrap.

The relatively high level of demand for primary nickel in the United States also has meant high demand for nickel-bearing scrap. U.S. exports of stainless steel scrap remained strong in spite of weakening prices. Exported stainless scrap contained an estimated 17,407 tons of Ni, an almost identical amount to that of 1992. These figures are based on the assumption that stainless scrap has been averaging 7.5% Ni since 1989, when the changeover to the Harmonized Tariff System took effect.[15] *(See tables 6 through 9 and figure 3.)*

World Review

On April 23, 1993, the International Nickel Study Group (INSG) held its third general session at The Hague, The Netherlands. The INSG has two primary functions. The first is to provide transparency to the nickel market by gathering, collating, and publishing international statistical data. The second is to provide an intergovernmental forum for discussion of issues of concern to both nickel-producing and nickel-consuming countries. In conjunction with the April meeting, the INSG published a directory of world nickel production facilities and on-going development projects. The directory proved to be popular and is currently being updated.[16] The international organization also publishes a monthly statistical bulletin, with annual data for 1983 and subsequent years appearing in the October issue.

Australia.—Western Mining Corp. Holdings Ltd. (WMC), one of the four largest nickel producers in the Western World, continued to expand production capacity. If the expansion and upgrading program stays on schedule, the company will be able to produce 90,000 tons per year of contained nickel by mid-1995. In the fiscal year ending June 30, 1993, WMC's mining operations in Western Australia produced 52,705 tons of Ni in concentrate. The Kambalda operation accounted for 32,107 tons, or 61%, of the 52,705 tons. The Kambalda concentrator treated 1.12 million tons of sulfide ore averaging 3.07% Ni, recovering about 93% of the nickel in the process. The remaining 20,598 tons of Ni came from the Leinster operation, which treated 1.06 million tons of ore averaging 2.38% Ni. The Leinster concentrator was enlarged in 1992-93 and can now handle 2 million tons of ore per year. The expansion required construction of a new primary crushing plant as well as the installation of a new grinding mill, more flotation cells, and a new flash dryer.[17]

In early 1993, WMC decided to develop the huge Mount Keith deposit by itself. On February 22, 1993, the company's board of directors announced that it was buying back the 50% interest in the Western Australian deposit held by Outokumpu. The Finnish nickel producer bought the 50% interest from WMC in June 1992, but wound up in the midst of a major restructuring and had to focus on the startup of its new Forrestania Mine, near Lake King, southwest of Kalgoorlie. Although Outokumpu decided not to participate in the A$440 million (US$320 million) project, it agreed to purchase half of Mount Keith's annual output for the first 10 years of operation. Outokumpu's share was to be about

14,000 tons per year of Ni contained in concentrate. The Finnish producer planned to use funds from the Mount Keith sale to expand and modernize its Harjavalta smelter in Turku ja Pori province.

Development of the Mount Keith Mine was expected to take about 2 years. The complex will be one of the largest metal mines in Australia. WMC plans to extract 210 million tons of low-grade sulfide ore, averaging 0.58% Ni, from the deposit over the next 20 years. Although the ore is considered low grade in terms of its Ni content, it is also low in sulfur-rich pyrrhotite. Less pyrrhotite in the concentrate translates directly into lower emissions of SO_2 at the smelter and, thus, lower smelting costs. Construction crews have been onsite since March 1993. The principal contractor is Leighton Holdings Ltd., a construction and civil engineering company based in New South Wales. About 700 workers were employed on the project in mid-1994. However, after commissioning, the mining complex will need only 250 employees to operate.

Removal of overburden began in June 1993 and was ahead of schedule. Construction of the onsite concentrator started at about the same time, with commissioning tentatively scheduled for January 1995. The concentrator will be capable of processing 18,000 tons of sulfide ore per day, or about 6.6 million tons per year. This equates to a production level of about 28,000 tons per year of Ni in concentrate. Leinster, 90 km to the southeast, was serving as a base for the operation. About 120 houses were being built at Leinster at a cost of US$14 million. Mount Keith was to have its own diesel-operated power station because of the remoteness of the site. In April 1994, the open pit was about 60 meters (m) deep, and 45% of the plant and infrastructure was in place.[18]

In November 1993, WMC completed the expansion and upgrading of its smelter at Kalgoorlie. The smelter can now treat at least 80,000 tons per year of Ni in concentrate, up from 54,000 tons per year. A new, 525-ton-per-day oxygen plant was built as part of the upgrading. Kalgoorlie has a flash furnace that has operated almost continuously since its commissioning in 1978. The smelter was shut down on September 8 for 2 months so that the furnace could be rebuilt. The facility can treat limited amounts of high-grade nickel sulfide ores in addition to conventional concentrate.

Outokumpu Metals & Resources Oy (OMR) officially commissioned its new Forrestania Mine on January 14, 1993. The A$100 million mine is about 170 km south-southeast of Southern Cross. The mine is currently producing about 8,600 tons per year of Ni in concentrates from sulfide ore that assays between 1.7% and 2.3% Ni. All of the concentrates are being shipped to OMR's Harjavalta smelter in Finland.

The Government of Western Australia approved the construction of a 1,400-km-long natural gas pipeline from the northwest coast through the Pilbara to the Goldfields region and the nickel smelter at Kalgoorlie.[19] On March 23, 1994, the Premier of Western Australia signed an agreement with the Goldfields Gas Transmission Joint Venture (GGTJV), setting conditions for non-discriminatory third-party access to the gas and establishing key design parameters. The pipeline agreement was ratified by the Western Australian parliament shortly afterward and was awaiting Royal Assent at the end of April 1994.

The joint venture was composed of WMC, Wesminco Oil Pty. Ltd. (a wholly owned WMC subsidiary), BHP Minerals Pty. Ltd., Normandy Poseidon Ltd., and Normandy Pipelines Pty. Ltd. Feasibility studies, environmental assessments, and community consultations were all underway. Construction could begin as early as 1995 if all of the studies are successful. Most of the gas would come from the offshore Griffin or North Rankin gas fields on the North West Shelf. However, some could also come from the onshore Tubridgi field.

The Government and consortium were hoping that the A$400 million pipeline would stimulate additional investment in the region's mining industry and encourage owners of existing mines along the route to build downstream processing facilities that would add value to their products. Some of the gas would be used to fuel a new power generation station near Kalgoorlie, replacing more expensive electricity currently being transmitted from Perth. Part of the remaining gas would be available for mineral extraction and processing. Cheaper energy could spur development of Bulong, Anaconda, and several other nickel laterite deposits.[20] Some of the gas could also be used for a 2-million-ton-per year direct-reduced iron plant proposed for the Pilbara.

The Queensland Nickel Joint Venture halted production at its Greenvale Mine on the eastern slope of the Great Dividing Range in October 1992 and now relies heavily on imports for its lateritic feed. The company imported 16,617 tons of Ni in lateritic ore from New Caledonia in 1993. An additional 9,776 tons of Ni in ore came from Gebe Island in Indonesia.[21] The material was being converted to nickel oxide (90%+ Ni) at the company's Yabulu hydrometallurgical refinery at Townsville. Queensland Nickel also shipped a limited amount of ore from its Brolga Mine at Yaamba, part way between Townsville and Brisbane.

Brazil.—Comphania Niquel Tocantins has doubled the capacity of its nickel-cobalt refinery at Sâo Miquel Paulista in the State of Sâo Paulo. The project had been on hold for several years. Tocantins is the only producer of electrolytic nickel in Latin America. The expansion cost $25 million and was completed at the end of 1993.[22] When all of the upgrading is finished, the plant will be able to produce 10,000 tons per year of cut cathode.

Nickel-cobalt carbonate feed for the plant comes from the company's Niquelândia mining, roasting, and ammonia leaching operations at Acampamento in the State of Goiás. In 1992, Tocantins spent about $110 million to increase the capacity of the carbonate plant from 10,000 tons per year to 20,000 tons per year. The laterite ore being mined at Niquelândia runs 1.4% Ni and 0.14% Co.

Canada.—In the fourth quarter of 1992, Inco began reducing nickel production and curtailing capital expenditures because of declining nickel prices. When prices continued to fall in early 1993, the company intensified its cost control measures. Inco kept its Canadian operations shut down for 3 weeks at the beginning of 1993 and extended its annual summer shutdown to 4 weeks. As a result of the two shutdowns, Inco's Canadian operations produced only 132,000 tons of finished nickel in 1993, down from 147,000 tons in 1992. Similar shutdowns overseas caused the company's total production of finished nickel to drop from 182,000 tons to 167,000 tons.[23] In October 1993, Inco announced that it would cut back production even further in 1994 because of the deteriorating market situation. The company made plans to reduce output by 27,000 tons of nickel over the 8-month period between December 1993 and July 1994.

The shutdowns and other measures were designed to conserve cash during a period of rising operating costs and lower realized prices for nickel. Inco's unit production costs at its Canadian operations almost doubled between 1987 and 1991 as a result of declining ore grades, higher labor costs, and the strengthening of the Canadian dollar against the U.S. dollar. The salaries of all corporate officers were cut by 10% in November 1992, and hiring had been frozen for some time. Planned capital expenditures for 1993 were reduced from $225 million to $186 million, and similar constraints were to be imposed in 1994. Technological improvements, workforce reductions, and the opening of several new mines have increased productivity by 18% since 1991, but declining ore grades remain a problem. The average ore grade for the Ontario mines declined from 1.28% to 1.23% Ni between 1992 and 1993. The ore grade for the Manitoba mines declined even more, dropping 7% from 2.62% to 2.43% Ni.[24]

Inco's Ontario Division had only 11 mines operating in 1993. The Shebandowan Mine and four others were kept on standby. The entire Ontario division had about 7,200 employees. The Manitoba Division had two underground mines and two open pits in operation, but the two open pits were almost depleted. Inco also had four mines in Manitoba on standby.

The Ontario Division began recovering ore from its new Lower Coleman Mine in early 1993. The Division also reopened the old Garson Mine at an initial capital cost of $32 million. The Garson Mine was closed in 1986 after a serious rockfall. Advanced mining methods were being used to overcome bad ground conditions that existed in parts of the mine. The Garson Mine has some of the richest nickel-copper ore in the Sudbury Basin and is scheduled to produce 1,800 tons of ore per day after it reaches full production in late 1995.

Inco also had three other mining projects under development—McCreedy East at Sudbury, and the Birchtree and Thompson 1-D in Manitoba. Future production from these projects will be needed to offset declining reserves at some of the older, higher-cost mines in the Sudbury region. Mining was recently suspended at the Levack Mine, and reserves at the McCreedy West and Frood are being rapidly depleted.[25]

Despite all of its market problems, Inco's management remained optimistic about the future. The company's $530 million sulfur dioxide abatement project at Sudbury was completed on time to meet the Provincial Government's January 1, 1994 deadline. SO_2 emissions from the smelter complex have been successfully reduced to less than 265,000 tons per year, down from 2,250,000 tons in 1965. This achievement is quite remarkable and represents the largest tonnage reduction in SO_2 emissions to date from any single source point in North America. Inco now recovers more than 90% of the sulfur in its concentrates.

Three major changes were made to the Sudbury operation. In 1991, the company increased the capacity of its Clarabelle mill and modernized the facility so that it would reject increased amounts of pyrrhotite from the concentrate prior to smelting. Then, the existing reverberatory furnaces at the Copper Cliff smelter were replaced by two oxygen flash furnaces that can smelt bulk copper-nickel concentrates. The first flash furnace was completed in October 1991; the second, in August 1993. The third change involved the development of a new copper recovery process that made smelting much simpler.[26] All of the chalcocite (Cu_2S) matte generated at the matte separation plant is now run through a newly designed "MK" reactor that converts the chalcocite to blister copper. Flash smelting of the chalcocite matte generates SO_2 gas that is then sent to either the liquid SO_2 plant or the sulfuric acid plant where it is combined with the SO_2 produced by the two oxygen flash furnaces. The two SO_2 recovery operations produced a total of 425,000 tons of sulfuric acid and liquid SO_2 in 1993.

Falconbridge operated six mines at Sudbury in 1993—the Craig, Fraser, Lindsley, Lockerby, Onaping, and Strathcona. The six underground mines hoisted a total of 2.5 million tons of ore that yielded 38,300 tons of nickel, 47,200 tons of copper, and 800 tons of cobalt in matte.[27] Because of improvements in productivity, nickel production was up 8% from 1992 even though the company shut down for a total of 8 weeks.

Like Inco, Falconbridge restructured its Sudbury Division and reduced its workforce to remain competitive in an oversupplied marketplace. The shaft-sinking project at the Craig Mine was put on hold to conserve cash. Improved flotation techniques and the installation of advanced magnetic separation equipment allowed the Strathcona mill to increase its pyrrhotite rejection rate without lowering nickel recovery. Because there was less pyrrhotite in the final concentrate, sulfur dioxide emissions decreased at the smelter, helping Falconbridge to meet its abatement goals. The smelter released 57,000 tons of SO_2 in 1993, well below the 100,000-ton limit set by the Provincial Government for 1994.

Falconbridge continued to explore for nickel and copper in the intrusive rocks that rim the Sudbury Basin. Efforts were being concentrated at the Nickel Rim prospect, 12 km north of the town of Falconbridge. Drilling to date has identified 520,000 tons of ore averaging 4.13% Ni at a depth of 2,500 to 2,700 m. The ore also contains significant copper, palladium, and platinum. Teams were also evaluating three other properties on the rim: Joe Lake; an area down-dip from the Craig and Onaping mines; and the Trill-Drury prospect near Fairbank Lake.

In 1993, Falconbridge completed its feasibility study of the Raglan deposit in northeastern Quebec. Since 1989, the company has spent more than $40 million evaluating the world-class nickel deposit. The company has begun applying for the necessary government permits to bring the property into production, but actual construction will not start until market conditions substantially improve. Exploration drilling has identified at least 18.1 million tons of ore averaging 3.13% Ni, 0.88% Cu, and 0.05% Co. Falconbridge was also evaluating properties in Manitoba, Botswana, Côte d'Ivoire, Greenland, and Zimbabwe.

In early 1994, Sherritt Inc. (formerly Sherritt Gordon Ltd.) completed the expansion and modernization of its nickel-cobalt refining complex in Fort Saskatchewan, Alberta. The new complex consisted of a nickel refinery designed to handle nickel feedstock with a high-cobalt content, a cobalt separation plant, and a cobalt reduction plant. Feed material was being supplied by Cubaniquel and Union de Empresas del Niquel under agreements concluded with the two Cuban organizations in 1991. Sherritt also was considering importing supplemental feedstocks from Australia. The Metals Division produced 18,345 tons of nickel, 10% more than in 1992. Cobalt production jumped 78% to 1,218 tons—an all-time high. The expansion will allow Sherritt to produce more than 25,000 tons per year of nickel when prices recover.[28]

Hudson Bay Mining and Smelting (HBMS) closed its Namew Lake Mine in northern Manitoba on November 5, 1993. Reserves at the underground mine, a joint venture of HBMS (60%) and Outokumpu Mines Ltd. (40%), were exhausted and efforts to find new ore bodies failed. The mine, which cost $60 million, was commissioned in November 1988. Most of the concentrates ended up at Sherritt Gordon's refinery in Fort Saskatchewan, Alta., or Inco's smelter in Thompson, Man.

China.—Jinchuan Nonferrous Metals Corp. produced 27,300 tons of cathode at its smelting and refining complex in Gansu Province. The complex accounted for 88% of China's total nickel output in 1993 and 90% of its platinum output. The ore came from four mining areas at the base of Longshou Mountain, which make up about 70% of China's nickel reserves. The ore occurs in a 6-km-long dike that cuts through all four mining areas. The principal ore minerals are pyrrhotite, pentlandite, and chalcopyrite. Different members of the cobaltite family also are present in minor amounts.

Jinchuan has been producing cathode since 1964 and recently installed a new flash furnace with the help of Outokumpu and WMC. The new furnace can smelt up to 50 tons per hour of concentrate averaging 6.8% Ni, 3.4% Cu, and 0.13% Co. When the expansion project is completed in 1995, Jinchuan will be able to produce annually 40,000 tons of nickel, 20,000 tons of copper, and 500 tons of cobalt. A new acid plant being constructed will generate 400,000 tons per year of sulfuric acid.[29]

Colombia.—The Cerro Matoso ferronickel operation in Colombia was only one of a number of mining and smelting complexes caught up in the spinoff of Billiton BV from the Royal Dutch/Shell Group (Shell). *(See Republic of South Africa section of this report.)* According to the INSG, Cerro Matoso produced 20,181 tons of nickel contained in ferronickel bars and granules. Essentially all of it went for export. Exports totaled 21,632 tons on a contained basis in 1993, 61% of which went to Europe.

Cuba.—Sherritt has been working closely with the Cuban nickel industry since 1991. Most of the nickel-cobalt sulfide precipitate produced at Moa Bay now goes to Sherritt's refinery at Fort Saskatchewan. In 1993, Cuba reportedly exported 12,116 tons of Ni in intermediate products to Canada. Before 1991, the bulk of the precipitate went to the Russian refinery at Orsk. Sherritt's oil exploration and development program in northern Matanzas Province has given the company a distinct advantage on the island over other Western nickel refiners. Sherritt has been producing oil from the Varadero and Boca de Jaruco fields east of Havana as part of a joint venture with the Government.

Sherritt also was considering a joint venture with La Compania General de Niquel S.A., the parastatal company responsible for operations at Moa Bay. The Pedro Sotto Alba plant on Moa Bay produces a mixed 50% Ni+Co sulfide precipitate from limonitic laterites. The laterites are leached under pressure with sulfuric acid at 250° C and 4,000 kiloPascals to prevent large amounts of iron from dissolving along with the nickel and cobalt. The proposed joint venture would upgrade the Moa plant and make it more energy efficient, incorporating new extractive technology developed by Sherritt. Both the Fort Saskatchewan refinery and the Moa Bay plant would become jointly-owned assets of the new venture. The proposed venture would be granted mining concessions with more than 60 million tons of nickeliferous limonite reserves, 80% of which were proven. The concessions would provide Moa Bay with enough ore to operate for 25 years. The venture would also establish a jointly-owned marketing corporation to better market the nickel and cobalt overseas.

Cuba produced 30,218 tons of nickel units in 1993. Oxide sinter (90% Ni) and different forms of the more conventional oxide (76% to 77% Ni) accounted for 16,185 tons of the nickel. This material came from the Nicaro and Punta Gorda plants, which use an ammonium carbonate leach process to recover nickel from serpentine laterites. The remaining 14,033 tons were contained in mixed precipitates from Moa Bay and other intermediate products.

Finland.—OMR moved ahead with its plans to modernize and expand the Harjavalta Works, despite weak nickel prices. The complex consists of a nickel smelter, a copper smelter, and a nickel refinery. The blister copper is shipped to Pori for electrolytic refining. The upgrading program will cost 1.8 billion Finnish markka (about US$330 million) and increase the complex's capacity to produce copper as well as nickel. Construction began in May 1993 and was scheduled to be completed in 1996.

The refined nickel capacity of Harjavalta will almost double, going from 18,000 tons per year to 32,000 tons per year of Ni. The additional 14,000 ton-per-year capacity will be used to make briquettes instead of cathode. The copper smelting capacity of the complex will jump similarly from 100,000 tons per year to 160,000 tons per year. The capacity of the copper refinery at Pori will increase from 70,000 tons per year to 125,000 tons per year. New pollution control equipment and the adoption of innovative technology should decrease sulfur dioxide emissions even though the smelter output is being raised.

More than half of the additional concentrate needed to feed the nickel smelter was coming from Outokumpu's new Forrestania Mine in Western Australia. It is the first mine outside Finland which is wholly owned, built, and operated by Outokumpu. An additional 14,000 tons per year will come from WMC's new Mount Keith Mine, which is scheduled to open in 1995. For a short period of time, Outokumpu held a 50% interest in Mount Keith but sold out to WMC. More feedstock could conceivably be obtained from the remote Keivitsa deposit recently discovered in Lapland by the Finnish Geological Survey.

In 1993, Outokumpu Harjavalta Metals Oy produced 14,800 tons of nickel cathode, 107,000 tons of blister copper, and 73,400 tons of cathode copper (a new record). Outokumpu Finnmines Oy was planning to close its Enonkoski and Vammala Mines in 1994 because of declining reserves and low nickel prices, leaving only the Hitura Mine operating.[30] The Telkälä Mine closed in 1992.

On October 20, OMR sold its 96% share in OM Group, Inc. (OMG) for $129 million. The shareholding was sold to individual and institutional investors by listing the former chemical subsidiary on the NASDAQ. OMG is now the largest producer of cobalt and nickel chemicals in the Western World. OMG produced 2,690 tons of Ni in chemicals during the first 10 months of 1993 while the company was still owned by OMR. *(See World Review section of 1992 Annual Report.)*

Indonesia.—P.T. International Nickel Indonesia (P.T. Inco) produced 34,400 tons of Ni in matte in 1993, down from a record high 36,300 tons in 1992. The matte typically contains 77% to 80% Ni and is shipped to Japan for refining, where it is admitted duty-free. The company was forced to cut back production in July 1993 when the main 65-megavolt-ampere (MVA) transformer feeding Furnace No. 2 failed. The furnace had just been rebuilt and brought back on line in May. A spare 50-MVA transformer was installed in its place, but the reduction in power capacity resulted in lower production. A new 75-MVA transformer was to be delivered in mid-1994. The furnace was one of three at the company's 45,400-ton-Ni-per-year Soroako smelting complex.[31]

P.T. Inco accelerated its revegetation of mined-out areas and has restored about 280 hectares (692 acres) to date. The Soroako area still has proven and probable reserves of 78 million tons of laterite containing 1.5 million tons of Ni. Recent reconnaissance work in the Pomalaa East area has identified a possible resource of 147 million tons. At least 55 million tons of this material runs 1.9% Ni. Construction of a 24-MW, three-unit diesel electric generating station was completed in August on schedule as budgeted. The additional power was to supplement the output of the company's existing hydroelectric facility.

P.T. Aneka Tambang also experienced furnace problems. The operation at Pomalaa produced only 5,267 tons of Ni in FeNi, down 4% from 5,507 tons in 1992. A second ferronickel plant with a capacity of 5,500 tons per year of contained Ni was under construction and scheduled to come onstream in early 1995. Production of ore for export dropped from 35,745 tons of contained Ni to 26,850 tons in 1993.

Macedonia.—The Feni-Mak mining and smelting complex at Kavadarci reportedly operated at less than 50% of capacity in 1993 and was producing only about 400 tons per month of Ni in ferronickel. The smelter is capable of producing 28,000 tons per year of ferronickel on a gross weight basis, but was unable to operate efficiently because of the civil war in Bosnia and Hercegovina, United Nations sanctions on neighboring Serbia, and related power outages and transport problems. The ferronickel had to be shipped from the Greek port of Salonika to Rotterdam, instead of being transported by rail through Belgrade to Austria and Germany.

New Caledonia.—Société Métallurgique le Nickel (SLN) shipped 36,888 tons of nickel in ferronickel, up from 32,080 tons in 1992. The company's three furnaces at Doniambo were recently upgraded and now have a combined capacity of about 53,000 tons per year of Ni in ferronickel. The ferronickel has been averaging about 29% Ni. The operation also produces matte, which is cast into ingots and sent to the Eramet-SLN refinery at Sandouville, France, for conversion to cathode. The matte operation at Doniambo operated at full capacity in 1993 and shipped 14,766 tons of matte containing 10,883 tons of Ni to Sandouville. The average grade of the matte was 73.7% Ni.[32]

Goro Nickel S.A., a French company created in 1992 to evaluate laterites at the southeastern tip of the island, shipped a bulk sample of ore to Inco's research laboratory in Mississauga, Ontario. Inco, which owns 85% of Goro, wanted to learn if new proprietary technology developed by the company could be used to economically process the high-iron, limonitic Goro ore. The Goro deposit reportedly has 150 million tons of ore averaging 1.57% Ni.

SLN's new Kopeto 2 Mine was essentially completed. Formal commissioning was scheduled for May 1994. The open pit mine is near Nepoui, about 250 km northwest of the capital of Nouméa. The mine was expected to produce 830,000 tons per year of lateritic ore during the next 15 years, and was designed to provide one-third of the feed material required by the Doniambo smelter. The garnierite-rich saprolitic ore assays about 2.1% Ni. The Nepoui area was worked during the 1970's and eventually abandoned. SLN decided to resume mining at the site when 14 untouched ore bodies of garnierite were discovered.[33]

Norway.—Productivity at Falconbridge's Nikkelverk refinery has been continuously improving during the last 10 years. In 1993, the operation recovered 56,800 tons of nickel, 37,200 tons of copper, and 2,400 tons of cobalt from matte shipped primarily from Sudbury, Botswana, and Russia. Nickel production was up 2% from that of 1992, despite a drop in employment of about 9%. The refinery currently has about 145 employees and is capable of recovering 64,000 tons of nickel, 40,000 tons of copper, and 2,600 tons of cobalt annually.

Russia.—Russian nickel production dropped significantly between 1992 and 1993. Cash flow problems, bad weather, rising costs for energy and transportation, supply shortages, equipment failures, and declining ore grades all contributed to the falloff. The Norilsk Nickel Combine produced only about 160,000 tons to 180,000 tons of refined nickel in 1993. The combine's principal mining, smelting, and refining operation is at Norilsk in north-central Siberia. The combine also has operations on the Kola Peninsula that include several mines near Nikel and Zapolyarnij, a smelter at Pechenga, and a smelting and refining complex at Monchegorsk. A large part of the production cutbacks apparently occurred at the Severonikel complex at Monchegorsk.

Significant production also came from the Yuzuralnikel Combine in the Ural Mountains. This second combine operates independently of Norilsk. In 1993, total Russian production of cathode, powders, and Ni in ferronickel was estimated to be somewhere between 175,000 tons and 195,000 tons, but official statistics still have not been released by the central government.

In recent years, production of ore and intermediate products at Norilsk proper has outpaced the capacity of the complex's processing facilities, with the excess going to either Severonikel at Monchegorsk or Pechenganikel at Nikel. Ore, concentrates, and matte destined for the Kola Peninsula are normally railed from Norilsk to the port of Dudinka, near the mouth of the Yenisey River. From Dudinka, the nickel goes by ocean vessel to Murmansk. Flooding at Dudinka in July 1993 apparently slowed shipments of these different feed materials. The transportation delays, in turn, created a shortage of feed material at Monchegorsk. Severonikel was able to offset part of the shortage by tolling material imported from the West. Because of the feed shortages, Severonikel's output of cathode and powder was significantly less than the estimated 97,000 tons to 102,000 tons produced in 1992. Finland reported shipping 2,888 tons (gross weight) of concentrates to Russia in 1993. Part of the concentrates reportedly went to Monchegorsk's nickel carbonyl plant for conversion to powder.

The July flooding was only part of the production problem. At the beginning of 1993, mining and concentrating operations at Norilsk were hampered by a period of harsh weather conditions. Air temperatures were abnormally high during the 1992-93 winter in north-central Siberia, generating very heavy snowfalls and unusually strong Arctic winds in Norilsk and the rest of the Rybnaya Valley.

In the spring of 1993, the new Russian Government put out a tender to upgrade the Pechenga smelter. The tender was eventually awarded to a Scandinavian consortium led by Elkem A/S. However, there were delays in signing the contract and a number of technical and financial matters still had to be negotiated. The consortium may have to significantly modify its proposal to bring costs down to a level more acceptable to the Russians. At least 30 Western companies initially participated in the competition, but only about 5 bids were eventually submitted.

The Pechenga smelter can produce up to 70,000 tons per year of nickel-copper matte averaging 40% to 50% Ni. The matte is shipped to Monchegorsk, where the two metals are separated from one another and cast into anodes suitable for electrolytic refining.

The Scandinavian consortium was composed of Elkem Technology (Oslo), Kvaerner Engineering (Oslo), and Boliden Contech AB (Stockholm). Elkem Technology is a major supplier of electric smelting furnaces and has considerable expertise in air pollution control technology and baghouse filter systems. The $300 million upgrading is expected to reduce sulfur dioxide emissions from the smelter more than tenfold. Some analysts believe that the upgrading of Pechenga will cost far more than $300 million and could easily exceed $800 million.

In October 1991, Outokumpu won an earlier tender to renovate Pechenga for $600 million, but a contract never materialized. Outokumpu had been considered a strong contender in the new bidding, but the Competition Commission of the Russian Federation eventually ruled in favor of the Elkem group.

The Russian Government was considering a plan to partially privatize Norilsk Nickel. Under the plan, the combine would operate somewhat like Outokumpu does currently in Finland. The combine would issue stock, with the Russian Government retaining 37% of the shares. Another 25% would be given to Norilsk's workforce free, while 10% would be held by management. The remaining 28% would be sold at public auction to Russian investors to raise cash for modernization. Foreigners would be prohibited from owning stock in the combine.

Large tonnages of Russian cathode entered LME warehouses in both 1992 and 1993, building up Western trading stocks to record high levels. Official Russian customs data on 1993 nickel exports were still being compiled at the time of publication. According to data received by the INSG from importing countries, Russia shipped a total of only 38,148 tons of unwrought nickel (in unalloyed form) to 15 countries in 1992, a significant drop from the 87,665 tons reported for 1991. The 38,148-ton figure is much lower than industry estimates of Russian exports for 1992, the difference being made up by "black" (smuggled) and "gray" (physically modified or deliberately misclassified) material. A total of 77,484 tons had been reported, as of this writing, from Russia for 1993, with the bulk going to Germany (23,501 tons), Italy (7,277 tons), the United States (6,629 tons), France (5,651 tons), and Canada (5,615 tons). Norilsk also sent significant amounts of nickel matte to Norway for refining. In 1993, Russia shipped 15,000 tons (gross weight) of matte to the Kristiansand refinery of Falconbridge Nikkelverk A/S. This was almost double the 8,500 tons shipped in 1992.

Yuzuralnikel Kombinat temporarily suspended nickel production at its Orsk smelting and refining complex in the southern Urals. The length of the shutdown was not disclosed. The State-owned complex was put in a difficult position by the ongoing economic restructuring of the Russian economy and the political situation in the Commonwealth of Independent States (CIS). The Orsk facility was set up originally to process lateritic ores from more than a dozen mines in the Orsk-Chelyabinsk-Sverdlovsk region and had satellite operations at Buruktal, Ufaley, and Rezh. Some ore apparently also came from the Aktjubinsk region of Kazakhstan. However, for more than a decade, Orsk also has been processing anodes made at Buruktal from Cuban nickel-cobalt sulfides.

The combine reportedly was forced to shut down both the Orsk and Ufaley smelters because of soaring production costs and a shortage of raw materials. Costs for electricity and fuel have risen dramatically since the elimination of many state subsidies. The combine also has had difficulty securing an adequate supply of sulfide concentrates. In 1991, the Cuban nickel industry started shipping the bulk of its mixed concentrates to Sherritt instead of to the combine. Cuban shipments to Buruktal fell off dramatically between 1991 and 1993, and are now less than 2,000 tons per year of contained Ni.

According to the INSG, the Orsk complex is capable of producing 16,000 tons per year of Ni in granules (averaging 98.6% Ni), 16,000 tons per year of Ni in refined metal, 8,000 tons per year of Ni in salts, and 2,500 tons per year of refined cobalt.

South Africa, Republic of.—Gencor Ltd. was in the process of buying Billiton BV from the Royal Dutch/Shell Group. Management teams from the two resource giants had been immersed in negotiations since late 1992 and were still working out key details of the complex transaction. *(See World Review section of 1992 Annual Report.)* Gencor would raise money for the acquisition by divesting itself of its papermaking, energy, and consumer products subsidiaries.[34]

Because many of Billiton's operations were joint ventures, the sale of individual mines and smelters depended upon whether the other shareholders choose to exercise their preemptive purchase rights. For example, Billiton owned 47% of Cerro Matoso S.A., the Colombian ferronickel producer, with the rest controlled by the Colombian Government. Gencor, on the other hand, had to deal with financing problems created by South African currency controls. The South African giant reportedly agreed to pay Shell $1.14 billion for Billiton. The long-awaited transfer of assets, scheduled to take place in September 1994, would transform Gencor from a South African mining house into an international resource group. Gencor's new subsidiary was to be called Billiton International Ltd. The South African mining company had to come up with $335 million in cash. The bulk of the remaining $809 million would be loaned to Gencor by a consortium of international banks.

Tanzania.—BHP Minerals International Exploration Inc. (BHP Minerals) was moving ahead with its $4 million drilling program in the Kagera region, southwest of Lake Victoria. The operation was part of a joint venture with Sutton Resources Ltd. of Richmond, British Columbia.[35] Exploration was continuing despite the influx of 400,000 refugees from Rwanda and Burundi into the region. BHP had three rigs drilling a series of geophysical and geochemical anomalies 70 km west of the lake. The anomalies lie along a 200-km-long belt stretching from Kabanga north to Kyaka.

According to Mine Development Engineering Ltd., a Sutton contractor, the previously identified deposit at Kabanga has 23.1 million tons of sulfide ore averaging 1.19% Ni, 0.20% Cu, and 0.10% Co, based on a 0.5% Ni cutoff. The sulfide ore is associated with a series of ultramafic intrusives, primarily peridotites and pyroxenites. In late 1993, stepout drilling 1,100 meters north of the Kabanga deposit located additional mineralization, with the highest cobalt-nickel grades found to date. Reconnaissance drilling at a second anomaly 40 km northeast of Kabanga also located nickel sulfide mineralization. *(See tables 10 and 11 for individual country data.)*

OUTLOOK

Since 1991, the supply of nickel has exceeded world demand. In recent months, this imbalance has shrunk considerably in the Western World but grown worse in the East. Consumption of nickel in the CIS has fallen faster than the dropoff in Russian production, freeing up large amounts of cathode and powder for export to the West. The bulk of the material shipped in 1992-94 went to, in decreasing order, Western Europe, North America, Japan, the Republic of Korea, and Taiwan.

The Russian push to export nickel is being driven by a combination of forces. First, the Russian nickel industry has had considerable excess capacity for more than a decade and has been a significant supplier to Western Europe and Japan since the early 1980's. Nickel production far exceeded internal needs under the former Soviet system, even when demand by the military was strong and stainless output was high.

Second, production of stainless steel within the entire former Soviet Union (FSU) has been declining since 1990 as a result of the shift from a centrally planned economy to a market economy. The FSU output of crude stainless has fallen steadily from 2,270,000 tons in 1988 to 550,000 tons in 1993. Some of the stainless allegedly was being sold in the West as scrap and remelted to make new stainless of better quality. Several CIS stainless plants were using obsolete technology or were situated in remote locations where the transportation infrastructure was limited.

Third, nickel exports have been an important source of hard currency for the FSU, and now Russia. Hard currency is vital to the new Russian economy because acceptability of the ruble in the West continues to be a problem.

Fourth, nickel consumption by the Russian defense industry has plummeted.

One of the more difficult challenges facing Western analysts will be to correctly forecast the point at which the Russian economy turns around and a rejuvenated Russian industry starts consuming more stainless and nickel.

Between 1981 and 1991, demand for nickel in the Western World grew at an average rate of almost 4% per year. However, demand began to slow in early 1991 as recessionary forces spread from North America to Western Europe and eventually to Japan. In 1991 and 1992, Western consumption of nickel actually declined, slowing the upward rate of growth. In 1993, Western nickel consumption began to pick up and is currently growing, causing the LME cash price to rise. On November 17, 1994, the LME price was $7,535 per ton ($3.418 per pound), up 45% from the $4,614 per ton ($2.093 per pound) quoted a year earlier.

If prices remain at the November level for some time, additional production will quickly come onstream to meet demand. There is already idle capacity in Oregon, Ontario, the Dominican Republic, Greece, and Macedonia, plus numerous deposits ready for development (e.g., Birchtree, Bulong, Fortaleza, Goro, Honeymoon Well, Loma de Hierro, McCreedy East, Raglan, Thompson 1-D, Victor, and Yakabindie). According to a senior company official in the nickel industry, nickel prices have to be at $6,600 per ton to $7,100 per ton (about $3.00 per pound to $3.20 per pound) for most Western nickel producers to break even.

How high the LME price will rise will depend, in part, upon the eagerness of the Norilsk Nickel Combine to earn hard currency and secure a permanent sales position in the West. Norilsk Nickel signed a cooperative agreement with Outokumpu in September 1993 and has strengthened ties to three or four Western trading companies. Norilsk also has its own sales agent in London, Normaco Ltd. Normaco is currently selling about 75,000 tons of cathode per year for the combine. Outokumpu was considering helping Norilsk upgrade some of its facilities in exchange for nickel and copper. One or two Russian-Finnish joint ventures also are possible if the Russian Government acquiesces. Long-term financing could be provided by a consortium of Scandinavian and EC investment banks.

In the second half of 1994, LME stocks climbed back and were again at record high levels. On November 10, 1994, LME warehouses held 150,498 tons of nickel metal, of which 149,802 tons, or 99.5%, were in the form of cut cathodes. At closing on the 10th, the Rotterdam depots had 140,346 tons on warrant, or 93% of total LME stocks. Two years earlier, Rotterdam only had about 56,000 tons on hand, while stocks at all of the remaining LME locations totalled less than 2,000 tons.

Austenitic stainless steel will continue to drive world nickel demand for both the short term (1995-97) and midterm (1998-2001). Japan is expected to be the dominant austenitic producer for the rest of the century and will continue to rely heavily on Australia, Indonesia, New Caledonia, and the Philippines for nickel matte and mine products. Japan is also the largest consumer of stainless of all types on a per capita basis. In recent years, Japanese stainless production has been 1.4 to 1.9 times greater than that of the United States. U.S. stainless production peaked in 1988 at 1.996 million tons and has since been averaging between 1.70 and 1.85 million tons. Nickel prices could conceivably rise to $9,900 per ton ($4.50 per pound) in mid-1995 as Japan begins to emerge from its recession and increases production of austenitic stainless.

Western demand for austenitic stainless should set a new record in 1995 despite lingering recessionary forces in Japan. The rest of East Asia will continue expanding stainless production capacity, although perhaps at a somewhat reduced pace. In recent years, there has been a significant shift in U.S. exports of stainless scrap from Japan and Western Europe to the Republic of Korea, Taiwan, and other rapidly developing Asian countries. The Republic of Korea is already making almost as much stainless as Spain and Sweden, while Taiwan is rapidly approaching Canadian production. Even Western Europe is expected to slightly increase stainless production. In 1993, Western Europe accounted for 40% of the 12.7 million tons of stainless (both austenitic and ferritic grades) produced worldwide.

The long-term forecast (2002-2005) is much more rosy. If the past is any guide to the future, world stainless steel production should grow on the average 3% to 5% per year over the next 10 years. Stainless currently accounts for almost 60% of primary nickel demand. Total nickel consumption should grow at an even faster rate because several novel, nonsteel uses are being developed for the element. The successful revitalization of

Russia and the rest of Eastern Europe, coupled with a restructuring of the Chinese economy, could generate unprecedented demand for nickel at the turn of the century.

A significant amount of nickel also goes into superalloys. In the United States, much of this material ends up either in jet turbine engines or in sophisticated chemical processing equipment, such as chemical reactors and pumps. In mid-1994, the U.S. aerospace industry was in a slump brought on by declining orders from both domestic airlines and the U.S. Dept. of Defense. Many domestic airlines were experiencing financial difficulties brought on by the recession, Government deregulation, a large debt load, new environmental controls, and escalating costs for jet fuel. However, this situation is expected to change within the next 2 or 3 years. Increased orders for civil aircraft should begin to materialize sometime after 1997 because air traffic is steadily increasing and aging fleets need to be replaced. Demand for nickel by U.S. superalloy producers will probably be flat until then.

The outlook for key segments of the chemical industry has improved substantially since mid-1993. Until recently, the sluggish U.S. economy and the slowdown in Europe and Japan discouraged chemical manufacturers from building new plants. Chemical companies around the world were forced to restructure, downsize, and make strategic alliances to penetrate previously closed markets. Orders for new chemical plants and equipment will continue to be weak through 1995. However, capacity utilization is currently quite high, with some chemical plants running at 85% to 90% of capacity. Further increases in chemical production will require the construction of new facilities, driving up demand for both stainless and superalloys. Demand should improve even more after Germany finalizes reunification and Japan escapes from recession. The long-term outlook for superalloys is optimistic.

Advanced batteries and electric vehicle technology probably will not significantly affect the nickel market before the year 2002. The nickel-metal hydride battery and the nickel-cadmium battery are both serious contenders for the power system of the futuristic automobile, but could lose out to their advanced lead-acid, sodium-sulfur, or zinc-air competitors. If a nickel battery were adopted universally, U.S. demand for the metal could easily double.

Commercial production of electric vehicles (EVs) powered by nickel batteries has been slowly moving closer to reality. On May 13, 1993, the California Air Resources Board (ARB) reaffirmed its requirement that, beginning with the 1998 model year, 2% of all vehicles sold within the State must have zero tailpipe emissions. The regulation, adopted in 1990, requires all automobile manufacturers who sell more than 35,000 cars or light trucks annually in California after 1997 to certify that at least 2% of their total sales were zero-emission vehicles (ZEVs). The sales requirement jumps to 5% in the year 2001, and then to 10% in 2003. At the present time, only electric vehicles can satisfy the zero-emission requirement. It is still unclear whether vehicles powered by certain fuel cells would be acceptable. Polymer electrolyte fuel cells running on methanol, for example, generate only water vapor and carbon dioxide—two essential ingredients for photosynthesis.

Several auto manufacturers had hoped that the ARB would delay the deadline, giving their companies more time to improve the performance of their prototype EVs. The auto manufacturers were concerned about the limitations of existing battery technology (range, speed, manufacturing cost, and so forth) and the absence of a network of recharging stations.[36] The Board, however, concerned about increasingly severe air quality problems in the Los Angeles basin, rejected the auto manufacturers' arguments. The Board then went on to adopt a report prepared by its staff which concludes that zero-emission vehicles are "technologically feasible in the timeframe provided."[37]

On February 1, 1994, the Governors of 12 northeastern States and the District of Columbia voted by a margin of 9 to 4 to follow California's lead. The Ozone Transport Commission (OTC) for the 12 coastal states, which stretch from Maine to Virginia, approved a plan that resembles the California program and calls for the introduction of zero-and low-emission vehicles into the region starting in 1999. On February 2, the OTC submitted its controversial plan to the EPA for approval. The EPA tentatively approved the controversial OTC clean air-clean car petition on December 19, 1994.

The California reaffirmation and the 12-State petition were important to nickel producers as well as battery manufacturers. During the mid-term (1998-2001), at least four nickel-based EV batteries are expected to strongly compete with the new high-performance lead-acid battery being developed in Texas and other lead-based batteries of advanced design. The four nickel-based technologies are: nickel-cadmium, nickel-iron, nickel-metal hydride, and sodium metal-nickel chloride.

A variety of advanced, affordable batteries also are being developed in Canada, Europe, and Japan. The performance of existing and prototype EVs has been reviewed on a world-wide basis in a 201-page book entitled *Electric Vehicles: Technology, Performance and Potential.* The book was published in 1993 under the auspices of the International Energy Agency (IEA) and its parent, the Organization for Economic Cooperation and Development (OECD).[38]

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TABLE 1
SALIENT NICKEL STATISTICS

(Metric tons of contained nickel unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Mine production	—	330	5,523	6,671	2,464
Plant production	347	3,701	7,065	8,962	4,878
Secondary recovery from purchased scrap:					
From ferrous scrap	[r]42,263	[r]48,608	[r]44,823	[r]47,735	47,247
From nonferrous scrap	[r]9,868	[r]8,759	[r]8,698	[r]8,136	7,455
Exports:					
Primary (nickel content)	4,242	8,873	9,104	8,560	7,183
Secondary (nickel content)	27,218	28,184	27,798	25,307	26,016
Imports for consumption:					
Ore (nickel content)	—	—	371	3,584	2,966
Primary (nickel content)	127,880	133,545	132,446	118,760	126,352
Secondary	9,137	11,634	6,212	9,506	6,713
Consumption:					
Reported:					
Primary	[r]103,868	[r]120,846	[r]108,779	[r]101,415	105,435
Secondary (purchased scrap)	[r]52,131	[r]57,367	[r]53,521	[r]55,871	54,702
Total	[r]155,999	[r]178,213	[r]162,300	[r]157,286	160,137
Apparent:					
Primary	[r]125,721	[r]127,197	[r]125,248	[r]119,050	122,077
Secondary (purchased scrap)	[r]31,382	[r]42,845	[r]31,415	[r]40,323	37,236
Total	[r]157,103	[r]170,042	[r]156,663	[r]159,373	159,313
Stocks, yearend:					
Government	33,760	33,760	33,760	33,760	31,551
Producer and traders	6,326	8,065	11,794	10,140	[p]15,534
Consumer:					
Primary	[r]9,619	[r]9,056	[r]10,486	[r]12,252	11,037
Secondary	[r]6,943	[r]4,915	[r]5,435	[r]5,182	3,345
Employment, yearend:					
Mine	—	12	8	10	2
Smelter	245	300	277	250	33
Port facility	—	—	—	23	5
Price, cash, London Metal Exchange:					
Per metric ton	$13,308	$8,864	$8,156	$7,001	$5,293
Per pound	$6.036	$4.021	$3.699	$3.176	$2.401
World: Mine production	[e][r]986,655	[e][r]968,622	[e][r]985,361	[e][r]974,342	[e]899,149

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

TABLE 2
NICKEL RECOVERED FROM PURCHASED SCRAP IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY[1]

(Metric tons of contained nickel)

	1989	1990	1991	1992	1993
KIND OF SCRAP					
Aluminum-base[2]	2,165	2,230	2,147	2,303	2,348
Copper-base	3,362	3,012	2,379	1,991	2,064
Ferrous-base[3]	[r]42,263	[r]48,608	[r]44,823	[r]47,735	47,247
Nickel-base	[r]4,341	[r]3,517	[r]4,172	[r]3,842	3,043
Total	[r]52,131	[r]57,367	[r]53,521	[r]55,871	54,702
FORM OF RECOVERY					
Aluminum-base alloys[4]	2,165	2,230	2,147	2,303	2,348
Copper-base alloys	[r]5,308	[r]4,769	[r]4,273	[r]4,086	3,675
Ferrous alloys	[r]42,317	[r]48,655	[r]44,871	[r]47,793	47,304
Nickel-base alloys	[r]2,336	[r]1,589	[r]2,163	[r]1,641	1,373
Miscellaneous and unspecified	[r]5	[r]124	[r]67	48	2
Total	[r]52,131	[r]57,367	[r]53,521	[r]55,871	54,702

[r] Revised.

[1] Significant changes were made to the computer program that generates data for this table. The changes were adopted after an extensive review of computational procedures and a reanalysis of industry reporting patterns. Because of these changes, consumption data for ferrous-base scrap were revised significantly upward. Some of these changes also affected data on copper-base and nickel-base scrap.

[2] Primarily used beverage cans and foundry borings and turnings.

[3] Primarily stainless and alloy steel scrap consumed at steel mills and foundries.

[4] Includes can scrap converted to ingot by toll smelters for sale on open market.

TABLE 3
REPORTED U.S. CONSUMPTION OF NICKEL, BY FORM

(Metric tons of contained nickel)

Form	1989	1990	1991	1992	1993
Primary:					
Metal	[r]80,257	[r]84,560	[r]77,053	70,006	72,281
Ferronickel	[r]14,174	[r]25,024	[r]21,690	[r]21,193	21,229
Oxide and oxide sinter[1]	5,883	5,578	3,901	4,578	4,439
Chemicals	[r]1,256	1,155	[r]1,246	[r]1,211	1,789
Other	[r]2,298	4,529	4,889	4,427	5,697
Total primary	[r]103,868	[r]120,846	[r]108,779	[r]101,415	105,435
Secondary (scrap)[2]	[r]52,131	[r]57,367	[r]53,521	[r]55,871	54,702
Grand total	[r]155,999	[r]178,213	[r]162,300	[r]157,286	160,137

[r] Revised.

[1] Includes chemical-grade oxide.

[2] Based on gross weight of purchased scrap consumed and estimated average nickel content. Data were revised for 1989 through 1992. (See footnote 1 of table 2.)

TABLE 4
U.S. CONSUMPTION OF NICKEL, BY USE

(Metric tons of contained nickel)

Use	Metal	Ferro-nickel	Oxide and oxide sinter	Chemicals	Other forms	Total primary	Secondary (scrap)	1993 grand total	1992 grand total[r]
Cast irons	220	W	W	W	36	256	1,422	1,678	1,202
Chemicals and chemical uses	W	—	W	1,385	—	1,385	—	1,385	51
Electric, magnet, expansion alloys	W	—	—	—	W	W	W	W	W
Electroplating (sales to platers)	16,309	W	W	292	10	16,611	—	16,611	16,538
Nickel-copper and copper-nickel alloys	2,990	W	W	W	W	2,990	3,088	6,078	6,313
Other nickel and nickel alloys	15,789	W	W	—	W	15,789	1,215	17,004	15,946
Steel:									
Stainless and heat-resistant	17,488	20,232	W	—	4,808	42,528	44,878	87,406	83,460
Alloys (excludes stainless)	3,927	W	W	—	W	3,927	947	4,874	4,988
Superalloys	10,782	—	1	W	W	10,783	W	10,783	10,872
Other[1]	4,776	997	4,438	112	843	11,166	3,152	14,318	17,918
Total reported	72,281	21,229	4,439	1,789	5,697	105,435	54,702	160,137	[2]157,286
Total all companies, apparent	XX	XX	XX	XX	XX	122,077	37,236	159,313	159,373

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

[1] Includes batteries, catalysts, ceramics, coinage, and other alloys containing nickel, and data represented by symbol "W."

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

TABLE 5
NICKEL IN CONSUMER STOCKS IN THE UNITED STATES, BY FORM

(Metric tons of contained nickel)

Form	1989	1990[r]	1991	1992	1993
Primary:					
Metal	[r]5,877	7,331	[r]7,738	[r]8,035	7,981
Ferronickel	[r]1,892	996	[r]1,360	[r]2,478	1,708
Oxide and oxide sinter	1,313	289	1,028	1,022	915
Chemicals	[r]260	223	[r]179	[r]212	275
Other	[r]277	217	181	[r]505	158
Total primary	[r]9,619	9,056	[r]10,486	[r]12,252	11,037
Secondary (scrap)[1]	[r]6,943	4,915	[r]5,435	[r]5,182	3,345
Grand total	[r]16,562	13,971	[r]15,921	[r]17,434	14,382

[r] Revised.

[1] Based on gross weight of purchased scrap consumed and estimated average nickel content. Data were revised for 1989 through 1992. (See footnote 1 of table 2.)

TABLE 6
U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel unless otherwise specified)

Class	1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought primary:				
Cathodes, pellets, briquets, and shot	887	$7,913	650	$5,332
Ferronickel	1,725	5,358	1,140	5,590
Powder and flakes	694	10,744	606	10,312
Metallurgical-grade oxide[1]	4,073	8,454	5,064	14,018
Chemicals:[2]				
Catalysts	1,202	40,138	1,224	49,145
Salts	292	4,440	420	6,962
Total[3]	8,873	77,047	9,104	91,359
Unwrought secondary:[4]				
Stainless steel scrap	17,472	212,368	17,407	196,380
Waste and scrap	10,712	49,355	10,391	47,025
Total[3]	28,184	261,723	27,798	243,405
Grand total	37,057	338,770	36,902	334,764
Wrought:				
Bars, rods, profiles and wire	181	1,786	206	2,242
Sheets, strip and foil	224	3,102	106	2,382
Tubes and pipes	61	1,049	42	1,132
Total[3]	465	5,937	354	5,756
Alloyed (gross weight):				
Unwrought alloyed ingot	2,694	27,479	2,858	23,849
Bars, rods, profiles and wire	4,836	72,714	5,073	73,483
Sheets, strip and foil	4,867	76,379	4,691	76,820
Tubes and pipes	1,092	26,857	996	22,532
Other alloyed articles	1,754	23,306	2,440	30,700
Total	15,243	226,735	16,058	227,384

Class	1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought primary:				
Cathodes, pellets, briquets, and shot	750	$4,302	755	$4,128
Ferronickel	2,374	9,752	669	2,313
Powder and flakes	568	9,132	573	8,091
Metallurgical-grade oxide[1]	3,443	6,701	3,749	6,552
Chemicals:[2]				
Catalysts	1,000	49,048	987	52,413
Salts	425	5,241	450	6,640
Total[3]	8,560	84,175	7,183	80,137
Unwrought secondary:[4]				
Stainless steel scrap	16,740	153,702	17,850	147,226
Waste and scrap	8,567	34,095	8,166	31,678
Total[3]	25,307	187,797	26,016	178,904
Grand total	33,867	271,971	33,199	259,041
Wrought:				
Bars, rods, profiles and wire	242	2,543	237	2,012

See footnotes at end of table.

TABLE 6—Continued

U.S. EXPORTS OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel unless otherwise specified)

Class	1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Wrought—Continued:				
Sheets, strip and foil	149	3,592	215	2,256
Tubes and pipes	56	1,819	99	1,487
Total[3]	447	7,955	551	5,755
Alloyed (gross weight):				
Unwrought alloyed ingot	2,526	23,137	1,887	18,556
Bars, rods, profiles and wire	4,700	65,824	4,544	63,603
Sheets, strip and foil	5,453	67,861	5,701	74,316
Tubes and pipes	895	17,548	1,055	24,903
Other alloyed articles	1,610	33,735	1,754	50,981
Total	15,184	208,105	14,941	232,359

[1] Chemical-grade oxide is included with salts.

[2] For the different salts, the nickel contents are assumed to be as follows: chlorides, 25%; sulfates, 22%; other salts, 22%; and oxide, sesquioxide and hydroxide, 65%. The typical catalyst is assumed to have a nickel content of 22%.

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

[4] The nickel content of waste and scrap is assumed to be 50%, while that of stainless steel has been shown to be about 7.5%.

Sources: Bureau of the Census and Journal of Commerce.

TABLE 7
U.S. EXPORTS OF NICKEL PRODUCTS IN 1993, BY COUNTRY

(Metric tons of contained nickel[1])

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Ferro-nickel	Metallurgical-grade oxide[2]	Waste and scrap	Stainless steel scrap	Salts and catalysts	Total	Wrought nickel[3]
Australia	—	1	—	14	63	9	1	88	7
Belgium	—	41	—	—	250	669	7	967	—
Canada	340	124	—	3,389	4,577	4,037	239	12,706	69
China	—	(4)	—	—	8	295	88	391	4
Colombia	6	2	—	2	—	—	9	19	11
Finland	—	—	493	—	147	—	—	640	—
France	57	7	—	1	14	101	8	188	25
Germany	—	25	—	(4)	384	54	30	493	5
India	—	1	—	—	116	270	7	394	—
Italy	—	5	—	—	—	1	34	40	14
Japan	—	33	—	329	893	3,324	75	4,654	5
Korea, Republic of	3	13	176	1	25	5,030	59	5,307	3
Mexico	215	106	—	5	10	51	139	526	71
Netherlands	4	(4)	—	—	719	366	21	1,110	2
Russia	77	—	—	—	49	—	3	129	—
Spain	—	1	—	(4)	493	2,594	3	3,091	—
Sweden	—	(4)	—	—	79	138	3	220	(4)
Taiwan	19	13	—	—	78	575	94	779	4
United Kingdom	2	152	—	1	196	55	65	471	18
Other	32	49	—	7	65	281	552	986	313
Total	755	573	669	3,749	8,166	17,850	1,437	33,199	551

[1] The nickel contents are assumed to be as follows: metallurgical-grade oxide, 77%; waste and scrap, 50%; and stainless steel scrap, 7.5%. The salts and catalysts category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; sulfates, 22%; other salts, 22%; and supported catalysts, 22%.

[2] Chemical-grade oxide is included with "Salts and catalysts."

[3] Not included in total.

[4] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel[1] unless otherwise specified)

Class	1990		1991	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought primary:				
Cathodes, pellets, briquets, and shot	104,501	$910,544	102,160	$844,670
Ferronickel	14,273	116,484	14,547	113,267
Flakes	8	53	(2)	1
Powder	9,126	91,179	8,913	86,011
Metallurgical-grade oxide	3,303	28,809	4,446	36,903
Chemicals:				
Catalysts	901	34,163	1,014	26,635
Salts	1,433	16,917	1,366	16,049
Total	133,545	1,198,149	132,446	1,123,536
Unwrought secondary:				
Stainless steel scrap	7,661	31,284	2,478	23,139
Waste and scrap	3,973	46,764	3,734	35,499
Total	11,634	78,048	6,212	58,638
Grand total	145,179	1,276,197	[3]138,659	1,182,174
Wrought:				
Bars, rods, profiles and wire	600	7,963	669	8,323
Sheets, strip and foil	350	5,228	322	4,969
Tubes and pipes	84	2,304	140	3,588
Total	1,034	15,495	1,131	16,880
Alloyed (gross weight):				
Unwrought alloyed ingot	1,738	17,444	2,050	19,554
Bars, rods, profiles and wire	1,785	22,251	1,798	23,836
Sheets, strip and foil	1,173	19,312	1,094	18,232
Tubes and pipes	743	17,068	2,646	52,995
Other alloyed articles	231	8,132	206	4,849
Total	5,670	84,207	7,794	119,466

Class	1992		1993	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Unwrought primary:				
Cathodes, pellets, briquets, and shot	89,502	$627,921	95,918	$515,625
Ferronickel	13,015	88,035	13,223	66,489
Flakes	1	21	212	1,316
Powder	8,992	83,419	8,485	73,724
Metallurgical-grade oxide	4,184	30,361	4,490	25,259
Chemicals:				
Catalysts	1,770	27,103	2,485	41,924
Salts	1,296	14,226	1,539	14,968
Total	118,760	871,086	126,352	739,305
Unwrought secondary:				
Stainless steel scrap	5,701	21,807	3,698	20,210
Waste and scrap	3,805	25,984	3,015	19,095
Total	9,506	47,791	6,713	39,305
Grand total	128,266	918,877	133,065	778,610

See footnotes at end of table.

TABLE 8—Continued

U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY CLASS

(Metric tons of contained nickel[1] unless otherwise specified)

Class	1992 Quantity	1992 Value (thousands)	1993 Quantity	1993 Value (thousands)
Wrought:				
Bars, rods, profiles and wire	472	5,421	449	4,921
Sheets, strip and foil	317	6,554	490	9,476
Tubes and pipes	162	3,344	52	1,039
Total	951	15,319	991	15,436
Alloyed (gross weight):				
Unwrought alloyed ingot	2,376	21,153	2,722	19,544
Bars, rods, profiles and wire	1,678	20,680	2,169	24,244
Sheets, strip and foil	923	12,961	1,282	15,998
Tubes and pipes	713	12,774	570	15,596
Other alloyed articles	254	4,949	306	5,445
Total	5,944	72,517	7,049	80,827

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[1] The nickel content of metallurgical-grade oxide from Australia is assumed to be 90%; elsewhere, 77%. The salts category contains the following: chemical-grade oxide, sesquioxide, and hydroxide, 65%; chlorides, 25%; sulfates, 22%; and other salts which are assumed to be 22% nickel. The typical catalyst is assumed to have a nickel content of 22%. Waste and scrap is assumed to be 50% nickel; stainless steel scrap, 7.5% nickel.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF NICKEL PRODUCTS, BY COUNTRY

(Metric tons of contained nickel[1])

Country	Cathodes, pellets, and briquets, (unwrought)	Powder and flakes	Ferronickel	Metallurgical-grade oxide[2]	Waste and scrap	Stainless steel scrap	Salts and catalysts	Totals		Wrought nickel[3]
								1993	1992	
Australia	7,580	1,910	—	4,107	14	—	4	13,615	14,042	—
Austria	—	65	316	—	—	—	(4)	381	16	(4)
Belgium	178	1	—	—	7	—	414	600	294	—
Brazil	1,188	—	1,032	—	18	2	—	2,240	1,801	7
Canada	51,230	6,161	—	355	795	1,916	1,810	62,267	64,811	113
Colombia	—	—	1,198	—	—	12	—	1,210	2,224	—
Dominican Republic	—	—	6,270	—	10	2	—	6,282	7,531	—
Finland	1,762	—	—	—	278	9	401	2,450	794	(4)
France	1,686	—	—	—	217	—	104	2,007	1,871	37
Germany	19	8	—	(4)	256	—	220	503	631	461
Japan	(4)	1	—	—	18	—	721	740	476	42
Macedonia	—	—	295	—	—	—	—	295	102	—
Mexico	—	—	—	—	47	1,403	9	1,459	1,209	—
New Caledonia	—	—	4,077	—	—	—	—	4,077	1,428	—
Norway	18,480	2	—	—	30	—	—	18,512	17,652	—
Russia	6,629	36	21	—	—	—	30	6,716	4,354	—
South Africa, Republic of	5,019	341	13	—	202	—	9	5,584	2,263	—
United Kingdom	90	66	—	28	598	4	37	823	974	12
Zimbabwe	1,947	—	—	—	—	—	—	1,947	3,221	—
Other	110	106	1	—	525	350	265	1,357	r2,574	319
Total	95,918	8,697	13,223	4,490	3,015	3,698	4,024	133,065	[5]128,266	991

rRevised.

[1] The nickel content of metallurgical-grade oxide from Australia is assumed to be 90%; elsewhere, 77%. The salts and catalysts category contains the following: chemical-grade oxide, sesquoxide, and hydroxide, 65%; chlorides, 25%; sulfates, 22%; and other salts, which are assumed to be 22% nickel. The typical catalyst is assumed to have a nickel content of 22%.

[2] Primarily oxide rondelles and sinter.

[3] Not included in "Total."

[4] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 10
NICKEL: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of nickel content)

Country	1989	1990	1991	1992	1993[e]
Albania (content of ore)[e]	11,200	8,800	7,500	150	75
Australia (content of concentrate)	[r]65,000	67,000	69,000	[r]57,683	[2]64,700
Botswana (content of ore milled)	23,700	23,200	23,500	[r]23,000	23,000
Brazil (content of ore)	18,826	18,788	20,456	[r][e]20,500	20,500
Burma (content of ore)[e]	[r]20	[r]50	[r]20	[r]20	20
Canada (content of concentrate)	200,899	196,225	192,259	[r]186,384	[2]188,378
China[e]	34,250	33,000	[r]30,400	[r]32,800	33,000
Colombia (content of laterite ore)	21,425	22,439	20,590	23,063	23,300
Cuba (content of oxide, sinter, sulfide)[e]	46,268	40,778	33,349	32,190	[2]30,218
Dominican Republic (content of ferronickel produced)	31,264	28,700	29,062	[r]27,535	[2]23,863
Finland (content of concentrate)	10,480	11,524	9,900	[r]9,870	8,300
Germany	1,476	872	—	—	—
Greece (laterite ore)[3]	18,900	18,500	19,300	18,700	[2]12,600
Indonesia (content of ore)	62,987	68,308	71,681	[r]77,600	65,800
New Caledonia (content of ore)	96,200	85,100	114,492	[r]113,000	98,100
Norway (content of concentrate)	780	3,100	2,200	3,398	[2]3,462
Philippines	15,380	15,818	13,658	[r]14,000	[2]10,200
Russia	—	—	—	[r][e]280,000	243,000
Serbia and Montenegro (content of ferronickel produced)[4]	—	—	—	[e]2,000	2,000
South Africa, Republic of (content of concentrate)	28,900	29,000	27,700	28,400	28,900
Ukraine	—	—	—	[e]5,000	4,500
U.S.S.R. (content of ore)[e] [5]	280,000	280,000	[r]280,000	—	—
United States (content of ore shipped)	—	330	5,523	6,671	[2]2,464
Yugoslavia (content of ferronickel produced)[e] [4] [6]	[r]5,100	[r]3,600	[r]2,400	—	—
Zimbabwe (content of concentrate)	[r]13,600	[r]13,490	12,371	[r]12,378	12,769
Total	[r]986,655	[r]968,622	[r]985,361	[r]974,342	899,149

[e]Estimated. [r]Revised.

[1] Insofar as possible, this table represents recoverable mine production of nickel. Where actual mine output is not available, data related to a more highly processed form have been used to provide an indication of the magnitude of mine output and this is noted parenthetically or by a footnote following the country name. Finland and the United States both reported receiving ferronickel originating from Macedonia in 1992, but definitive information on the output of the Kavadarci operation was not available. Table includes data available through Aug. 1, 1994.

[2] Reported figure.

[3] This series (content of laterite ore) differs from that published previously. The earlier series shown (content of ferronickel produced) is given in table 11.

[4] All production in Yugoslavia from 1989-91 came from Serbia and Montenegro.

[5] Dissolved in Dec. 1991.

[6] Dissolved in Apr. 1992.

TABLE 11
NICKEL: WORLD PLANT PRODUCTION BY COUNTRY AND PRODUCT[1]

(Metric tons of nickel content)

Country[2] and product	1989	1990	1991	1992	1993[e]
Albania: Metal[e]	1,800	2,500	2,200	50	50
Australia: Unspecified	44,000	[r]43,000	[r]50,000	[r]50,000	50,000
Austria: Ferronickel	2,800	3,300	3,500	2,500	2,500
Brazil:[3]					
Ferronickel	9,445	8,847	8,620	[r]9,000	9,000
Metal	4,228	[r]4,157	5,220	[r]5,926	6,000
Total	13,673	[r]13,004	13,840	[r]14,926	15,000
Canada: Unspecified[4]	[r]142,800	[r]134,700	[r]131,500	[r]135,200	[5]123,140
China: Metal[e]	25,600	[r]27,500	[r]28,900	[r]30,800	32,000
Colombia: Ferronickel	16,939	18,424	20,194	20,195	20,200
Cuba: Oxide[6]	26,251	[r]21,126	[r][e]18,756	[r]16,920	[5]16,185
Czechoslovakia: Metal[7][8]	3,800	[e]2,970	[r][e]2,400	[r]1,621	—
Dominican Republic: Ferronickel	31,264	28,700	[r]29,062	[r]27,535	[5]23,863
Finland:					
Chemicals	[r]1,933	[r]1,644	[r]2,163	2,890	[5]3,126
Metal	13,355	16,882	13,850	14,781	14,800
Total	[r]15,288	[r]18,526	[r]16,013	17,671	17,926
France:					
Chemicals	1,400	1,090	1,000	[e]1,200	1,200
Metal	8,632	8,540	7,400	[e]6,800	6,800
Total	10,032	9,630	8,400	[e]8,000	8,000
Germany: Eastern states: Metal	2,271	1,657	850	—	—
Greece: Ferronickel	16,097	15,727	16,005	[e]15,400	12,000
Indonesia: Ferronickel	4,964	5,005	5,318	[r]5,506	[5]5,266
Japan:					
Ferronickel	62,834	56,474	68,045	57,447	51,100
Metal	21,938	22,274	23,658	22,038	23,100
Oxide	21,444	21,500	22,500	[r]27,500	25,000
Total	106,216	100,248	114,203	[r]106,985	99,200
Korea, Republic of: Metal	4,173	5,987	[e]11,340	[e]10,000	10,000
New Caledonia: Ferronickel	36,285	32,278	34,411	31,895	[5]36,850
Norway: Metal	54,886	57,812	58,730	55,686	[5]56,817
Russia:[e][9]					
Ferronickel	—	—	—	[r]22,000	17,000
Metal	—	—	—	[r]205,000	160,000
Oxide	—	—	—	[r]13,000	10,000
Chemicals	—	—	—	[r]3,000	2,000
Total	—	—	—	[r]243,000	189,000
Serbia and Montenegro:					
Ferronickel[e]	—	—	—	2,000	2,000
South Africa, Republic of: Metal	28,100	28,200	26,863	27,621	30,000
Sweden: Metal	572	610	490	[e]500	500
Taiwan: Metal[e]	10,000	10,400	[r]11,200	10,000	9,000
Ukraine: Ferronickel[e]	—	—	—	[r]4,000	3,500

See footnotes at end of table.

TABLE 11—Continued

NICKEL: WORLD PLANT PRODUCTION BY COUNTRY AND PRODUCT[1]

(Metric tons of nickel content)

Country[2] and product	1989	1990	1991	1992	1993[e]
U.S.S.R.:[e] [9]					
Ferronickel	25,000	[r]22,000	20,000	—	—
Metal	255,000	[r]240,000	[r]230,000	—	—
Oxide	15,000	[r]13,000	12,000	—	—
Total	295,000	[r]275,000	[r]262,000	—	—
United Kingdom: Metal	26,100	26,800	29,030	[e]28,000	28,000
United States: Ferronickel	347	3,701	7,065	8,962	[5]4,878
Yugoslavia:					
Ferronickel[e]	5,100	3,600	2,500	—	—
Metal	956	—	—	—	—
Total[e]	6,056	3,600	2,500	—	—
Zimbabwe: Metal[10]	11,633	11,426	11,297	[r]10,349	[5]11,097
Grand total	[r]936,947	[r]901,831	[r]916,067	[r]885,322	806,972
Of which:					
Chemicals	[r]3,333	[r]2,734	[r]3,163	[r]7,090	6,326
Ferronickel	211,075	[r]198,056	[r]214,720	[r]206,440	188,157
Metal	[r]473,044	[r]467,715	[r]463,428	[r]429,172	388,164
Oxides	[r]62,695	[r]55,626	[r]53,256	[r]57,420	51,185
Unspecified	186,800	177,700	181,500	185,200	173,140

[e] Estimated. [r] Revised.

[1] Table includes data available through Nov. 1994.

[2] In addition to the countries listed, North Korea is believed to have produced metallic nickel and/or ferronickel, but information is inadequate to make reliable estimates of output levels. Finland and the United States both reported receiving ferronickel originating from Macedonia in 1992 and 1993, but definitive information on the output of the Kavadarci operation was not available. Several countries produce nickel-containing matte, but output of nickel in such materials has been excluded from this table in order to avoid double counting. Countries producing matte include the following, with output indicated in metric tons of contained nickel: Australia (estimated): 1989—45,000; 1990—45,000; 1991—45,000; 1992—45,000; and 1993—45,000; Botswana: 1989—19,759; 1990—19,022; 1991—19,294; 1992—18,873; and 1993—21,620; Canada: 1989—44,320; 1990—43,300 (estimated); 1991—40,000 (estimated); 1992—40,000 (estimated); and 1993—40,000 (estimated); Indonesia: 1989—29,030; 1990—24,949; 1991—27,433; 1992—39,307; 1993—40,000 (estimated); New Caledonia: 1989—10,650; 1990—9,683; 1991—9,041; 1992—7,475; and 1993—10,883.

[3] Brazil is believed to also produce nickel oxide, but information is not available on which to base estimates.

[4] Nickel contained in products of smelters and refineries in forms which are ready for use by consumers.

[5] Reported figure.

[6] Cuba also produces nickel sulfide but, because it is used as feed material elsewhere, it is not included to avoid double counting. Output of processed sulfide was as follows, in metric tons: 1989—20,017; 1990—19,652; 1991—14,593; 1992—15,270; 1993—14,033.

[7] Dissolved Dec. 31, 1992.

[8] All production in Czechoslovakia from 1989-92 came from Slovakia. Production for 1993 is estimated to be zero.

[9] Includes production from sulfidized concentrates shipped from Cuba for toll refining.

[10] Excludes production from matte shipped from Botswana for toll refining.

FIGURE 1

LONDON METAL EXCHANGE CASH PRICE AND STOCKS, 1990-94

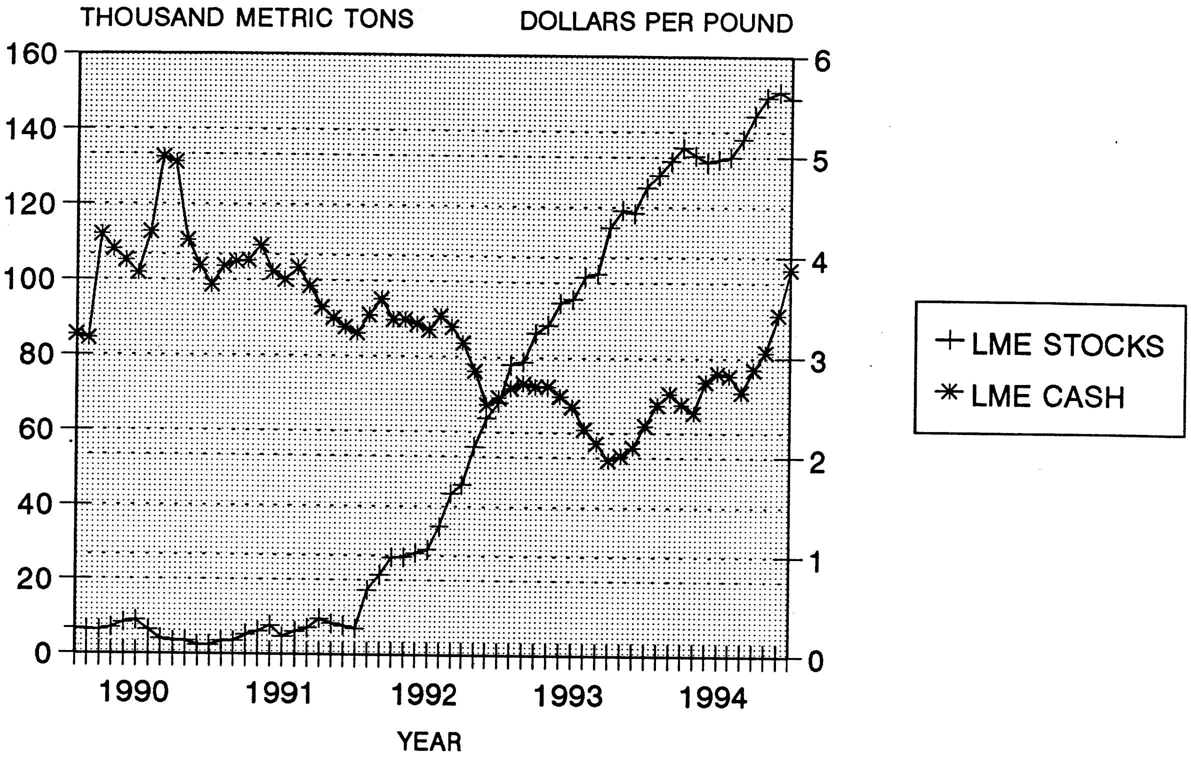


FIGURE 2

U.S. NICKEL CONSUMPTION IN 1993, BY FORM AND USE

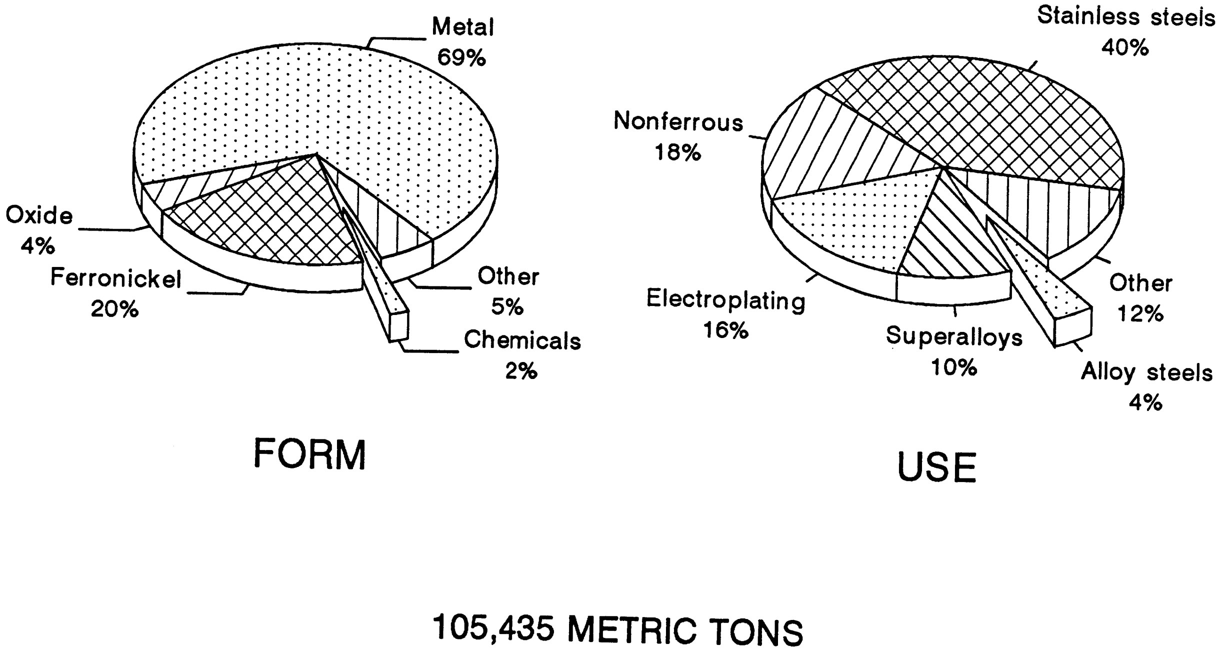
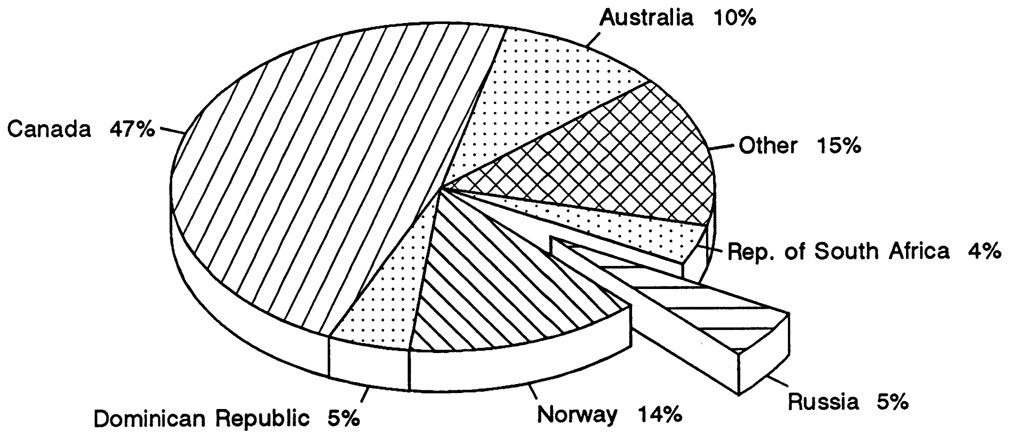


FIGURE 3
COMBINED U.S. PRIMARY AND SECONDARY NICKEL IMPORTS, BY COUNTRY



133,065 METRIC TONS

NITROGEN

By Raymond L. Cantrell

Mr. Cantrell joined the U.S. Bureau of Mines as a physical scientist in 1988 following 25 years in the private sector. He coordinated fertilizer market research for the W. R. Grace & Co. Agricultural Chemicals Group (1972-87); conducted plastics product development for Hasbro Industries (1968-72); and fertilizer and organics research and development, Columbia Nitrogen Corp. (1964-68). Domestic survey data were prepared by Gail D. Mason, statistical assistant; and the world ammonia production table was prepared by Amy Burk, international data coordinator.

Synthetic anhydrous ammonia (NH_3) is the basic building block for a seemingly endless variety of agricultural and industrial nitrogen (N) compounds essential to life and prosperity on Earth. In agriculture, nitrogen compounds serve as fertilizers and crop protection chemicals vital to the production of enough food, fiber, and protein to sustain a global population rapidly approaching 6 billion. In industry, nitrogen compound demand ranges from relatively simple but important consumer products like ammonia cleaning agents to more advanced technical applications in the mining, polymer, and environmental remediation industries. Therefore, it is not surprising to find ammonia or downstream nitrogen compound consumption in virtually every country. Elemental nitrogen (N_2) mined from the atmosphere is used extensively by the electronics, metals, food, and aerospace industries because of its inert and cryogenic properties.

In 1993, more than 75 countries produced an estimated 111 million metric tons of anhydrous ammonia product (82.2% N) that carried a landed value of about $14 billion. World ammonia production declined for the fourth consecutive year owing to continued restructuring in the former U.S.S.R. and Eastern bloc countries, and recession in Western Europe.

U.S. ammonia plants continued to operate at near capacity, indicative of another good year for the U.S. nitrogen fertilizer and industrial sectors. Ammonia output was 15.7 million tons, or 14% of the global total, while consumption, including imports, accounted for roughly 17% of world demand. U.S. production of elemental nitrogen gas reached a record high 0.9 billion cubic feet.

Several historic events occurred in the U.S. nitrogen fertilizer industry during 1993. Record floods across several Midwestern States during the summer and early fall of 1993 damaged or destroyed significant acreages of feed grains, which reduced grain inventories to low levels, and created a more favorable outlook for 1994. At the same time, Arcadian Corp. of Memphis, TN, continued to gain a more dominant posture in the nitrogen business through plant acquisitions, including B.P. International's facility at Lima, OH, together with a large operation in Trinidad and Tobago.

In the ammonium phosphate sector of the nitrogen business, Cargill, Inc.'s purchase of Seminole Fertilizer, together with the formation of a joint venture between IMC Fertilizer and the Agrico Div. of Freeport-McMoRan, resulted in the aggregate consolidation of approximately 45% of U.S. ammonium phosphate capacity. Restructuring of this historically volatile export-oriented business was welcomed by the industry as a whole and should bring some semblance of stability to the supply side of the equation.

The Uruguay Round of General Agreement on Tariffs and Trade (GATT), under negotiation since 1986, was finally resolved in principle by yearend. A meeting was to be held in Morocco during early 1994 to negotiate the liberalization of agricultural trade policies that should enhance U.S. agricultural trade opportunities. The North American Free Trade Agreement (NAFTA) was approved by Congress late in the year and should enhance the outlook for U.S. agricultural trade with Canada and Mexico.

On July 9, 1993, the International Trade Administration (ITA), U.S. Department of Commerce, published a notice of intent in the Federal Register to revoke a urea antidumping duty order in force against countries of the former U.S.S.R. and Romania since mid-1987. On July 22, 1993, a private industry group, the AD Hoc Committee of Domestic Nitrogen Producers, objected to ITA's proposed ruling, and the order was rescinded.[1]

The metric system is the official system of measurement of most countries. The U.S. Bureau of Mines, in an effort to provide statistical data on nitrogen compounds that are in compliance with Public Law 100-418, began to report nitrogen data in metric units in 1992. *(See table 1.)*

DOMESTIC DATA COVERAGE

Industry statistics for anhydrous ammonia and derivative products were developed by the Bureau of the Census, U.S. Department of Commerce. Preliminary monthly data were published under product codes 28731, 28732, and 28742 in Current Industrial Reports (CIR), Fertilizer Materials, M28B. In 1991, the Bureau of the Census adopted a quarterly format and replaced monthly series M28B with the quarterly series

MQ28B, under the same title. Final data are subsequently published in a companion annual report MA28B. During 1993, the Bureau of the Census surveyed approximately 250 known producers of inorganic fertilizer materials. Statistics covering industrial gases were reported in the Bureau of the Census CIR publications M28C, M28QC, and MA28C, Industrial Gases.

BACKGROUND

Nitrogen chemical matter developed as part of our solar system about 5 billion years ago, according to astrophysics. Outgassing from the interior, soon after the Earth was formed, is believed to be the source of the nitrogen-rich atmosphere as we know it today. Nitrogen was discovered independently in 1772 by the Swedish druggist, Carl Scheele, and the Scottish botanist, Daniel Rutherford.[2]

Earth is enveloped by an atmosphere dominated by nitrogen (N_2), oxygen (O_2), and water vapor. The air we breathe consists of about 78% N_2 and about 21% O_2 by volume; argon makes up most of the remainder. Trace amounts of helium, hydrogen, krypton, neon, and xenon are natural atmospheric sources, together with the greenhouse gases—global warming gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Nitrogen is an absolute requirement for all life forms on Earth. The gas cycles between its inert diatomic form (N_2) in the atmosphere and chemically fixed forms on Earth, weaving an intricate balance with the carbon cycle that is driven by the photosynthesis processes of living plants. Plants absorb carbon dioxide from the atmosphere, synthesize carbohydrates and essential amino acids and proteins (nitrogen forms), and emit oxygen. The microorganisms of the rhizosphere topsoil supply available mineral nitrogen to nonleguminous plants and biological nitrogen to leguminous (nitrogen fixing) plants for human and animal nutrition.

At the turn of the 20th century, natural sources of nitrogen chemical materials supplied virtually all of the nutrient requirements for agricultural crop production. Mineralized organic soil nitrogen, domestic animal manures and byproducts, guano, seed meals, and coke oven ammonia predominated. The mineralized occurrences of sodium nitrate found in the Atacama Desert of northern Chile also provided strategic supplies of agricultural nitrogen to the global community.

In the late 1800's, agronomists warned that a global food crisis would materialize unless supplemental nitrogen forms could be found to increase crop production for the exploding world population. Four major industrial nitrogen fixation technologies evolved between 1900 and 1920: (1) the electric arc process, developed by Birkeland and Eyde in Norway, produced nitric oxide (NO) from atmospheric nitrogen and oxygen that was used to produce nitric acid (HNO_3); (2) the cyanamide process, discovered by Frank and Caro in Germany, synthesized calcium cyanamide ($CaCN_2$) from calcium carbide (CaC_2) and N_2; (3) the cyanide process, developed by Bucher of Brown University in Rhode Island, produced sodium cyanide (NaCN) from N_2 and sodium carbonate (Na_2CO_3) as an intermediate to ammonia production; and, (4) the ammonia process, developed by Haber and Bosch in Germany, reacted N_2 and hydrogen (H_2) under high temperatures and pressures in the presence of a catalyst to form ammonia (NH_3).

The Haber-Bosch process overshadowed all other industrial methods for producing nitrogen chemical materials and fostered today's mammoth ammonia-based nitrogen fertilizer and industrial sectors. This process was ideally suited for the large-scale commercial production of ammonia (82.2% N) because of the enormous natural resources of essential chemical feedstock elements: nitrogen from the atmosphere, hydrogen from fossil fuels (natural gas, petroleum, coal), and water.

Definitions, Grades, and Specifications[3]

At ordinary ambient temperature and pressure, anhydrous ammonia is a colorless gas with a very sharp, characteristic odor. Ammonia condenses to a liquid at minus 33° C (-28° F). Anhydrous ammonia is not a poison and has no cumulative toxic effects on the human body. It, however, is corrosive and may cause lung, throat, mouth, nose, and eye irritation. When liquid anhydrous ammonia comes into direct contact with the skin, a severe burn may result. Anhydrous ammonia is not combustible except when its concentration in the air falls between 16% to 25% at temperatures in excess of 850° C (1,560° F).

Ammonia vapor becomes "life threatening" only when exposure levels reach 2,500 to 6,500 parts per million (ppm) for up to 30 minutes or "rapidly fatal" if exposure levels reach 5,000- to 10,000-ppm concentrations for up to 30 minutes. Steel is the only acceptable metal allowed in the process of transfer, storage, and transport of anhydrous ammonia.

Technology

Elemental nitrogen is mined from the air by cryogenic separation and membrane technologies. In a typical air separation plant, liquefied air is separated into its individual components by fractional distillation. The resources of nitrogen in the air are virtually unlimited and renewable because of the continuous nitrogen cycle between fixed forms on Earth and atmospheric nitrogen.

Mining.—Mineralized occurrences of sodium nitrate ($NaNO_3$) and potassium nitrate (KNO_3) are mined in significant quantities in the Atacama Desert of northern Chile. The extremely arid nature of this region, with its paucity of soil microorganisms, creates an ideal environment for preserving the nitrate deposits that formed in Miocene times. The nitrate content of the deposits range from about 6.5% to 50%, with an estimated reserve base of about 2.5 billion tons.

Product grades of sodium nitrate and sodium nitrate-potassium nitrate mixtures are obtained through selective precipitation and filtering, followed by granulation. In 1992, Sociedad Quimica y Minera de Chile S.A. (SQM) produced more than 1 million tons of granular sodium nitrate and mixed potassium products for fertilizer and industrial use.[4]

SQM's principal product line, in order of importance, included sodium nitrate (16% N) and homogeneous chemical mixtures of sodium nitrate and potassium nitrate containing 15% N and 14% potash (K_2O). Sodium nitrate was also blended with potash to produce a mixed fertilizer containing 13% N and 44% K_2O.

Processing.—Anhydrous ammonia is typically produced through a sequence of catalytically driven reactions involving the steam reforming of natural gas in the presence of air to produce hydrogen and nitrogen in the proper ratio to effect ammonia synthesis. The latest state-of-the-art plants operate at about 25 million British thermal units (Btu) per ton, resulting in an energy efficiency of more than 70%.

Modern ammonia plants employ efficient centrifugal compressors for air and synthesis gas compression. Temperatures and pressures fluctuate throughout an ammonia plant depending on the process, but typically vary between 315° C to 980° C (600° F to 1,800° F) and 350,000 to 2,110,000 kilograms per square meter (kg/m^2) or 500 to 3,000 pounds per square inch gauge (psig), respectively. A nickel catalyst is used in the reformer and associated front-end sections of the plant where nitrogen and hydrogen are manufactured from natural gas, compressed air, and steam, while an iron-promoted catalyst is used to combine nitrogen and hydrogen to synthesize ammonia.

Urea is formed when ammonia is reacted with byproduct carbon dioxide (CO_2) generated during ammonia synthesis. The materials are reacted under high pressure in a two-step process at about 200° C (400° F) to first form ammonium carbamate, which then decomposes to urea (NH_2CONH_2).

Nitric acid is formed when ammonia is passed over a platinum-rhodium catalyst at about 930° C (1,700° F) and 84,400 kg/m^2, or 120 psig. As ammonia passes over the catalyst gauze, it reacts with oxygen to form nitric oxide (NO), which is converted to nitric acid by mixing with water in a countercurrent absorption tower.

Ammonium nitrate, in turn, is formed by the simple acid-base reaction between ammonia and nitric acid, and urea and ammonium nitrate may be blended to produce the popular U.S. urea-ammonium nitrate (UAN) fertilizer solutions containing 28% to 32% N.

Economic Factors

Between 1970 and the early 1980's, natural gas prices rose dramatically, causing ammonia production costs to become much more sensitive to feedstock costs. Natural gas feedstock costs as a percentage of total production costs rose from 45% in 1970 to 75% by 1982. Natural gas prices declined after 1985, and feedstock costs in 1992 represented about 65% of total ammonia production costs. Gas prices rose in 1993 and accounted for 68% of ammonia production costs.

The U.S. ammonia industry experienced record profitability during 1974-75 because of a tight global supply-demand situation, in spite of the rising dependency on feedstock costs; a similar situation developed during 1979-81. Conversely, the U.S. ammonia industry suffered substantial losses in 1986-87 owing to a sustained period of oversupply in the world fertilizer and grain markets.

A dramatic recovery in the U.S. agricultural sector since 1987, accompanied by favorable energy prices, has led to a return to profitability in the domestic converted nitrogen industry. The profit margin for straight nitrogen compounds (urea, ammonium nitrate, and UAN solutions) has been more consistent, on average, than the more volatile, cyclical price swings experienced by the export-dependent ammonium phosphate industry.

U.S. natural gas futures have been traded on the New York Mercantile Exchange (NYMEX) since April 3, 1990. Natural gas futures trading was designed to allow suppliers, producers, and end users to shift or hedge price risks. NYMEX believed that natural gas futures contracts would provide the same liquidity, unambiguous price reference, and hedge against risk characterized by its successful petroleum contract system. NYMEX futures trading suggested that a renewed upward spiral in natural gas prices would continue into 1993.

ANNUAL REVIEW

Legislation and Government Programs

NAFTA was signed into law by the President on December 8, 1993 (Public Law 103-182).[5] The act was to liberalize agricultural and industrial trade between Canada, Mexico, and the United States designed to gradually phase out most tariff barriers.

Also, the long-awaited agreement to finalize the Uruguay Round of multilateral trade negotiations involving more than 100 nations was enhanced by the signing of Public Law 103-49 on July 2, 1993, extending "fast track" procedures to conclude the Uruguay Round of GATT trade negotiations.[6] The GATT agreement was designed to liberalize agricultural and industrial trade on a global basis. The United States and more than 100 other nations were scheduled to sign the Uruguay Round agreement in Marrakesh, Morocco, on April 15, 1994.

The Food, Agriculture, Conservation, and Trade Act of 1990, Public Law 101-624, signed on November 28, 1990,[7] introduced several creative mechanisms designed to promote environmentally sound and cost-effective agricultural management practices, with the added objective of cutting discretionary Federal spending for farm programs. The 1990 farm bill provided the U.S. farmer with planting flexibility options ("triple base flexibility"), long-term Conservation Reserve and Wetlands Reserve Programs (CRP and WRP) designed to protect the environment and control grain inventories, and an Export Enhancement Initiative that would allow U.S. grain to compete in a global marketplace laden with unfair trade practices.

Under triple base, farmers lost Government deficiency payments on 15% of their base acreage but gained the flexibility to plant virtually any crop except fruits and vegetables on this land and still receive Government price support loans. The triple base initiative provided the impetus for a $13 billion reduction in Government "entitlement" farm program spending over a 5-year period as prescribed by the Omnibus Budget Reconciliation Act of 1990 (Public Law 101-508), signed on November 5, 1990.[8]

Agricultural provisions in the 1990 act were revised by the Omnibus Budget Reconciliation Act of 1993 (Public Law 103-66), signed by the President on August 10, 1993.[9] Agricultural policy changes in the new act will produce savings of $3.2 billion over 5 years. Major spending cuts involved more stringent restrictions on farm setaside programs. Current law exempted gasoline used on the farm for farming purpose from Federal excise taxes.

Total CRP acreage was originally mandated to increase from a level of 14 million hectares (34 million acres) in 1990 to between 16 to 18 million hectares (40 to 45 million acres) by 1995. Following the 12th CRP signup in mid-1992, the U.S. Department of Agriculture (USDA) reported that total CRP acreage had increased to 14.7 million hectares (36.4 million acres). Congress, however, did not include money for the fiscal year 1993 signup, and allocations would reportedly be directed toward the WRP in the future.

Lands available for WRP include restorable farmed wetlands that were converted to cropland prior to December 23, 1985, and functionally related wetlands, uplands, and riparian areas. In fiscal 1993, USDA was expected to accept about 20,000 hectares (50,000 acres) in WRP. Also, landowners in Midwestern States flooded in 1993 were to have the opportunity to return cropland to wetlands during the second signup period for the Emergency Wetlands Reserve Program (EWRP). The first EWRP signup returned an estimated 10,000 hectares (25,000 acres) to wetlands in the Midwest. Missouri and Iowa led the list of States accepted with 5,000 hectares (12,300 acres) and 2,400 hectares (6,000 acres), respectively.

The Alternative Agricultural Research and Commercialization Center (AARC) in Washington, DC, was empowered under title XVI (subtitle G), sections 1660 and 1661, of the 1990 farm bill to create the world's most effective organization in generating new industrial (nonfood, nonfeed) market demand for U.S. farm and forestry products. AARC includes a distinguished board of directors from private industry whose mission is to apply sound business and technical practices that will facilitate the prudent development and commercialization of cost-effective, environmentally friendly renewable industrial and consumer products. The new private ventures will create jobs, enhance rural economic development, and diversify agricultural markets.

The AARC Center expects, at minimum, matching funds for projects. Successful projects are expected to repay the AARC Center Revolving Fund through negotiated arrangements. In 1993, the Center was spending $10 million on projects and $25 million came from private-sector funds. Overall, private companies, nonprofit research organizations, and universities proposed 407 projects and requested $175 million in AARC Center funds to supplement $273 million in private investments.[10]

In February 1993, the Environmental Protection Agency (EPA) issued a final ruling on Standards for the Use or Disposal of Sewage Sludge.[11] The new regulations established requirements for the final use and disposal of sludge in three circumstances: (1) land application for beneficial purposes, including sewage sludge or sewage sludge products that are sold or given away for use in home gardens; (2) sludge disposal on land for placement on surface disposal sites, including sewage sludge-only landfills; and, (3) regulatory requirements for the incineration of sludge.

EPA noted that assessing the potential for adverse effects on public health and the environment from sludge pollutants had been a major challenge, but expressed confidence that the regulations would adequately protect public health and the environment. The Agency stated that when even given very conservative assumptions that probably overstated exposure, studies revealed virtually no adverse effects from sludge disposal on the land when used as a soil conditioner or fertilizer. EPA emphasized that while public exposure to incinerator emissions would pose the greatest threat to human health, available data indicated that detrimental effects should be minimal.

The Clean Air Act of 1990 (Public Law 101-549)[12] contained 11 titles that targeted 3 principal forms of pollution: acid rain, smog, and toxic air pollutants. One of the major impacts of the new clean air bill will be the emphasis placed on clean burning alternative fuels and the use of oxygenated fuels as air pollution control strategies. This strategy will have broad implications for both the United States and the international motor fuels market. The principal fuel oxygenates are methyl tertiary butyl ether (MTBE); ethanol, a derivative of corn; ethyl tertiary butyl ether (ETBE); and tertiary amyl methyl ether (TAME).[13]

EPA's Oxygenated Fuel Program became effective November 1, 1992, requiring gasoline marketers to supply oxygenated fuels for at least 4 months out of the year having a minimum average oxygen content of 2.7% by weight in the 39 cities that do not meet Federal air quality standards for carbon monoxide (CO). The National Corn Growers Association, a trade group in St. Louis, MO, and Information Resources, Inc., a Washington, DC, consulting firm, estimated that approximately 1.1 billion gallons of ethanol (419 million bushel corn equivalent) may be required to help meet the projected U.S. oxygenated fuel demand created by the Clean Air Act in 1993 and up to 2.4 billion gallons (894 million bushel corn equivalent) by the year 2000.[14]

EPA's Reformulated Fuel Program will commence on January 1, 1995, wherein the nine worst U.S. ozone nonattainment areas (Los Angeles, New York, Greater Connecticut, Baltimore, Philadelphia, Chicago, Milwaukee, Houston, and San Diego) will be required to sell gasoline with a minimum 2% by weight oxygen, 1% maximum by volume benzene, 25% aromatics maximum by volume, and no heavy metals (e.g., lead, manganese).

EPA was expected to announce a Renewable Oxygenate Standard (ROS) in mid-1994 mandating that 30% of oxygenated fuel used to produce reformulated gasoline for the Reformulated Fuel Program be made from renewable resources such as ethanol. Although 70% of oxygenates could still be nonrenewable and although the renewable resources would replace less than 2% of gasoline, most oil companies reportedly were opposed to the EPA decision.[15]

Acid rain is caused primarily by sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions from coal-fired electrical powerplants. Under title IV, SO_2 emissions were slated to decline 10 million tons from 1980 levels by the year 2000 and NO_x emissions were to be cut by 2 million tons.

Under title III, a list of 190 hazardous chemicals and materials was established for regulation with the requirement that maximum achievable control technology (MACT) be applied to industries emitting major sources of air pollutants. Several important industrial nitrogen-containing compounds were on the list, including acrylonitrile, aniline, caprolactam, ethyl carbamate (urethane), hydrazine, coke oven byproducts, and cyanides.

Section 313 of EPA's Emergency Planning and Community Right-to-Know Act of the Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) required EPA to establish a national inventory of toxic chemical emissions from certain facilities, called the Toxic Release Inventory (TRI). The 1991 TRI indicated that for 285 chemicals surveyed, a total of 3.3 million tons was released to the environment or transported to publicly owned treatment works (POTW's), of which about 1.5 million tons (45%) was released directly to the air, water, and/or injected underground.[16]

In 1991, a total of approximately 220,000 tons of ammonia was released into the environment: 39% to the air; water, 8%; injection into underground wells, 50%; and disposal in landfills, 3%. Another 53,000 tons was disposed of in POTW's. The 1991 TRI data could not be compared statistically with prior surveys because of a change in survey methodology.

Between 1987 and 1989, ammonia losses to the atmosphere declined by 18%, and discharges into rivers, lakes, streams, and other bodies of water declined 25%. Ammonia processed through municipal waste-treatment plants rose 14%, and underground injection disposal methods increased 17%. Ammonium nitrate and ammonium sulfate solutions of unknown concentration were released to the environment in an aggregate total of about 75,000 tons in 1991, about 60% of which was disposed of in POTW's.

The Energy Policy Act of 1992 (H.R. 776) was signed into law on October 24, 1992. The comprehensive energy bill contained 30 titles covering nonrenewable and renewable energy resources and was underscored by environmental and energy efficient mandates for the implementation of new technology and for long-range research and planning.

Some of the provisions that apply to agriculture and the Department of the Interior may be found in Title III—Alternative Fuels, General—the economic development of an 85% mixture of ethanol with gasoline or other nonrenewables; Title XII—Renewable Energy—biomass chemical conversion or direct combustion technology development; and Title XIII—Coal—clean coal technology that would reduce sulfur dioxide and nitrogen oxides in commercial powerplants and in nonfuel uses. The Secretary of the Interior was to provide consulting services to the Secretary of Energy for research and development of effective utilization of coal wastes and for the administration of mineral rights for coalbed methane projects on Federal lands. Title XVI—Global Climate Change—includes provisions for a 75% increase in energy derived from renewable resources over 1988 levels by the year 2005 and a reduction in the Nation's oil use from a level of approximately 40% of total energy consumption in 1990 to 35% by the year 2005.

Issues

A major issue for the fertilizer industry in coming years will be the Accidental Release Prevention program currently under development by EPA. Ammonia is the major fertilizer material targeted by EPA to be subject to program mandates. The Fertilizer Institute (TFI) of Washingston, DC, was working to assist the industry in preparing for the risk communication aspects of the program.

The U.S. ammonia industry has done a creditable job in implementing best management practices designed to significantly reduce ammonia emissions to the air and water. TFI recently conducted a survey of 28 U.S. ammonia plants representing 71% of industry capacity, and the results were impressive. In fact, TFI's study demonstrated that ammonia releases to the environment had been reduced by a significant 74% between 1987 and 1994.

Legislation involving fertilizer use taxes was introduced that would tax fertilizer production and use along with industrial and commercial water use to pay for city water and treatment facilities. The legislation as currently formulated would add approximately $14 to a ton of ammonia and would tax the release of chemicals on the TRI list at a minimum of $250 million annually.

EPA's multiyear phase 2 Drinking Water Well Survey released in late 1991 concluded that nitrate occurrence in U.S. waters is a limited, site-specific problem and cannot be generally predicted by a simple set of factors. EPA concluded that a variety of environmental conditions and human activities combine to affect the occurrence of nitrate in drinking water wells and that no one single factor can explain their presence.

TFI continued to communicate with EPA on the nitrate in drinking water issue. TFI pointed out that EPA's study had refuted the commonly held theory that a national drinking water quality problem exists and that a simple reduction in nitrogen fertilizer use would solve the problem. It was further pointed out that there were already two successful Federal programs in force establishing limits on the nitrate concentration in the Nation's water supply: the Safe Drinking Water Act and the Clean Water Act. TFI also reported that the few documented cases of "Blue Baby Syndrome" on record involved nitrate levels at several multiples of EPA's 10-ppm limit.

The large Saskferco ammonia and urea project that came on-stream in the fall of 1992 at Belle Plaine, Saskatchewan, continued to be monitored by the U.S. Ad Hoc Committee of Domestic Nitrogen Producers and the Canadian Council of Nitrogen Producers. The International Trade Commission (ITC), ITA, U.S. Department of Commerce, and the U.S. Trade Representative had been lobbied by the groups in 1991 regarding potential injury to other North American nitrogen producers and unfair subsidization of the project, a joint venture between Cargill Fertilizer of Minneapolis, MN, the Crown Corp. of Saskatchewan, and Citibank Canada.

Production

The U.S. ammonia industry operated at 99% of design capacity in 1993, indicative of a continuation of relatively balanced supply-demand conditions for ammonia and straight nitrogen conversion products. Thirty firms in twenty-three States across the country produced 15.7 million tons of anhydrous ammonia (82.2% N).

Ammonia production declined 6% owing to a combination of reduced demand for domestic product and plant closures, but capacity fell by a net of only 2% owing to a combination of debottlenecking activities in active plants and the startup of inactive units. Principal closures included Arcadian Corp's. ammonia and urea plant at Lake Charles, LA, and Nitrogen Products', Inc. ammonia and nitric acid plant at Helena, AR. Ammonia production ceased in Washington State altogether with the closure of Occidental Petroleum's small plant at Tacoma.

The gas-rich States of Louisiana, Oklahoma, and Texas, in order of importance, continued to provide about 60% of total U.S. production; the Midwest, 16%; South and Southeast, 14%; and the Western States, predominately Alaska, 9%. Natural gas feedstock costs at the well-head averaged $1.99 per million Btu, providing the industry with reasonably favorable profit margins at the wholesale level in the case of straight nitrogen fertilizers and for industrial products. The TFI annual survey of domestic ammonia producers, however, indicated that average ammonia production costs rose 15% to $117 per ton in 1993.[17] Production costs rose principally because of a runup in natural gas prices.

About 90% of the ammonia produced in U.S. plants was allocated to domestic fertilizer use and trade, and about 10% went into industrial products. Major downstream ammonia fertilizer derivatives included urea, 46% N; diammonium phosphate (DAP), 18% N; monoammonium phosphate (MAP), 11% N; ammonium nitrate (35% N); and ammonium sulfate, 21% N. Important industrial chemical derivatives and intermediates were urea, ammonium nitrate, nitric acid (22% N) and organic nitration products, acrylonitrile (26% N), caprolactam (12% N), and amine ($-NH_2$) derivatives. *(See tables 2 and 3.)*

Industry Profile.—Arcadian Partners, L.P., a master limited partnership, is a leading domestic and international producer and marketer of nitrogen fertilizers and chemicals used in agricultural and industrial applications. Arcadian's principal products are ammonia, urea, ammonium nitrate, and nitrogen solutions. Nitrogen solutions are Arcadian's most versatile fertilizer materials. Arcadian's sales mix is favorably balanced with approximately two-thirds destined for agriculture and the remainder to industrial products. With eight plants along the East Coast and Gulf Coast, the Midwest and in Trinidad, Arcadian has easy access and low transportation costs to most U.S. agricultural and industrial markets east of the Rocky Mountains. In addition, the Trinidad plant is well situated to serve Latin America and other world markets.[18]

In 1993, Arcadian made several strategic moves designed to increase market share and to improve the firm's competitive economics in the nitrogen fertilizer and industrial chemicals arena. In March, the firm purchased two adjacent fertilizer plants in the Republic of Trinidad and Tobago, an island country in the Caribbean Sea off the coast of Venezuela. The complex at Point Lisas consisted of two ammonia production units having a combined annual capacity of 700,000 tons and a granular urea production unit having a capacity of 530,000 tons.

The ammonia units had been jointly owned by Amoco Corp. of the United States and, Fertilizers of Trinidad and Tobago, Ltd. (FERTRIN), Trinidad and Tobago, while the urea plant, Trinidad & Tobago Urea Co., Ltd., was wholly owned by Trinidad and Tobago. Debottlenecking projects were to increase ammonia capacity 17%, to 820,000 annual tons, and urea capacity 21%, to 640,000 annual tons, by yearend.

In May, Arcadian acquired an integrated nitrogen fertilizer complex at Lima, OH, from BP Chemicals Inc. The plant geographics coincided with Arcadian's strategy of improving competitiveness through the acquisition of production capacity in close proximity to key market areas. Annual plant capacities at Lima were approximately 500,000 tons of ammonia, 310,000 tons of urea, and 200,000 tons of nitrogen solutions. Plans were also formulated to increase production capacity and improve the energy efficiency of nitrogen production facilities at Geismar, LA, and Memphis, TN.

Later in the year, Arcadian signed a letter of intent to purchase certain assets associated with a 350,000-ton-per-year nitric acid plant closed by E. I. Du Pont de Nemours & Co. Inc. at Gibbstown, NJ. Arcadian also leased a large subterranean ammonia storage cavern on-site. Du Pont was to continue to operate sodium nitrite facilities at Gibbstown.[19]

Arcadian's 400,000-ton-per-year ammonia plant at Lake Charles, LA, was mothballed in late July 1992 following irreversible damage to a 190,000-ton-per-year urea synthesis reactor. The ammonia plant was scheduled to be dismantled and sold to a firm in Pakistan.

In January 1993, Mississippi Chemical Corp. (MCC) started up a $32 million state-of-the-art nitric acid plant and ammonium nitrate neutralizer section at Yazoo City, MS. The new 550-ton-per-day nitric acid plant replaced two obsolete plants having a combined capacity of 330 tons per day and utilized the latest NO_x air emissions control technology. The new plants operated well above design levels in producing record levels of Amtrate solid ammonium nitrate and N-Sol UAN solution. MCC, along with Arcadian Corp. and Agricultural Minerals Corp., form the UAN Solutions Export Association operated under provisions of the Webb-Pomerene Act.

MCC officials announced the discovery of a new process for producing a unique industrial explosives-grade ammonium nitrate material possessing superior physical properties and detonation characteristics. The patented material was successfully produced in a pilot project.[20]

MCC's ammonium phosphate facility at Pascagoula, MS, Mississippi Phosphates, was brought to full capacity based on the reaction between ammonia and wet-process phosphoric acid derived from imported Moroccan phosphate rock. Atlantic Fertilizer and Chemical Corp. marketed the DAP output rated at 700,000 tons per year.

CF Industries Inc. of Long Grove, IL, a major North American cooperative, supplies nitrogen, phosphate, and potash fertilizer products to more than 1 million farmers and ranchers in 46 States and 2 Canadian Provinces. CF's ammonia, urea, and UAN Nitrogen Complex at Donaldsonville, LA, is the largest facility of its kind in the United States. CF also operates a wholly owned ammonium phosphate facility at Plant City, FL, having an annual capacity of 2 million product tons and holds a joint-venture interest in Canadian Fertilizers Ltd., a large ammonia and urea complex at Medicine Hat, Alberta.

CF's $87 million nitric acid and UAN solution expansion project at Donaldsonville, LA, was completed in mid-1993. Annual urea capacity was increased by 240,000 tons per year and UAN solution capacity by 440,000 tons per year. The new urea unit began commercial production in September, as planned.

The Donaldsonville ammonia plants were capable of operating at 1.8 million tons per year—120% of design capacity—because of revamp and retrofit initiatives that led to further improvements in the cooperative's competitive economics. CF management reported that ammonia emissions were reduced by 60% and NO_x emissions by 33% from 1987 levels. Ammonia production at the firm's Medicine Hat, Alberta, facility reached a record 1 million tons.

In 1993, two projects were completed to facilitate rail shipments from CF's ammonia terminal on Tampa Bay, acquired from Mulberry Phosphates in mid-1992. Throughput capacity is now rated at more than 800,000 tons annually. Primary assets include an ammonia terminal on the Port of Tampa having a 40,000-ton storage tank and related distribution equipment, together with the Tampa Bay Ammonia Pipeline system owned jointly with Cargill Fertilizer of Minneapolis, MN. The location of the storage facility is strategic in that only 37 rail miles are now required to deliver ammonia to CF's Plant City ammonium phosphate plant. The Tampa Bay Ammonia Pipeline system supplies ammonia to major producers of ammonium phosphates in Polk County, FL.

In mid-1993, construction was begun on the 3.5-million-ton-per-year South Pasture phosphate rock project in Hardee County, FL, following approval by the CF Board of Directors. The new state-of-the-art mine and beneficiation plant will provide CF with an independent and economic source of phosphate rock to meet demand for ammonium phosphate production at the Plant City complex for at least 20 years. The beneficiation plant from the depleted North Pasture mine was to be relocated, modified, and expanded.[21]

On May 4, 1993, Cargill purchased the phosphate production and mining assets of Seminole Fertilizer Corp., a subsidiary of Tosco Corp. of Stamford, CT. The transaction included the large ammonium phosphate complex at Bartow, FL; the Hookers Prairie phosphate rock mine in Polk County, FL; and an ammonia terminal at Port Sutton on Tampa Bay. Tosco initially retained its 50% interest in a large wet-process phosphoric acid plant at Ft. Meade, FL, owned jointly with U.S. Agri-Chem. (Sinochem) of China, but sold out to Agri-Chem. later in the year. Agri-Chem. operates a large ammonium phosphate facility at Bartow.

Cargill reportedly will have the aggregate capability of producing about 3 million tons per year of ammonium phosphates from its two large plants at Bartow and Tampa, FL, or 15% of the U.S. total. Ammonia requirements for ammonium phosphate production are sourced from the Tampa Bay Pipeline system—jointly owned by Cargill and CF Industries—and should average more than 500,000 tons per year.[22]

In mid-1993, the IMC Fertilizer Group Inc. (IMCF) of Mundelein, IL, and Freeport-McMoRan Resource Partners L.P. (FMRP) of New Orleans, LA, finalized one of the more significant consolidations in the history of the U.S. fertilizer industry. The new venture, IMC-Agrico, involved the merger of nitrogen and phosphate operations of FMRP's wholly owned Agrico Chemical Co. with IMCF, the leading producer of phosphate raw materials and finished ammonium phosphate fertilizers in the United States. According to information published by the International Fertilizer Development Center (IFDC) at Muscle Shoals, AL, the new joint-venture share of U.S. ammonium phosphate capacity approximates 30%, equating to an ammonia consumption potential of more than 1 million tons.[23] IMCF was to assume responsibility for operating the Agrico facilities.[24]

Agrico's primary nitrogen production facility—the Faustina plant—is on the Mississippi River near Donaldsonville, LA. Annual production capabilities at Faustina were 450,000 tons of ammonia, 225,000 tons urea, 2 million tons ammonium phosphates, and 500,000 tons P_2O_5 wet-process phosphoric acid. Agrico also operated a 1-million-ton-per-year ammonium phosphate plant at Taft, LA, together with wet-process phosphoric acid plants at Uncle Sam, LA, and Pierce, FL.

IMCF was operating the largest wet-process phosphoric acid and ammonium phosphate complex in the United States at New Wales, FL. IMCF had previously reached an agreement in principal to purchase the Conserv, Inc. 550,000-ton-per-year DAP plant at Nichols, FL, formerly owned by EniChem Agricoltura S.p.A. of Milan, Italy.

Farmland Industries, Inc. is a major U.S. cooperative specializing in the production of nitrogen and phosphate fertilizers. The firm ranks among the top nitrogen fertilizer producers in the United States. Farmland and J.R. Simplot have held joint-venture ownership of the former Chevron phosphate rock mine at Vernal, UT, and DAP plant at Rock Springs, WY, since early 1992. Annual DAP production capability at Rock Springs is 410,000 tons. Farmland has also moved the former Chevron Finley, WA, nitrogen solutions plant to its primary nitrogen production complex at Enid, OK.

In late 1991, Norsk Hydro became a joint-venture partner in Farmland's Green Bay, FL, phosphate operation. The Farmland Hydro Ltd. Partnership group operates from headquarters in Bartow, FL. DAP/MAP production capability approximates 1 million tons per year.

Agricultural Minerals Corp. (AMC) of Tulsa, OK, is traded publicly on the New York Stock Exchange as Agricultural Minerals Co. LP. AMC was founded in March 1990 by former Agrico executives to facilitate a leveraged buyout of the firm's nitrogen fertilizer production facilities at Verdigris, OK, and Blytheville, AR. Ammonia, urea, and UAN solutions are the primary products produced by AMC, along with the highly efficient slow-release Super N fertilizers containing dicyandiamide. AMC was among the top five U.S. nitrogen fertilizer producers. AMC is a member of the UAN Export Association.

Koch Industries, Inc. continued to operate a large ammonia complex at Sterlington, LA, acquired from IMCF in 1992. The Sterlington complex consists of two ammonia trains having a total capacity of 1 million tons per year. The acquisition provided a good fit for Koch Industries, owner of the Gulf Central Ammonia Pipeline that serves the Sterlington plant. An ammonia supply contract for a portion of IMCF's New Wales, FL, DAP-MAP complex was also negotiated.

In August, Air Products and Chemicals Inc. disclosed plans to shut down its 263,000-ton ammonia plant at New Orleans, LA, in the next 12 to 18 months. The firm was considering a plan to retrofit the plant for hydrogen production. The ammonia plant is in a large chemical complex that also produces hydrogen, oxygen, carbon dioxide, and other products. Hydrogen is a strategic product produced for the National Aeronautics and Space Administration (NASA).[25]

Air Products was completing a $1.5 million ammonium nitrate upgrade project at its Pace Junction, FL, facility in October that was to increase capacity 10% to 15%. The firm produces ammonia, ammonium nitrate, and nitrogen solutions at Pace Junction. At the same time, the firm reduced ammonia capacity by 50% to 91,000 tons per year by yearend.

Terra International, Inc. completed a 70,000-ton-per-year ammonia expansion at Port Neal, IA, in late 1992 that was to bring total annual capacity to about 270,000 tons. Emissions were also to be reduced 30%. Terra also announced a $15.5 million retrofit project that would provide for the optional production of up to 400 tons per day of methanol in the existing 1,200-ton-per-day ammonia plant at Woodward, OK, by early 1994. Ammonia capacity would reportedly be reduced by up to 20% because of the swing with methanol, but there was an upside advantage in hedging against fertilizer market seasonality. Methanol was to be sold to producers of methyl tertiary butyl ether (MTBE), the leading automotive fuel oxygenate.

In early November 1993, Cypress Chemicals began production of granular NitroS ammonium sulfate on the site of the former Nitrogen Products, Inc. plant at Helena, AR. The plant production capability was rated at 40,000 tons per year assaying 21% N and 24% sulfur (S). Cypress had earlier purchased the bankrupt facility at auction in April with the purpose of creating a regionalized granulation operation. Officials of Mulberry Phosphates, Inc. and other undisclosed parties reportedly provided financing for the new operation.[26]

Nitrogen Products' 190,000-ton-per-year ammonia plant at Helena, AR, together with an associated nitric acid plant, was closed in bankruptcy proceedings by the Dutch-owned bank NMB in late 1992 and later dismantled.

Coastal Chem, Inc's. planned 175,000-ton-per-year ammonia expansion at Cheyenne, WY, based on the reconstruction of a plant on-site, was delayed. Coastal completed a 130,000-ton-per-year nitric acid plant at Elko, NV, in 1992 to be used for the production of ammonium nitrate-based explosives.

Hydro Agri Ammonia, Inc. (HAAI), a U.S. affiliate of the Norwegian firm Norsk Hydro, continued to market ammonia from the former W.R. Grace & Co. joint-venture Tringen plants now run by Norsk and the Government of Trinidad and Tobago at Point Lisas. HAAI is headquartered in Tampa, FL, for this purpose and is staffed by key personnel from the former Grace marketing team in Memphis, TN.

Nitram, Inc. continued to produce about 300,000 tons per year of ammonium nitrate prills for the fertilizer and industrial nitrogen sectors. High-density fertilizer-grade product (34% N) averages 992 kilograms per cubic meter (kg/m^3) (62 pounds per cubic foot) and is about 1.7 millimeters, or 10 to 14 mesh. Low-density industrial explosives-grade material (33.5% N) averages 800 kg/m^3 (50 pounds per cubic foot) and is about the same screen size. Product is sold in bulk and bag through a co-op structure.

Union Chemical Co. (Unocal) permanently closed the former Chevron 130,000-ton-per-year ammonia plant at Finley, WA, purchased in 1991, but continued to use the complex for storage and distribution. Unocal was to toll ammonia from Chevron's 20,000-ton-per-year El Segundo, CA, plant. Chevron planned to continue operating a wholly owned 80,000-ton-per-year ammonia plant at St. Helens, OR, until a buyer could be found and planned to sell its 1,000-ton-per-day nitric acid plant at Riverton, KS, shuttered since 1982. *(See table 4.)*

American Cyanamid's 680-ton-per-day ammonia plant at Fortier, LA, idle since 1983, was to be converted to methanol production for MTBE synthesis. Lurgi and the U.S.-based Pritchard Corp. were contracted to execute a detailed engineering design for a 1,700-ton-per-day methanol plant to be operated as a joint venture between Cytech, the new American Cyanamid chemicals business, and the firm Methanex.

Consumption and Uses

U.S. apparent domestic consumption of ammonia was 15.3 million tons N, representing a moderate 3% decline from the 13-year record-high 15.8 million tons recorded in 1992. Fertilizer materials accounted for about 80% of domestic ammonia demand and industrial applications about 20%.

Urea and ammonium nitrate found extensive use in the fertilizer and industrial sectors in both solid and liquid form. Anhydrous ammonia continued to be the leading direct application fertilizer material in the United States, but UAN solution fertilizers that contain 28% to 32% N were growing in popularity because of their safe handling and storage characteristics and ease of application.

In the industrial sector, urea was used in the production of synthetic fibers, resins, and polymers and as a protein supplement in ruminate animal feeds. Ammonium nitrate-fuel oil explosives (ANFO) dominated the industrial explosives sector. Nitric acid was used in chemical synthesis and in metal treatment. Acrylonitrile, caprolactam, and hexamethylenediamine found respective use in the production of acrylic and nylon fibers, resins, and plastics. Toluene 2,4-diisocyanate, an ammonia derivative, is employed in polyurethane resins; whereas hexamethylenetetramine, produced from ammonia and formaldehyde, is used in the manufacture of phenolic thermosetting resins. *(See table 5.)*

Other uses for ammonia and ammonia-based compounds included consumption as ammonia refrigerant, in specialty horticultural and lawn and garden fertilizers, home and industrial cleaners, solvents, fuel ethanol derived from corn and other biomass species, and as sodium azide propellant in vehicular air bags. Ammonia and urea were also becoming popular low-cost agents that significantly reduced NO_x atmospheric emissions when injected into combustion gas streams.[27]

In 1993, ammonia and ammonia derivatives accounted for 10.3 million tons N, or 54% of the 19.0-million-ton primary fertilizer nutrient market in the United States. The ratio of nitrogen (N) nutrient consumption to phosphate (P_2O_5) and potash (K_2O) fertilizer nutrient consumption was 2.5:1 and 2.2:1, respectively, according to statistics published by the National Fertilizer and Environmental Center, Tennessee Valley Authority (TVA), at Muscle Shoals, AL.

U.S. nitrogen fertilizer consumption fell by a moderate 1% in 1993, from 10.4 million tons N in 1992. Single-nutrient compounds led by direct application ammonia, UAN solutions, urea, and ammonium nitrate, in order of importance, provided 80% of the total. A 13% decline in direct application ammonia consumption, owing to wet weather across the Midwest, was largely offset by increases in direct application solid urea, UAN solutions, and granular bulk-blend fertilizers. *(See table 6.)*

Wet weather, flooding, and lower feed grain plantings across the six key States that comprise the Midwest Corn Belt—Illinois, Indiana, Iowa, Missouri, Nebraska, Ohio—together with Minnesota, resulted in a 7% decline in nitrogen fertilizer consumption to 3.9 million tons N. In consequence, the region suffered a 3% loss in market share to 38% of the U.S. total. Nitrogen fertilizer consumption in Texas, Kansas, California, North Dakota, and Oklahoma, in order of importance, was up 9% to 2.7 million tons N, representing a 2% increase in market share to 26% of the U.S. total. This area was aided by a drop in setaside acreage for food grains and barley. The State of Texas displaced Iowa as the leading U.S. consumer of nitrogen fertilizers in 1993, with 0.85 million tons N, or 8% of total.

U.S. planted crop acreage dropped 4.5 million hectares (11 million acres) or 3% to 134 million hectares (332 million acres) in 1993, and another 24 million hectares (60 million acres) was idled by crop programs and the CRP, according to U.S. Department of Agriculture statistics. Planted acreage dropped principally because of the Secretary of Agriculture's prescribed 10% setaside on most feed grain acreage, together with widespread flooding across the Midwest that hampered planting intentions. Planted feed grain acreage declined 4 million hectares (9 million acres) or 8% to about 40 million hectares (100 million acres), while harvested acres dropped 5 million hectares (13 million acres) or 14% to 34 million hectares (83 million acres).

Harvested acres were down substantially owing to wet weather and flooding across the Midwest that damaged or destroyed crops and negatively affected yields. As a consequence, feed grain yields plunged 22% from the record yields of the previous year, and carryout inventories dropped to near-record lows established back in 1976. Carryout inventories of wheat and most other food grains ended the year at relatively low levels. U.S. net cash farm income in

1993 was estimated to approximate a record $59 billion, while net farm income was estimated at $43 billion, 12% below the record $49 billion of 1992. The Secretary of Agriculture lowered the acreage setaside (ARP) on corn and other feed grains from 10% to 0% for next year and maintained wheat at 0%.

Stocks

U.S. stocks of major nitrogen compounds declined about 9% at the producer level and ended the year at 1.6 million tons N. There was a 19% drawdown in anhydrous ammonia inventories. *(See table 7.)*

Transportation

Ammonia was transported by refrigerated barge, rail, pipeline, and truck. In late 1990, the Research and Special Programs Administration (RSPA) of the U.S. Department of Transportation (DOT) classified anhydrous ammonia as a nonflammable gas linked to a required "inhalation hazard" label. RSPA officially classified anhydrous ammonia a division 2.2 nonflammable, nonpoisonous compressed gas for domestic shipments.[28] The inhalation hazard label requirement, including nurse tanks, became effective October 1, 1992.

International shipments, however, were classified as a division 2.3 "poison gas" consistent with United Nations regulations. International shippers were originally required to comply under the new regulations on January 1, 1991. Because of the documented inhalation hazards of anhydrous ammonia when released in large quantities, RSPA was also requiring the words "INHALATION HAZARD" on packages and shipping papers, in addition to other current hazard communications information.

The Interstate Commerce Commission (ICC) replaced the Federal Energy Regulatory Commission (FERC) as the Federal agency responsible for ammonia pipeline regulation in late 1990. FERC had been responsible for ammonia pipeline regulation since 1977, when ICC transferred power of control under the Department of Energy act.

Koch Industries operated the Gulf Central Ammonia Pipeline built in 1969 that extended about 3,060 kilometers (km) (1,900 miles) from the Gulf of Mexico into the Midwest, as far north as Iowa. The annual capacity of this pipeline is about 2 million tons, and storage tanks along its path have an additional capacity of more than 1 million tons. Koch Nitrogen, a subsidiary, purchased four Midwest ammonia terminals from ConAgra Fertilizer in 1991 having a combined capacity of 150,000 tons. The pipeline was extended 24 km (15 miles) to the firm's Wood River, IL, terminal by yearend 1992.

Mapco Ammonia Pipeline Inc. operated Mapco Ammonia Pipeline and its sister company, Mid-America Pipeline, along a 1,770 km (1,098-mile) corridor that extended in a northeasterly direction from Borger, TX, in northern Texas, to Mankato, MN, in southern Minnesota. Mapco built the first leg of the pipeline in 1968-69 and, by 1978, had added six extensions. The Mapco pipeline has an annual capacity of about 1 million tons, and about 500,000 tons of ammonia storage capacity was located along the pipeline.

Mapco Ammonia Pipeline neither produced nor marketed ammonia independently, but transported ammonia on behalf of five shippers. Competition from the rail and truck transportation sectors was minimized because areas served by Mapco Ammonia Pipeline did not have river access. Mid-America Pipeline had more than 400 shippers and competed with the other transportation sectors.[29]

Between January and May 1993, Seminole Fertilizer and CF Industries were operating the Tampa Bay Pipeline system, a joint-venture ammonia pipeline that serves ammonium phosphate producers in Polk County, FL. Cargill Fertilizer, Inc. purchased Seminole on May 4, 1993, and assumed joint ownership of the pipeline with CF Industries.

Markets and Prices

Anhydrous ammonia prices continued firm at about $130 per ton, f.o.b. barge, New Orleans, through the first quarter, following a significant runup during the fall of 1992. Prices dropped thereafter, reaching lows of about $100 per ton between midyear and early September. Ammonia prices declined for a number of reasons, including lower direct application ammonia fertilizer demand during the wet spring season, a steady flow of imported ammonia and urea, and a continuing oversupply of diammonium phosphate.

Ammonia prices rose steadily during the fall as supplies tightened owing to an improvement in domestic fertilizer demand and a more optimistic outlook for ammonium phosphate markets and prices. Ammonia peaked at about $145 per ton by yearend. In mid-December, ammonia futures contracts were trading at $134 per ton on the Chicago Board of Trade (CBOT) for April 1994 delivery, f.o.b. barge, Louisiana. There was an indication that ammonia futures were experiencing upward movement because of improving prospects for a strong spring fertilizer season and improving ammonium phosphate trade.

Urea and ammonium nitrate prices were stable to firm during the first half of the year. Granular urea prices peaked at a firm $165 per ton, f.o.b. New Orleans, during the April through early June period before falling in the third quarter. Urea prices picked up during late fall and ended the year at $140 per ton. Ammonium nitrate prices declined marginally during the fall.

DAP prices, f.o.b. central Florida, continued to be depressed and fell from $124 per ton in early January to about $113 by the end of June, continuing a downward spiral that began back in the fourth quarter of 1991. The U.S. DAP industry was plagued by an inordinate supply overhang from 1992 and a significant decline in export sales to China. The market turned up during the fall and DAP product sold for more than $150 per ton by December. At yearend, June 1994 DAP futures contracts were trading on the CBOT for upward of $160 per ton, f.o.b. central Florida. *(See table 8.)*

Foreign Trade

The total U.S. nitrogen trade deficit more than doubled in 1993 and reached a level of 2.1 million tons N, or $1 billion. Approximately 70% of the increase was attributable to urea, where shipments from most traditional U.S. trading partners were up significantly, along with new entries (a trade deficit occurs when imports exceed exports).

Although Canada shipped approximately 50% of the urea import volume, where Cargill operated the new Saskferco plant in Saskatchewan, Canada, was by no means the decisive factor in the overall increase. Shipments were up substantially from Brazil, Trinidad, and Venezuela and Bulgaria in the Eastern bloc, which landed urea at $23 per ton below the $134 c.i.f. average. Nigeria was a new entry, along with Saudi Arabia and Qatar in the Persian Gulf. A shipment of 8,000 tons was even reported from Belarus, a former Soviet country still tied to an antidumping duty order of the ITC. Urea antidumping duties imposed in 1987 against the former German Democratic Republic (now Germany), Romania, and countries of the former U.S.S.R. protected U.S. producers against unfair trade practices for the most part.

In 1993, the U.S. ammonia trade deficit remained at 2.8 million product tons, or roughly $0.3 billion. Ammonia imports originated predominately from Trinidad, Canada, the former U.S.S.R., and Mexico, in order of importance. An approximate 50% drop in Mexican ammonia imports was offset by shipments from Bahrain, Quatar, and Saudi Arabia in the Middle East, Algeria, and Western Europe. U.S. ammonia imports in 1993 were valued at $415 million, representing an average landed price of $128 per ton, c.i.f., compared with $112 million in 1992. *(See tables 9 and 10.)*

Anhydrous ammonia import tonnage data from the former U.S.S.R. continued to be withheld from the public domain during 1993 because of a previous ruling by the Bureau of the Census that determined Occidental Petroleum to be the proprietary U.S. agent. Occidental's long-term trade pact with the former U.S.S.R. involving ammonia for superphosphoric acid was conceptually no longer in effect, however, owing to the dissolution of the U.S.S.R. in late 1991. Although Occidental was successful in dealing for ammonia in the recent past, the new independent republics were forced to discontinue purchases of Occidental superphosphoric acid because of a lack of hard currency. Agrovit, a subsidiary of the Russian trade agency Agrichem Export, was now handling Soviet ammonia shipments on behalf of Occidental.

Ammonia shipments from the former U.S.S.R. originated predominately from the Black Sea port at Yuzhnyy in the Ukraine with minor shipments from Latvia on the Baltic Sea. MAP shipments from Russia and the Ukraine to the United States were 132,000 tons compared with 122,000 tons the previous year in line with the global press for hard currency. MAP was landed at a value of $16.6 million, or $125 per ton c.i.f., somewhat lower than the $134 per ton, c.i.f. price of 1992.

Ammonium nitrate was also imported in significant quantities amounting to 0.5 million tons valued at $58.5 million, or roughly $120 per ton, c.i.f. About 75% of the total was Canadian product. The United States exported a modest 66,000 product tons in 1993.

U.S. ammonium phosphate exports fell 10% to 8.3 million product tons (1.4 million tons N equivalent), from 9.2 million tons in 1992. The major decline can be traced to DAP trade with China, where volume plunged 40% to 2.1 million tons compared with 3.6 million tons in 1992. MAP trade was up about 23% overall to 1.1 million tons in 1993. *(See tables 11 and 12.)*

World Review

In 1993, global ammonia production fell significantly for the fourth consecutive year to a level of 91.5 million tons N, representing a decline of 1.8 million tons or 1.9%. Production fell in virtually every region of the world except for the Middle East, where countries were recovering from the Persian Gulf Crisis, together with relatively minor increases in Asia. The former U.S.S.R., Western Europe, Latin America, North America, and the Eastern bloc experienced the brunt of the decline, in relative order of importance.

Since 1989, global ammonia production has fallen by 7.8 million tons N (8%) from a near-record level of 99.3 million tons N. During this 4-year period, production in the former U.S.S.R. has declined 5.8 million tons (-30%); Eastern bloc countries, 4.5 million tons (-48%); and Western Europe, 2.3 million tons (-18%). This 12.6-million-ton N drop has been partially offset by rising net production in other regions, especially Asia and North America.

Anhydrous ammonia was produced in about 79 countries during 1993, of which about 9 million tons N (10%) was directly traded. Ammonia was converted into about 36.1 million tons of urea N in 62 countries, of which about 9.4 million tons (26%) was traded. Total world nitrogen fertilizer consumption fell about 2% to a level of 73 million tons N, according to data available in May 1994.

While China—the world's largest urea importer—experienced a dramatic fall in urea imports, India and Vietnam continued to gain as large-volume urea importers. This, together with the increased urea import take in the United States, Latin America, and Middle East, served to maintain a relatively level global urea nitrogen materials trade balance in 1993.

Eastern Europe and the former U.S.S.R. have suffered significant losses in domestic production and consumption because of sweeping political reforms, accompanied by high inflation and foreign exchange problems. Western Europe has been impacted negatively by inflated natural gas prices, an attendant decline in competitive economics, and a downturn in domestic agriculture. Recession, the reunification of Germany, transition to the new European Community reform

(EC-92), and declining demand in Eastern Europe and the former U.S.S.R. also have been contributing factors. The Mideast downturn through 1992 was primarily a result of events surrounding the Persian Gulf Crisis and ensuing Operation Desert Storm initiatives of 1990 and 1991.

It is estimated that between 1991 and 1993, domestic nitrogen fertilizer consumption has declined 3.3 million tons N (42%) in the former U.S.S.R.; 0.3 million tons (-17%) in Eastern Europe, compared with -62% during the previous 3 years; and 1.1 million tons (-11%) in Western Europe.

The dissolution of the centrally planned economy of the U.S.S.R. commanded global attention in 1992 and resulted in the evolution of 15 independent republics. The new republics have been plagued by a combination of high inflation and drastic cuts in domestic nitrogen fertilizer production and consumption. The region continues to dominate global nitrogen trade, accounting for 3.5 million tons N, or 39% of global ammonia exports, and 2.5 million tons N, or 27% of global urea exports in 1993. The former U.S.S.R. has traditionally experienced pressures to generate hard currency and is thus motivated to be an aggressive trader. In 1993, ammonia exports were level at 4.3 million tons of product, although urea trade was off 7% to 5.5 million tons.

Ammonia was produced in 10 of the 15 new independent republics in 1993, of which Russia accounted for 60% of the 13.6-million-ton N total; the Ukraine, 24%; Uzbekistan, 8%; Belarus, 5%; Estonia, Georgia, and Lithuania, 2%; and the remainder, 1%. The ammonia plants were designed for output but not efficiency, and gas costs were reported to have risen dramatically in 1993. Natural gas costs in the Russian Republic, for example, rose from $0.08 per million Btu in March 1992 to $0.63 per million Btu in May 1994, an approximate sevenfold increase. In the Ukraine where Russian gas is used, the price jumped 35%, from $1.30 per million Btu in October 1993 to $1.75 in May-June 1994.

Gas supplies were extremely short in the Ukraine during 1993, and a substantial gas debt with Russia ultimately resulted in the disruption of Russian ammonia and urea export shipments to the Ukrainian port at Yuzhnyy on the Black Sea. The situation was reportedly resolved late in the year.

If gas were fully deregulated by the end of 1993 in Russia, as planned, which now does not seem plausible, feedstock prices may increase to roughly $60 per thousand cubic meters, or $1.70 per million Btu. This could potentially escalate ammonia production costs to about $90 per ton and urea to $100 per ton, values that may be prohibitive to export competitiveness on the U.S. gulf coast. A full-scale revamp of Russian ammonia and urea plants was needed. Russian gas was deregulated and priced at roughly $2.50 per million Btu to Europe.

All Eastern European countries are now forced to rely heavily on costly, deregulated Russian gas for ammonia and urea production and other uses. Romania, Hungary, Poland, and the former Yugoslavia, in order of importance, have sizable gas production, but still require significant imports. Bulgaria and Czechoslovakia rely almost exclusively on Russian gas imports. Romania, Poland, Bulgaria, the former Yugoslavia, Czechoslovakia, and Hungary, in respective order of importance, are all major participants in the Eastern European ammonia industry. In 1992, about 47% of the natural gas consumed in Eastern Europe was supplied from domestic production and 53% was imported from the former U.S.S.R. Escalating natural gas prices have driven ammonia and urea production costs up to near-prohibitive levels, precipitating critical shortages of nitrogen fertilizers for domestic use and export.

Operation Desert Storm resulted in severe damage to nitrogen plants in both Kuwait and Iraq during January and February 1991. Information available on the damage and destruction of nitrogen production facilities in the two countries last year indicated that nitrogen output would be restored on a more timely basis than previous estimates of approximately 5 years, but now the pendulum has swung once again to longer term prospects. Kuwait, in particular, is now planning to divert much of its scarce natural gas feedstock supplies to petrochemical and plastics synthesis.

In Kuwait, a 271,000-ton-per-year N ammonia plant and 216,000 tons per year of urea N came back into operation during 1992 at Shuaiba, but preinvasion capacity levels may now be delayed beyond 1994 as previously expected. In Iraq, the new 272,000-ton-per-year N ammonia plant at Baiji was operational in 1992, together with a 265,000-ton-per-year N urea facility. Approximately 63% of preinvasion capacity was scheduled to be restored by 1994.

Iraq and Kuwait, in combination, had represented about 1.5% of total world ammonia capacity and 2.5% of world urea capacity. In 1989, Iraq and Kuwait accounted for about 5% of total world urea and ammonia N trade. This, together with the supply potential of the other Persian Gulf countries, accounts for about 15% of world nitrogen trade in the form of ammonia and urea.

Industry Structure.—Global ammonia was produced in 79 developed and developing countries that had access to fossil fuel feedstocks, principally, natural gas, naphtha, petroleum refinery offgases and condensates, and coal and coke gases. The supply pattern, in general, followed the world population trend, with Asia and Eastern Europe, including the former U.S.S.R., accounting for more than 60% of the global ammonia supply potential and 58% of production in 1993. The developed regions—North America (United States and Canada), Western Europe, and Oceania—produced ammonia primarily for domestic use and accounted for about 25% of world supply potential and 30% of global production. The energy-rich countries of the Middle East accounted for about 4% of the world supply potential and 4% of global production in 1993 and exported significant quantities of ammonia and urea to the global community. Latin America and Africa, in order of importance, accounted for roughly 6% of global ammonia supply potential.

Capacity.—Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

In 1993, there was a net gain in global ammonia capacity of about 0.6 million tons per year N (0.5%) and about 1.5 million tons per year N (3%) of urea. At yearend, world ammonia capacity stood at about 119 million tons per year N and urea at 47 million tons per year N.

New ammonia and urea capacity was brought on-stream in Asia: Bangladesh, China, Indonesia, and Pakistan; the Middle East: Kuwait (repairs), Saudi Arabia, and Turkey; and Africa: Egypt, South Africa, and Zambia; all in relative order of importance. In the Ukraine, a new 160,000-ton-per-year urea plant was coming on-stream.

A total of approximately 1.4 million tons per year of ammonia N was closed in 1993. In Western Europe, ammonia capacity declined 0.7 million tons N (5%) owing to closures in Finland, Italy, the Netherlands, and Norway. In Latin America, ammonia capacity fell 0.4 million tons per year N owing to the Petromex closure at Cosoleacaque; and, in the former U.S.S.R., ammonia capacity declined by a collective 0.3 million tons per year (1.5%) in Belarus, Russia, and Turkmenistan.

Major world ammonia and urea capacity contracted or under construction and scheduled on-stream between 1993 and 1998 is equally divided between 8 million tons per year of ammonia N and 8 million tons per year of urea N. Potentially, up to 2 million tons per year of ammonia N in the former U.S.S.R. and Western Europe, in order of importance, will close during this timeframe, resulting in a net increase of roughly 6 million tons per year.

Individual region/country ammonia and urea capacity profiles follow. New ammonia and urea capacity additions in Asia are projected to approximate 12 million tons N and to account for approximately 75% of the world total.

Asia.—**China**.—2.6 million tons ammonia N and 3.1 million tons urea N. Bangladesh—0.3 million tons ammonia N and 0.3 million tons urea. India—1.9 million tons ammonia N and 1.7 million tons urea N. Indonesia—0.9 million tons ammonia N and 0.6 million tons urea N. Pakistan—0.2 million tons ammonia N and 0.2 million tons urea N.

Africa.—**Egypt**.—0.1 million tons ammonia N. Republic of South Africa—0.1 million tons ammonia N. Nigeria—0.3 million tons ammonia N and 0.2 million tons urea N.

Eastern Europe.—**Romania**.—0.3 million tons ammonia N (restart idle plant). Former Yugoslavia—0.4 million tons ammonia N and 0.1 million tons urea N (restart idle plants).

Former U.S.S.R.—A net of approximately 1.3 million tons per year of ammonia N was planned to close—Uzbekistan (55% of the total); Russia (22%); Belarus (14%); and the Ukraine (9%). Urea capacity, however, was scheduled to increase by a total of 0.4 million tons per year N, predominately in the Ukraine, and to a lesser extent in Russia and Belarus. *(See table 13.)*

Middle East.—**Iran**.—0.3 million tons ammonia N and 0.2 million tons urea N. Iraq (reconstruction)—0.3 million tons ammonia N and 0.3 million tons urea N. Qatar—0.4 million tons ammonia N and 0.3 million tons urea N. Saudi Arabia—0.2 million tons ammonia N and 0.2 million tons urea N. Bahrain was to add 0.3 million tons per year of urea N, while Kuwait planned an indefinite hold on the reactivation of plants having annual capacities of 0.3 million tons ammonia N and 0.2 million tons urea N.

North America.—**Canada**.—Cargill was operating a new C$435 million nitrogen fertilizer complex at Belle Plaine, Saskatchewan—the Saskferco project—commissioned in the fall of 1992. The operation was structured through a corporation formed between its Canadian subsidiary, Cargill Ltd., the Crown Investments Corp. of the Province of Saskatchewan, and Citibank Canada. The plant was designed to produce 510,000 tons per year of ammonia and 680,000 tons per year of granular urea.

More than one-half of the Saskferco output was scheduled to move through Cargill retail and wholesale distribution outlets. Agreements were reportedly reached with other large retail distributors for the sale of the remaining product, including Land O'Lakes, Inc., and Farmland Industries, Inc. in the United States. Product was to be marketed in western and eastern Canada, the north-central region of the United States, and offshore.[30]

ICI Canada's nitrogen fertilizer production facility at Courtright, Ontario, was purchased by Terra International of the United States in April 1993. The plant produces ammonia, ammonium nitrate, and related products.

Current Research

During October 1993, the U.S. Bureau of Mines held a seminar on the topic: Agricultural Commodities Competing With Traditional Metals and Materials. Speakers from the AARC Board of USDA, the Institute for Local Self-Reliance, and the Novon Products Group of Warner-Lambert Co. addressed the situation and outlook for renewable materials development in the United States. There was a consensus that prospects were favorable for a continuing penetration of the nonrenewables organic sector by industrial and consumer materials derived from renewable organic materials grown on our Nation's farms and forests.

Speakers cited steady improvement in renewables technology and processing efficiency, environmentally friendly aspects, the availability of skilled labor and resources in rural America, plus the opportunity to reduce agricultural subsidies as focal points for a slow but steady revival in renewable materials. Warner-Lambert disclosed recent developments in its Novon line of biodegradable plastics materials, including garbage bags and cutlery that had been successfully composted and recycled on a commercial scale.

Tetra Technologies, Inc. of The Woodlands, TX, developed a continuous countercurrent ion exchange (CCIX) method for the removal of nitrate contaminants from mine waste streams, including residual unreacted ammonium nitrate-fuel oil explosives, and in gold mining where waste nitrates result from the nitric acid washing of activated carbon and the oxidation of cyanide during heap detoxification. The system was also reported to be effective in controlling nitrate effluent levels in dairy and other agricultural operations, according to the firm.

M. W. Kellogg of Houston, TX, continued to publicize two major advances in its ammonia process technology: the Kellogg Reforming Exchanger System (KRES) and the Kellogg Advanced Ammonia Process (KAAP), a joint technology development with British Petroleum.

Kellogg's KRES design was revolutionary in that it completely eliminated the conventional fired primary reformer from the ammonia production process. KRES is environmentally attractive because without a primary reformer, nitrogen oxide emissions are substantially reduced. The system could be easily installed in new or existing plants and would save up to 10% on capital costs.

The KAAP process employs a novel ammonia synthesis catalyst that was claimed to be the first significant breakthrough in catalyst technology since 1927. The proprietary KAAP catalyst is up to 20% more active than conventional iron catalysts. The KAAP system was to be employed in a retrofit project designed to increase production capability by 40% at Ocelot's ammonia plant in Kitimat, British Columbia.

Norton Chemical Process Products of Akron, OH, developed a novel line of NC-300 zeolite catalysts for NO_x removal utilizing the injection of ammonia. Zeolite-based NC-300 catalysts are used in Selective Catalytic Reduction (SCR), a process in which ammonia is injected into the exhaust gas ahead of the catalyst reactor. As the gas passes through the NC-300 catalyst, ammonia reacts with NO_x to produce inert nitrogen gas and water. Norton's patented SCR process catalysts can be used with gas turbines and reciprocating engine systems, industrial boilers and process heaters, electric utility boilers, waste incinerators, nitric acid plants, nuclear fuel reprocessing, and miscellaneous chemical and combustion processes, according to the firm's product literature.

Exxon Research and Engineering Co. of Florham Park, NJ, has developed a process that significantly reduces NO_x emissions by injecting ammonia into flue gas streams emanating from stationary combustion sources. The Exxon process is based on a noncatalytic gas phase homogeneous reaction between NO_x in flue gas and ammonia that produces nitrogen and water. The patented process was offered for license by Exxon Research and Engineering Co.[31]

A catalytic process (SNOX) was developed by Haldor Topsoe A/S of Denmark for the cleanup of flue gas from fossil fuel burning equipment. Nitrogen oxides and sulfur oxides emanating from industrial and utility boilers burning fossil fuels are converted to elemental nitrogen, water vapor, and sulfuric acid. The SNOX process is offered under license in North America by ABB Environmental Systems.

USDA and DOE's "memorandum of understanding" on biomass research has accelerated the development of ethanol and other alternative fuels and fuel additives from agricultural and forestry products.[32] This agreement promised significant new markets for U.S. farmers and supported DOE's National Energy Strategy that focused on a reduction in foreign energy dependency.

In September 1991, the former Solar Energy Research Institute at Golden, CO, was designated the National Renewable Energy Laboratory (NREL), reflecting a strong commitment to renewable energy technology research and development (R&D) in the United States. In April 1992, work began on the National Alcohol Fuels User Facility, including construction of a process development unit for testing new biofuel conversion technology. DOE was developing a cellulose-to-ethanol process development unit at NREL to evaluate methods for converting wood cellulose into ethanol fuels that was to serve as the centerpiece for the National Alcohol Fuels User Facility.[33]

Fuel ethanol research is receiving a boost from a cooperative R&D agreement (CRADA) between NREL and New Energy Co. of Indiana. The CRADA partners are developing a method of converting corn fiber to ethanol, a technology honored by R&D magazine as one of the top technological innovations of 1993. New Energy currently produces ethanol by the fermentation of corn starch, but starch makes up only about 72% of the corn kernel. Currently, the residual fibrous residue consisting of cellulose, hemicellulose, and lignin, along with protein and fat, is dried and sold as an animal feed known as distiller's dried grains and solubles (DDGS).[34]

New Energy will utilize novel NREL technology for converting cellulose and hemicellulose in DDGS to sugar for fermentation to ethanol. Ethanol yields are expected to increase by as much as 13% by taking advantage of the carbohydrates left in this material. Another plus will be that DDGS, with the carbohydrate fraction removed, will become a protein concentrate, reduce shipping costs, and should command a premium price. The research will utilize two 8,000-liter fermentation tanks, already completed.

According to recent DOE information, ethanol production from corn starch could probably be increased fivefold without unduly affecting grain prices. Corn cobs and stover also hold promise as lignocellulosic feedstocks for ethanol production. Beyond the corn industry, potential feedstocks are virtually unlimited, ranging from specially grown grasses or trees to wastepaper.

In the field of microbiology, NREL was conducting research that could pave the way to vast ponds of microalgae from which economic quantities of environmentally friendly biodiesel may be produced. Large coal-burning plants in the southeastern United States offer an excellent potential source of CO_2 essential to large-scale microalgae production and downstream production of biodiesel. The symbiosis between these two technologies would substantially increase the amount of energy generated per unit of greenhouse gas produced. Research is targeted at demonstrating an environmentally suitable technology converting lipid-rich microalgae to biodiesel fuel at a total cost of $0.26 per liter ($1 per gallon equivalent). Negligible CO_2 costs and a plant size of about 1,000 hectares (3.9 square miles) are believed necessary to compete with petroleum-based diesel. Biodiesel releases up to 70% less smoke than conventional diesel and emits no sulfur or aromatics.[35]

Deshen International of Newton, MA, continued to develop markets for mobile power-intensive nitrogen plants based on the electric arc nitrogen fixation process. Several electrical power utility facilities worldwide were interested in the process, which could be used to improve powerplant efficiencies during off-peak periods, according to Mr. Mosche Alamaro, president of Deshen International.

OUTLOOK

The U.S. Bureau of Mines ammonia nitrogen demand forecast was developed from World Bank-United Nations Fertilizer Working Group projections[36] taking into consideration world per capita consumption trends and geopolitical factors in the former U.S.S.R., Europe, and the Mideast. Steady-state conditions were assumed for weather. World ammonia capacity projections were provided by the International Fertilizer Industry Association Ltd. (IFA), Paris, France. *(See table 14.)*

Global ammonia demand and operating rates dropped to an exceptionally weak 77% in 1993, 1% point below the 78% operating rate estimated last year. Operating rates, for example, were 83% to 85% in 1988-89. The downturn can be traced largely to the dramatic fall in domestic demand during the past 4 years in the former U.S.S.R., Eastern Europe, and more recently in Western Europe. Global per capita nitrogen consumption has dropped 16%, from 19 kilograms in 1989, to an estimated 16 kilograms in 1993.

Conceptually, a substantial drop in per capita nitrogen consumption means that many people are not eating as well these days, and certainly this must be true, particularly in the former Eastern bloc and U.S.S.R. countries. It also should be recognized, however, that nutrient efficiency has improved dramatically in the new Soviet republics since the dissolution of the U.S.S.R. in 1991. Thus, the sizable reductions in global per capita nitrogen consumption and operating rates experienced during the past 4 years hopefully may not be quite as severe in real terms as indicated by current statistics. It is known that world grain stocks have been drawn down to quite low levels in the recent past.

The world ammonia supply-demand outlook anticipated by the U.S. Bureau of Mines suggests that soft market conditions will continue to prevail at the global level into 1994 and persist for an indefinite period because of new additions to world capacity, a protracted period of recovery anticipated in the former U.S.S.R. and Europe, and lower expectations for fertilizer demand. Recent projections by IFA indicate that growth in global nitrogen fertilizer demand will average no better than 1.3% per year between 1993 and 1998.

Ammonia production and demand are projected to decline by another 2% in 1994 owing to a continued downturn in the former U.S.S.R., especially in the Ukraine. There is also concern that China will be forced to shut down a portion of its inefficient 10-million-ton-per-year ammonium bicarbonate production capability and that India and Indonesia may be in jeopardy of running new plants at reduced rates or experiencing startup delays because of natural gas shortages. Gas shortages also have been experienced in Trinidad and Tobago, but the situation will reportedly be resolved in the near-term.

The upside to this seemingly gloomy forecast is that world supply-demand fundamentals outside the severely affected regions should continue in reasonable balance. For example, limited increases in domestic supplies from major consuming countries like China and India could provide trade opportunities for ammonia, urea, and ammonium phosphates. The combination of continuing declines in former U.S.S.R. and Eastern bloc production capabilities and rising production costs may further restrict exports from these dominant regions. Also, capacity rationalization in Western Europe and caps on subsidized acreage setasides may provide opportunities for fertilizer and grain trade from outside the region.

In the United States, the outlook for continued strength in the nitrogen fertilizer and grain sectors is anticipated. The U.S. ammonia industry is running at near capacity, grain stocks are still relatively low at the domestic and global levels, herd rebuilding is needed, and U.S. and North American ammonia capacity expansion plans are minimal. Planted acreage should be up approximately 4.9 million hectares (12 million acres) in 1994, mostly in feed grains, translating to a robust spring season for the U.S. farmers and suppliers of agricultural fertilizers and crop protection chemicals. Crop demand should be adequate to hold up planted acreage near current levels during the next 5 years. The mechanisms of CRP and WRP acreage setaside programs, together with regular farm ARP, should assist in holding U.S. crop acreage at about the current 138-million-hectare (340-million-acre) level. This, together with the Export Enhancement Initiative, should control crop inventories and provide favorable crop prices for the U.S. farmer.

The new farm bill to be enacted in

1995 was being deliberated on Capitol Hill and around the farm community in general. Of major concern was the fate of 36 million acres in the CRP, contracts on which were to begin to expire in 1995. By late 1996, about 5.7 million hectares (14 million acres) will move back into active farm program crop acreage under existing law, a total of 10.1 million hectares (25 million acres) by the end of 1997, and a grand total of 14.6 million hectares (36 million acres) by the end of 1999. Congress and the farm community face the challenge of effectively controlling planted crop acreages to avert a possible return to the excessive grain oversupply and depressed price situation of the mid-1980's.

The U.S. converted nitrogen supply-demand outlook will be critically dependent upon the following: (1) a continuation of reasonably priced natural gas for U.S. ammonia production; (2) a return to favorable supply-demand fundamentals by the ammonium phosphate industry; (3) new industrial outlets for U.S. agricultural crops, including corn-based ethanol in reformulated motor fuels under the provisions of the Clean Air Act of 1990 and USDA's new AARC initiative; (4) favorable provisions in the 1995 farm bill that will continue to strengthen agricultural economics in the United States, including sound management of CRP acreage; (5) acceptable markets for the new Saskferco ammonia and urea nitrogen complex, which came on-stream in the fall of 1992 in Saskatchewan, that would minimize the closure of U.S. nitrogen fertilizer capacity; (6) favorable implications for the recently negotiated GATT agreement that would liberalize global agricultural trade and provide opportunities for the United States to compete more effectively in world trade; (7) improved agricultural trade with Canada and Mexico under provisions of NAFTA legislation and for the granting of most-favored-nation (MFN) status to the former U.S.S.R. and other Eastern European countries; (8) a more expedient transition in democratic reforms in Eastern Europe and the former U.S.S.R.; (9) resolution of the MFN-status debate with China; and (10) a balanced approach to fertilizer nutrient management in the United States based on pending legislative amendments to the Clean Water Act of 1972.

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TABLE 1
SALIENT AMMONIA STATISTICS[1]

(Thousand metric tons of contained nitrogen unless otherwise specified)

	1989	1990	1991	1992	1993[p]
United States:					
Production	12,280	12,680	[r]12,803	[r]13,643	12,865
Exports	346	482	580	354	378
Imports for consumption	2,861	2,673	2,742	2,690	2,657
Consumption, apparent[2]	14,871	14,923	[r]14,826	[r]15,856	15,348
Stocks, Dec. 31: Producers'	849	797	936	[r]1,059	855
Average annual price per ton product, f.o.b. gulf coast[3]	$104	$106	$117	$106	$121
Net import reliance[4] as a percent of apparent consumption	17	[r]15	[r]14	[r]14	16
Natural gas price: Wellhead[5]	$1.69	$1.71	$1.64	[r]$1.74	$1.99
World:					
Production	[r]99,331	[r]97,160	[r]94,472	[e]93,253	[e]91,497
Trade[6]	9,823	10,004	[r]9,587	[r]9,231	8,935

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

[1] Synthetic anhydrous ammonia, calendar year data, Bureau of the Census; excludes coke oven byproduct.

[2] Calculated from production, plus imports minus exports, and industry stock changes.

[3] Green Markets, Fertilizer Market Intelligence Weekly, Pike & Fischer, Inc.

[4] Defined as imports minus exports, adjusted for industry stock changes.

[5] Monthly Energy Review, U.S. Department of Energy. Average annual cost at wellhead in dollars per thousand cubic feet.

[6] International Fertilizer Industry Association statistics—World Anhydrous Ammonia Trade.

TABLE 2
FIXED NITROGEN PRODUCTION IN THE UNITED STATES

(Thousand metric tons of contained nitrogen)

	1989	1990	1991	1992	1993[p]
Anhydrous ammonia, synthetic:[1]					
Fertilizer	11,131	11,573	[r]11,559	[r]12,294	11,226
Nonfertilizer	1,148	1,107	[r]1,244	[r]1,349	1,639
Total[2]	12,280	12,680	[r]12,803	[r]13,643	12,865
Byproduct ammonia, coke plants:[3]					
Ammonium sulfate[e]	48	47	42	41	40
Ammonia liquor[e]	5	5	4	4	4
Total[e] [2]	53	52	45	44	44
Grand total[2]	12,332	12,731	[r]12,849	[r]13,687	12,909

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

[1] Current Industrial Reports, MA28B, M28B, and MQ28B, Bureau of the Census.

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

[3] Quarterly Coal Report, U.S. Department of Energy. Production estimates based on reported coke production trend.

TABLE 3

MAJOR DOWNSTREAM NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand metric tons)

Compound	1989	1990	1991	1992	1993[p]
Urea:					
Gross weight	7,261	[r]7,454	[r]7,378	[r]8,147	7,105
Nitrogen content	3,340	[r]3,429	[r]3,394	[r]3,748	3,268
Ammonium nitrate:					
Gross weight	7,140	[r]6,998	[r]7,093	[r]7,106	7,615
Nitrogen content	2,499	2,449	[r]2,483	[r]2,487	2,665
Ammonium phosphates:[2]					
Gross weight	14,862	15,871	[r]16,431	[r]17,250	14,484
Nitrogen content	2,517	2,673	[r]2,713	[r]2,915	2,459
Ammonium sulfate:[3]					
Gross weight	2,163	2,285	2,035	[r]2,169	2,175
Nitrogen content	[r]459	[r]485	[r]432	[r]460	461
Nitric acid, direct use:[4]					
Gross weight	1,951	[r]1,684	[r]1,605	[r]1,701	1,748
Nitrogen content	434	[r]374	[r]357	[r]378	388
Acrylonitrile:					
Gross weight	1,183	1,373	1,201	1,283	1,138
Nitrogen content	312	363	318	338	300
Caprolactam:					
Gross weight	595	626	582	[r]625	616
Nitrogen content	73	78	73	78	77
Total:[5]					
Gross weight	35,155	36,291	[r]36,325	[r]38,281	34,881
Nitrogen content	[r]9,634	[r]9,851	[r]9,770	[r]10,404	9,618

[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 netted for use in production of ammonium nitrate.

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

Sources: Bureau of the Census and International Trade Commission.

TABLE 4
DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1993

(Thousand metric tons per year of ammonia)

Company	Location	Capacity[1]
Agricultural Minerals Corp.[2]	Blytheville, AR	363
Do.	Verdigris, OK	907
Air Products and Chemicals Inc.	New Orleans, LA[3] [4]	263
Do.	Pace Junction, FL[5]	91
Allied Chemical Corp.	Hopewell, VA[3]	392
Ang Coal Gas	Beulah, ND	22
Arcadian Corp.	Augusta, GA	499
Do.	Clinton, IA	236
Do.	Geismar, LA	372
Do.	LaPlatte, NE	172
Do.	Lima, OH[3] [6]	481
Do.	Woodstock, TN	308
Borden Chemical Co.	Geismar, LA	386
Carbonaire Co. Inc.	Palmerton, PA	32
CF Industries Inc.	Donaldsonville, LA	1,633
Chevron Chemical Co.	El Segundo, CA	18
Do.	St. Helens, OR	77
Coastal Chem, Inc.	Cheyenne, WY	154
Cominco American Inc.	Borger, TX[3]	381
Cytec (American Cyanamid Co.)	Fortier, LA[3]	404
Diamond Shamrock	Dumas, TX	127
E.I. du Pont de Nemours & Co. Inc.	Beaumont, TX	445
Farmland Industries Inc.	Beatrice, NE[3]	236
Do.	Dodge City, KS[3]	218
Do.	Enid, OK[3]	880
Do.	Fort Dodge, IA	200
Do.	Hastings, NE	(7)
Do.	Lawrence, KS[3]	399
Do.	Pollock, LA[3]	440
First Mississippi Corp. (Ampro)	Donaldsonville, LA[3]	440
Green Valley Chemical Corp.	Creston, IA	32
IMC-Agrico[8]	Donaldsonville, LA	454
Koch Industries	Sterlington, LA	998
Jupiter Chemicals	West Lake, LA	27
LaRoche Industries Inc.	Cherokee, AL	159
Mississippi Chemical Corp.	Yazoo City, MS[3]	454
Monsanto Co.	Luling, LA[3]	445
Phoenix Chemical Co. (Vigoro)	East Dubuque, IL	245
PPG Industries Inc.	Natrium, WV	45
J.R. Simplot Co.	Pocatello, ID	93
Terra International, Inc.[9]	Port Neal, IA	308
Do. (Oklahoma Nitrogen)	Woodward, OK[3]	408

See footnotes at end of table.

TABLE 4—Continued

DOMESTIC PRODUCERS OF ANHYDROUS AMMONIA IN 1993

(Thousand metric tons per year of ammonia)

Company	Location	Capacity[1]
Triad Chemical Co.[10]	Donaldsonville, LA[3]	408
Union Chemical Co. (Unocal)	Kenai, AK[3]	1,134
Wil-Grow Fertilizer Co.	Pryor, OK	85
Total		15,871

[1] Engineering design capacity adjusted for 340 days per year of effective production capability.

[2] Plants purchased from Freeport-McMoRan Feb. 28, 1990.

[3] Revamp and/or retrofit.

[4] Scheduled to close in 1994.

[5] Capacity cut 50% at yearend.

[6] Purchased from B.P. Intl. Ltd. in 1993.

[7] Plant (140,000 tons per year) mothballed.

[8] Joint venture formed midyear 1993; Freeport-McMoRan owns Agrico.

[9] Expansion (60,000 tons per year) complete late 1992.

[10] Joint venture between First Mississippi Corp. and Mississippi Chemical Corp.

Sources: Tennessee Valley Authority and International Fertilizer Development Center (IFDC); North American Fertilizer Capacity, Ammonia. Muscle Shoals, AL, Jan. 1994. Blue, Johnson and Associates, North American NPK Plants and Capacities, Foster City, CA, Jan. 1, 1992.

TABLE 5

CONSUMPTION TRENDS FOR MAJOR NITROGEN COMPOUNDS PRODUCED IN THE UNITED STATES[1]

(Thousand metric tons of contained nitrogen)

	1989	1990	1991	1992	1993[p]
Fertilzer materials:					
Urea:					
Solid	1,831	1,917	1,871	[r]1,992	1,767
Solution	1,118	1,158	1,139	[r]1,323	1,147
Total	2,949	3,075	3,010	[r]3,315	2,914
Ammonium phosphates[2]	2,517	2,673	[r]2,713	[r]2,915	2,459
Ammonium nitrate:					
Solid	719	697	696	[r]677	713
Solution	1,170	1,018	1,167	[r]1,172	1,286
Other[3]	-12	68	[r]15	[r]2	[e]—
Total	1,877	1,783	[r]1,878	[r]1,851	1,999
Ammonium sulfate:					
Synthetic and byproduct	[r]459	[r]485	[r]432	[r]460	461
Coke oven byproduct[e]	53	52	45	44	44
Total	[r]512	[r]537	[r]477	[r]504	505
Total fertilizer	[r]7,855	[r]8,068	[r]8,078	[r]8,585	7,877
Nonfertilizer materials:					
Urea:[2]					
Feed	175	82	95	[r]104	115
Industrial	217	270	[r]289	[r]329	239
Total	392	352	[r]384	[r]433	354
Ammonium nitrate[2]	621	667	605	[r]636	[e]666
Nitric acid	434	[r]374	[r]357	[r]378	388
Acrylonitrile	312	363	318	338	300
Caprolactam	73	78	73	78	77
Total nonfertilizer	1,832	[r]1,834	[r]1,737	[r]1,863	1,785
Grand total[4]	[r]9,687	[r]9,902	[r]9,815	[r]10,448	9,662

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

[1] Ranked in relative order of importance.

[2] Solid and solution.

[3] Unaccounted distribution.

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

Sources: Current Industrial Reports, MA28B and MQ28B, Bureau of the Census, and International Trade Commission.

TABLE 6

U.S. NITROGEN FERTILIZER CONSUMPTION, BY PRODUCT TYPE[1]

(Thousand metric tons nitrogen)

Fertilizer material[2]	1992[r]	1993[p]
Single-nutrient:		
Anhydrous ammonia	3,723	3,248
Nitrogen solutions[3]	2,183	2,298
Urea	1,476	1,642
Ammonium nitrate	588	592
Ammonium sulfate	172	166
Aqua ammonia	62	61
Other[4]	181	200
Total	8,385	8,207
Multiple-nutrient[5]	2,029	2,107
Grand total	10,414	10,314

[p] Preliminary. [r] Revised.

[1] Fertilizer years ending June 30.

[2] Ranked in relative order of importance by product type.

[3] Principally urea-ammonium nitrate (UAN) solutions.

[4] Includes other single-nutrient nitrogen materials and all natural organics.

[5] Various combinations of nitrogen (N), phosphate (P), and potassium (K): N-P-K, N-P, and N-K.

Source: National Fertilizer and Environmental Research Center. Commercial Fertilizers, Dec. 1993.

TABLE 7

U.S. PRODUCER STOCKS OF FIXED NITROGEN COMPOUNDS AT YEAREND[1]

(Thousand metric tons nitrogen)

Material[2]	1992	1993[p]
Ammonia	[r]1,059	855
Nitrogen solutions[3]	313	305
Urea	[r]203	245
Ammonium phosphates[4]	100	85
Ammonium nitrate	[r]73	101
Ammonium sulfate	41	34
Total	[r]1,789	1,625

[p] Preliminary. [r] Revised.

[1] Calendar year ending Dec. 31.

[2] Ranked in relative order of importance.

[3] Urea-ammonium nitrate and ammoniacal solutions.

[4] Diammonium, monoammonium, and other ammonium phosphates.

Source: Current Industrial Reports, MA28B and MQ28B, Bureau of the Census.

TABLE 8

PRICE QUOTATIONS FOR MAJOR NITROGEN COMPOUNDS AT YEAREND

(Per metric ton product)

Compound	1992	1993
Ammonium nitrate: F.o.b. Corn Belt[1]	$138-$149	$138-$149
Ammonium sulfate do.	121- 132	133-147
Anhydrous ammonia:		
F.o.b Corn Belt	147- 160	157- 171
F.o.b. gulf coast[2]	129- 130	143- 146
Diammonium phosphate: F.o.b. central Florida	122- 127	152- 154
Nitrogen solutions (28% to 32%):		
F.o.b. South Central[3]	95- 103	99- 112
Urea:		
F.o.b. Corn Belt, prilled	149- 160	141- 165
F.o.b. gulf coast, granular[2]	142- 146	139- 141
F.o.b. gulf coast, prilled[2]	139- 141	128- 130

[1] Illinois, Indiana, Iowa, Missouri, Nebraska, and Ohio.

[2] Barge, New Orleans.

[3] Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, and Texas.

Source: Green Markets, Fertilizer Market Intelligence Weekly, Dec. 21, 1992, and Dec. 20, 1993.

TABLE 9

U.S. EXPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand metric tons ammonia)[1]

Country	1992	1993[p]
Korea, Republic of	277	284
South Africa, Republic of	54	23
China	57	(2)
Taiwan	(2)	13
Norway	—	21
Mexico	2	6
Suriname	2	2
Jamaica	(2)	2
Costa Rica	—	36
Morocco	15	50
Canada	15	21
Other[3]	[r]9	2
Total	431	460

[p] Preliminary. [r] Revised.

[1] Value data suppressed by Bureau of the Census. Ranked in relative order of importance by country and geographics.

[2] Less than 1/2 unit.

[3] Thirteen countries, principally in Latin America.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS OF ANHYDROUS AMMONIA, BY COUNTRY

(Thousand metric tons ammonia)[1]

Country	1992		1993[p]	
	Gross weight	Value[2] (thousands)	Gross weight	Value[2] (thousands)
Trinidad and Tobago	1,031	$113,594	986	$127,151
Canada	1,000	117,395	979	128,859
Russia and Ukraine[3]	[4]644	71,824	[4]631	81,905
Latvia	—	—	[4]25	NA
Estonia[3]	10	1,068	—	—
Mexico	542	57,318	285	38,340
Venezuela	—	—	82	10,479
Middle East[5]	—	—	141	14,577
West Europe[6]	22	2,503	53	7,331
Algeria	—	—	50	6,007
Japan	1	112	(7)	21
Australia	21	2,012	—	—
Total[8]	3,271	365,826	3,233	414,669

[p] Preliminary. NA Not available.

[1] Ranked in relative order of importance by country and region.

[2] C.i.f. value.

[3] Independent republics of the former U.S.S.R., effective Jan. 1992.

[4] Tonnage data based on U.S. Bureau of Mines industry intelligence. Data suppressed by Bureau of the Census since Jan. 1, 1989.

[5] Qatar, Saudi Arabia, and Bahrain, in order of importance.

[6] The Netherlands, Norway, France, the United Kingdom, and Portugal, in order of importance.

[7] Less than 1/2 unit.

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

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

TABLE 11
U.S. EXPORTS OF MAJOR NITROGEN COMPOUNDS IN 1993

(Thousand metric tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
Fertilizer materials:			
Ammonium nitrate[2]	66	22	NA
Ammonium sulfate[2]	757	159	NA
Anhydrous ammonia	460	378	NA
Diammonium phosphate	7,238	1,303	NA
Monoammonium phosphate	1,098	121	NA
Nitrogen solutions	28	8	NA
Sodium nitrate	2	(3)	NA
Urea	659	303	NA
Mixed chemical fertilizers[4]	329	52	NA
Other ammonium phosphates[5]	69	11	NA
Other nitrogenous fertilizers[6]	171	7	NA
Total[7]	10,877	2,365	NA
Industrial chemicals:			
Ammonia, aqua (ammonia content)	20	16	$1,623
Ammonium compounds[8]	9	3	8,839
Ammonium phosphate (ortho)	(3)	(3)	152
Potassium cyanide	(3)	(3)	1,127
Sodium cyanide	62	17	50,859
Other cyanides and cyanates	1	(3)	6,261
Hydrazine, hydroxylamine and related inorganic salts	13	6	21,291
Bismuth/silver nitrates	(3)	(3)	7,231
Potassium nitrate	18	3	4,441
Other nitrates	4	1	7,851
Nitric/sulfonitric acids	15	3	5,282
Nitrates	7	1	4,120
Total[7]	149	50	119,075
Grand total[7]	11,025	2,414	119,075

NA Not available.

[1] Export values f.a.s.

[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, 3105.59.0000, and 3102.70.0000.

[6] Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, and 3102.90.0000.

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

[8] Carbonates, chloride, fluorides, and tungstate.

Source: Bureau of the Census. Effective Jan. 1, 1989, U.S. exports and imports were reported under the new international Harmonized Commodity Description and Coding System (Harmonized System).

TABLE 12
U.S. IMPORTS OF MAJOR NITROGEN COMPOUNDS IN 1993

(Thousand metric tons)

Compound	Gross weight	Nitrogen content	Value[1] (thousands)
Fertilizer materials:			
Ammonium nitrate[2]	485	162	$58,476
Ammonium nitrate-limestone mixtures	12	3	1,249
Ammonium sulfate[2]	367	77	31,992
Anhydrous ammonia[3]	3,233	2,657	414,669
Calcium nitrate	(4)	(4)	11,855
Diammonium phosphate	38	7	7,096
Monoammonium phosphate	157	17	25,978
Nitrogen solutions	391	117	38,205
Potassium nitrate	28	4	8,751
Potassium nitrate-sodium nitrate mixtures	39	5	6,573
Sodium nitrate	123	20	20,915
Urea	2,964	1,363	395,979
Mixed chemical fertilizers[5]	200	24	32,246
Other ammonium phosphates[6]	92	15	10,750
Other nitrogenous fertilizers[7]	141	28	25,524
Total[8]	8,269	4,501	1,090,257
Industrial chemicals:			
Ammonia, aqua (ammonia content)	11	3	751
Ammonium compounds[9]	15	4	22,502
Calcium cyanamide	1	(4)	782
Potassium cyanide	1	(4)	1,358
Sodium cyanide	3	1	3,454
Other cyanides and cyanates[10]	4	1	4,950
Hydrazine, hydroxylamine and related salts	2	1	5,653
Bismuth/silver nitrates	(4)	(4)	2,148
Strontium/other nitrates	4	1	3,454
Nitric/sulfonitric acids	10	2	2,645
Sodium/other nitrites	2	(4)	1,092
Total[8]	51	12	48,789
Grand total[8]	8,320	4,513	1,139,047

[1] Import values c.i.f.

[2] Includes industrial chemical products.

[3] Anhydrous ammonia tonnage data for the former U.S.S.R. reported by U.S. Bureau of Mines; includes industrial ammonia.

[4] Less than 1/2 unit.

[5] Harmonized codes 3105.10.0000 and 3105.20.0000.

[6] Codes 3105.51.0000, 3105.59.0000, and 3105.40.0050.

[7] Codes 3101.00.0000, 3102.29.0000, 3102.60.0000, 3102.90.0000, and 3105.90.0050.

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

[9] Carbonates, chloride, fluorides, and tungstate (exports and imports); bromide, molybdate, orthophosphate, and perrhenate (imports).

[10] Data for code 2837.19.0020 (other cyanides) deleted or omitted by Bureau of Census.

Source: Bureau of the Census. Effective Jan. 1, 1989, U.S. exports and imports were reported under the new international Harmonized Commodity Description and Coding System (Harmonized System).

TABLE 13
AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of contained nitrogen)

Country	1989	1990	1991	1992	1993[e]
Afghanistan[e]	40	40	40	40	40
Albania[e]	110	100	80	[r]15	15
Algeria	132	288	269	[r]438	[2]380
Argentina	74	70	[r]63	[r]71	[2]77
Australia	344	385	[e]414	[r,e]391	400
Austria[e]	410	410	400	400	400
Bahrain	319	325	[r]325	[r]345	[2]348
Bangladesh[3]	775	701	667	[r]937	[2]991
Belarus	—	—	—	916	[2]619
Belgium	292	[r]274	[r]272	[r]514	500
Bosnia and Herzegovina[e]	—	—	—	[r]5	2
Brazil	[r]935	938	[r,e]940	[r,e]940	[2]914
Bulgaria	[r]1,326	1,309	[r]1,093	[r,e]910	750
Burma	120	[r]77	[r]111	[e]130	130
Canada	3,339	3,054	3,016	3,104	[2]3,410
China[e]	17,000	17,500	18,000	18,000	19,000
Colombia	92	[r]90	[r]92	[r]86	[2]99
Croatia	—	—	—	[r]300	300
Cuba[e]	[2]134	140	140	135	135
Czech Republic[4]	—	—	—	—	[2]149
Czechoslovakia[5]	797	793	551	[e]385	—
Egypt	728	735	863	[r]943	[2]941
Estonia	—	—	—	[r]115	[2]45
Finland	42	23	24	[e]10	10
France	1,476	1,586	1,604	[r]1,848	1,800
Germany:					
Eastern states	[r]1,200	[e]700	—	—	—
Western states	1,732	1,671	—	—	—
Total	[r]2,932	2,371	2,123	[r]2,113	2,000
Georgia	—	—	—	96	[2]58
Greece	242	257	210	[r]140	[2]57
Hungary	673	445	[r]319	[r]261	300
Iceland	9	8	9	9	9
India[6]	6,661	[r]7,010	[r]7,132	[r]7,038	[2]7,124
Indonesia	2,526	[r]2,789	2,706	[r]2,688	[2]2,888
Iran	336	420	468	[r]657	700
Iraq[e]	[2]474	[r]240	[r]40	[r]200	300
Ireland	386	[e]395	429	[r]384	[2]367
Israel[3]	48	42	[r]35	[r]37	[2]41
Italy	1,446	1,197	1,147	[e]1,098	[2]729
Japan	1,539	1,531	1,553	1,602	[2]1,447
Kazakhstan	—	—	—	220	[2]231
Korea, North[e]	500	500	550	550	600
Korea, Republic of	480	411	407	[r]442	400
Kuwait	665	292	—	140	[2]320

See footnotes at end of table.

TABLE 13—Continued
AMMONIA: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of contained nitrogen)

Country	1989	1990	1991	1992	1993
Libya[e]	[2]212	200	200	200	200
Lithuania	—	—	—	275	[2]130
Malaysia	279	229	286	331	330
Mexico	2,100	2,164	2,221	[r]2,203	[2]1,758
Netherlands	2,901	3,188	3,033	[r]2,588	2,500
New Zealand[e]	70	70	70	[r][2]68	80
Nigeria	[r]364	[r]405	[r]367	[r][e]360	350
Norway	382	431	384	343	[2]315
Pakistan	[e]1,175	[r]1,214	[r]1,154	[r]1,144	[2]1,446
Peru[e]	91	90	95	[r]90	90
Poland	2,360	[r]1,962	[r]1,531	[r]1,490	1,500
Portugal	151	198	198	100	[2]91
Qatar	587	584	569	622	[2]516
Romania	2,736	1,785	[r][e]1,800	[e]1,100	1,100
Russia	—	—	—	8,786	[2]8,138
Saudi Arabia	863	942	827	904	[2]1,097
Serbia and Montenegro	—	—	—	[r]148	150
Slovakia[4]	—	—	—	—	[2]263
South Africa, Republic of	455	456	457	541	[2]607
Spain	552	[r]466	557	479	[2]354
Switzerland	[e]32	32	33	31	[2]28
Syria	123	104	[r]17	[r]81	[2]67
Taiwan	203	216	243	[e]224	[2]220
Tajikistan[e]	—	—	—	30	40
Trinidad and Tobago	[e]1,550	1,520	1,524	1,568	[2]1,462
Turkey	380	373	357	[r]344	[2]526
Turkmenistan	—	—	—	25	[2]32
U.S.S.R.[7]	19,400	18,200	17,100	—	—
Ukraine	—	—	—	[r]3,908	[2]3,242
United Arab Emirates	324	295	286	[r]273	[2]306
United Kingdom	1,037	1,148	1,011	869	[2]873
United States[8]	12,280	12,680	[r]12,803	[r]13,643	[2]12,865
Uzbekistan	—	—	—	1,309	[2]1,105
Venezuela	532	557	450	404	[2]535
Vietnam[e]	36	36	36	[r]45	[2]52
Yugoslavia[9]	680	802	[e]700	—	—
Zambia	12	4	5	[e]7	[2]10
Zimbabwe[e]	62	[2]63	[r]66	[r]67	[2]93
Total	[r]99,331	[r]97,160	[r]94,472	[r]93,253	91,497

[e]Estimated. [r]Revised.

[1] Table includes data available through June 3, 1994.

[2] Reported figure.

[3] May include nitrogen content of urea.

[4] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[5] Dissolved Dec. 31, 1992.

[6] Data are for years beginning Apr. 1 of that stated.

[7] Dissolved in Dec. 1991.

[8] Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

[9] Dissolved in Apr. 1992.

TABLE 14
WORLD ANHYDROUS AMMONIA SUPPLY-DEMAND RELATIONSHIPS[1]

(Million metric tons nitrogen)

	1988	1989	1990	1991	1992	1993[e]	1994[2]	1995[2]	1996[2]	1997[2]	1998[2]
Capacity[3]	[r]117.0	[r]119.0	[r]118.7	[r]117.0	[r]118.2	[r]118.8	[r]121.0	[r]122.5	[r]123.0	[r]124.4	125.3
Demand:[4]											
Fertilizer	88.8	[r]88.7	[r]86.8	[r]84.1	[r]82.8	[r]80.9	[r]79.4	[r]80.8	[r]82.2	[r]84.1	85.5
Industrial	10.5	10.6	10.4	[r]10.4	[r]10.5	[r]10.6	[r]10.6	[r]10.7	[r]10.8	[r]10.9	11.0
Total	99.3	[r]99.3	[r]97.2	[r]94.5	[r]93.3	[r]91.5	[r]90.0	[r]91.5	[r]93.0	[r]95.0	96.5
Operating rate[5] (percent)	[r]85	[r]83	[r]82	[r]81	[r]79	[r]77	[r]74	[r]75	[r]76	[r]76	77
Consumption:											
Kilograms capita[6]	19.5	19.1	18.3	[r]17.5	[r]16.9	[r]16.3	[r]15.8	[r]15.8	[r]15.7	[r]15.8	15.8
Population:											
Billion[7]	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1

[e] Estimated. [r] Revised.

[1] Calendar years.

[2] Forecast.

[3] Design capacity, 340-day-per-year effective operation.

[4] Ammonia consumed in the production of fertilizer and industrial products, including process losses.

[5] Total demand as a percent of design capacity.

[6] Ammonia demand expressed in kilograms per person.

[7] Statistical Abstract of the United States 1993; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

NONRENEWABLE ORGANIC MATERIALS

By Raymond L. Cantrell

Mr. Cantrell has served as a physical scientist in the Branch of Industrial Minerals since 1988. His 30-year career in the public and private sectors includes organic chemicals research, plastics and rubber product development, and fertilizer market research. Ms. Deborah A. Kramer, Branch of Industrial Minerals, facilitated data input and prepared graphics.

Nonrenewable organic materials refer to nonfuel derivatives of finite fossil fuel feedstocks of petroleum, natural gas and associated liquid fractions, and coal, as opposed to those derived from renewable natural organic biomass sources. All organic materials contain carbon, most commonly associated with hydrogen, oxygen, nitrogen, and sulfur, and comprise a vast number of chemical compounds.[1] Organics range from the simplest hydrocarbon compound, methane (CH_4), to high molecular weight thermoplastic and thermoset polymers, and complex biological matter associated with all life forms on Earth. The terms "plastics," "resin," and "polymers" are often used interchangeably by the synthetic organic chemicals industry.[2]

Products manufactured from nonrenewable organic materials include a variety of items such as household goods, beverage containers, food packaging, cosmetics, and sporting goods; solvents, paints and coatings, ink, pigments, and adhesives; textiles, construction materials, pipe and hose, electrical devices, and computer goods; automotive components, tires, battery casings, engine oil, grease, and asphalt; fertilizers, pesticides, pharmaceuticals, medical devices, eyewear, and a multitude of other items vital to modern society.

The U.S. nonrenewable organics industry ranks third in terms of value in the United States behind the automotive and petroleum industries, in respective order of importance. In 1993, the organics industry—including feedstocks and salable nonfuel petroleum byproducts—was valued at more than $90 billion, f.o.b. plant, according to the U.S. International Trade Commission (ITC).[3] Basic raw material feedstock costs calculated from U.S Department of Energy (DOE) information were about $12.5 billion, based on point-of-origin prices for crude petroleum, dry natural gas, and liquid fractions, plus coal and salable downstream residual byproducts.[4]

In 1993, domestic production in the large-volume polymeric resin, rubber, and fibers industries increased about 3% and domestic consumption increased 5% compared with 1992. However, the U.S. resin industry—polyethylene (PE) in particular—continued to be adversely impacted by slow economic recovery at home and a substantial capacity overhang at home and abroad, which created downward pressure on margins and prices. The situation was exacerbated by continuing recession in Europe, Japan, and the former U.S.S.R. In contrast, polyvinyl chloride (PVC), thermoplastic elastomers, thermosets, synthetic rubber, paints and coatings, and other specialty resins and organic products experienced solid growth; and the U.S. trade surplus for all organic materials held relatively constant at about $12 billion. Domestic demand for construction materials, automotive industry materials and accessories, along with durable and nondurable consumer goods improved as the economy strengthened, especially in the second half of 1993.

Organic chemicals production moved up 9% in 1993 among the top 50 chemicals in the United States, compared with overall chemicals growth of only 3%. Of particular note was the 120% increase in production of methyl tertiary butyl ether (MTBE), the leading fuel oxygenate, and a 30% and 20% increase in MTBE precursors methanol and isobutylene, respectively. Propylene glycol production increased 74%, ethylene dichloride, 18%; and perchloroethylene, 11%, relative to 1992. Sizable increases also were established for vinyl chloride, terephthalic acid, and the dimethyl ester thereof.

Major issues faced by the organics industry during 1993 included the imminent ban of 11 ozone depleting chlorofluorocarbons (CFC's) and chlorinated hydrocarbons beginning in January 1996. Producers were developing stopgap hydrogenated CFC's (HCFC's) alternatives and more desirable hydrogenated fluorocarbons (HFC's) to replace CFC refrigerants, solvents, and blowing agents. Probably one of the most critical chlorinated hydrocarbons on the list was 1,1,1-trichloroethane, the leading solvent used in vapor degreasing of electronic components and numerous other solvent applications. Consumers were slow to accept any proposed alternatives.

Perchloroethylene, the major dry cleaning solvent in the United States, was under strict regulation by the U.S. Environmental Protection Agency's (EPA) Clean Air Act provisions designed to significantly reduce volatile organic carbon materials (VOC's). In related developments, the Society of the Plastics Industry, Inc. (SPI) expressed concern over the administration's proposed chlorine ban, citing the potential threat to strategic supplies of and pesticides on EPA's toxic inventory list, many of which were destined for extinction owing to VOC and carcinogenic issues. Also, the paint industry was reformulating to more environmentally friendly water-based coatings and high-density solvent materials. Powder coating and other nonsolvent technologies also continued to be developed.

The organics industry has reacted to the downturn of the recent past by initiating significant cost-cutting measures directed at improving efficiency and competitiveness. Creative employee reduction incentive programs were prominent among the major petrochemicals producers, including E.I. du Pont de Nemours and Co. (DuPont), Exxon Corp., Occidental Petroleum Corp. (OxyChem), and Texaco, Inc., to name a few. Additionally, industry restructuring and the rationalization of obsolete capacity were underway. The U.S. industry also was continuing to become multinational in scope, as witnessed by its growing presence abroad.[5]

U.S. crude oil production in 1993 reached the lowest level since 1958, as domestic prices fell 11% to an average of about $14.20 per barrel, the lowest level in 5 years. Still, refineries ran at more than 90% of capacity as the U.S. import reliance increased from about 40% in 1992 to almost 45% in 1993. Imported crude prices also fell 11%, to an average of $15.75 per barrel, c.i.f., the lowest level in 5 years. Although there was an increase of more than 10% in natural gas prices during the year, the average annual price of about $2 per million British thermal units (Btu) was still reasonable. *(See table 1.)*

DOMESTIC DATA COVERAGE

Data were obtained from a variety of government sources, including the ITC publication Synthetic Organic Chemicals—derived from an annual canvass of the U.S. organic chemicals industry under the authority of Section 332g of the Tariff Act of 1930; the Annual Energy Review 1993, Petroleum Supply Annual 1993, and coal reports published by the Energy Information Administration (EIA); U.S. Department of Commerce reports; U.S. Bureau of Labor statistics; and the EPA.

Several private trade groups provided data on nonrenewable organic materials for use by the U.S. Bureau of Mines (USBM), including the SPI; American Plastics Council; Chemical Manufacturers Association; Federation of Societies for Coatings Technology; Fiber Economics Bureau, Inc.; American Fiber Manufacturers Association, Inc.; Rubber Manufacturers Association; the Asphalt Institute; Asphalt Roofing Manufacturers Association; The Fertilizer Institute; and the National Agricultural Chemicals Association. Information also was gathered from industry trade journals.

BACKGROUND

Organic chemical materials were first categorized as naturally occurring carbon compounds associated with human and animal life-forms, like urea excrement in urine. It was later recognized, however, that organic compounds also were associated with plant matter and could be further isolated from metamorphosed carbonaceous materials like coal and coal ignition byproducts. Later, chemists demonstrated that organic chemicals could be produced synthetically in commercial quantities through sophisticated chemical reaction mechanisms involving coal, natural gas, and petroleum derivatives.

Charles Goodyear perfected the vulcanization process for natural rubber in 1846, and in the mid-1800's, John and Isaiah Hyatt experimented with the polymer cellulose nitrate, produced from nitric acid and cellulose, in searching for a viable substitute for billiard balls made traditionally from expensive ivory. In 1872, the term "celluloid" was coined by Isaiah Hyatt for materials made from cellulose nitrate and camphor, and the Hyatt's firm, Celluloid Manufacturing Co., is known today as Hoechst Celanese Corp. Shortly after the turn of the 20th century, Leo Bakeland developed and introduced Bakelite, an industrially significant phenol-formaldehyde thermosetting heat-resistant polymeric resin.

The Petroleum Age

A major wildcat oil strike by Edwin L. Drake near Titusville, PA, on August 27, 1859, gave birth to a new technological era in the United States—the petroleum age. An abundant source of fluid organic chemical feedstock containing a multitude of carbon compounds had been found that was relatively easy to pump and process, unlike solid coal minerals. Although the first U.S. petroleum refinery was built in 1860 near the Titusville oilfield, the major contributing factor that transformed petroleum into an industrial giant was the commercial development of the internal combustion engine in the early 1900's.

The 1920's served as the major benchmark for major oil discoveries in the United States, and during the 1930's there were enormous finds in east Texas and at Prudhoe Bay, AK, by 1967. U.S. oil output exceeded 3 billion barrels in 1966 and reached a peak of more than 3.5 billion barrels in 1970. During this period, the United States was the world's leading oil producer. Today, the United States continues as the world's leading consumer of petroleum, with about 20% of world consumption, but has gradually developed a significant import dependency in the mid-40% range.

The petroleum industry developed sophisticated distillation and associated technologies for the production of gasoline and lubricants for the growing automotive industry. Heating oils, diesel fuel, asphalt for road building, and a number of consumer products also were produced. Many light fractions of petroleum manufacture such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}) were vented and flared because technology had not been developed for their use. Natural gas, or methane, along with liquid organic fractions thereof, also was found to be associated with petroleum, but much was flared as a nuisance item of crude oil production.

Petrochemicals

During World War II, important organic synthesis technology developed earlier by noted research scientists was put to practical use. Petroleum engineers learned how to recover the lighter, more reactive organic molecules and crack both small and large ones into forms that could be turned into synthetic organic chemical feedstocks and downstream polymers and other items of commerce. Nylon was developed by Wallace Carothers and DuPont between 1927 and 1940 and was used in parachutes during the war. Following the war, nylon hosiery and other nylon fabrics precipitated a major synthetic fiber revolution. Synthetic rubber (styrene-butadiene, neoprene, and butyl) was developed to augment supplies of natural rubber cut off from Indonesia, Malaysia, Singapore, and Thailand during the war. Military explosives also were involved in the organics revolution, including trinitrotoluene (TNT) and nitroglycerine (dynamite).

During the 1950's, PE, polypropylene (PP), polystyrene (PS), and other nonrenewable synthetic organic materials began to significantly displace or supplement minerals and renewable organic resources traditionally used in the manufacture of consumer goods like bottles, films, fiber, and rubber, and in automotive components. PVC materials were compounded with industrial minerals, such as calcium carbonate, clays, talc, and titanium dioxide; extruded into pipe, vinyl siding, and garden hose; or fabricated into vinyl sheet and film as a superior substitute for "linoleum" flooring and upholstery. Polyvinyl acetate and acrylic water-based emulsions were developed as a substitute for natural resins and oils in adhesives and paints. Synthetic organic urea nitrogen fertilizers replaced low-analysis fertilizers and, along with more effective organic pesticides, improved crop yields.

Polyethylene terephthalate (PET) soda bottles and the popular polyurethane (PUR) roller blades are recent successful entries in the marketplace, along with a growing repertoire of other new polymeric materials, such as aromatic copolyester and liquid crystal polymers for electrical applications introduced in 1984 and 1985, together with polymethylpentene, a high-temperature, transparent polymeric material introduced in 1988. Microcircuitry revolutionized the computer, communications, and timepiece industries; and integrated circuits and computer chips merged high-tech polymeric resins and minerals-derived materials.

Definitions, Grades, and Specifications

Petrochemical feedstocks for nonfuel organics use are obtained principally from crude oil, natural gas, and, to some extent, from coal. There are about eight primary organic chemical feedstocks needed to produce intermediate and finished petrochemical materials, as shown in figure 1. It is interesting to note that of the eight, only methane is directly available from petroleum and natural gas. The other seven feedstocks must be synthesized from crude petroleum and liquid hydrocarbon fractions of natural gas by processes such as catalytic cracking (cat cracking), reforming, and other chemical engineering processes, to obtain chemically reactive ("unsaturated") bonds between the carbon atoms.

Crude Oil.—Petroleum is a complex mixture containing thousands of different organic compounds ranging from the most simple hydrocarbon form, methane (CH_4), to very high molecular weight compounds. Most of the compounds are straight chain saturated hydrocarbons called alkanes or paraffins, which are in the family of compounds grouped with methane (CH_4). This simply means that the four available reaction sites for each carbon atom are filled. But, for C_3 saturated forms and higher, the molecules can be arranged in a ring structure as well.

Benzene is an important ring compound found in petroleum in limited amounts (0.5% to 1%), but synthesized in large quantities from petroleum feedstock. Benzene is an organic ring compound belonging to a unique family of organic compounds known as aromatics. The benzene ring (C_6H_6) contains only one-half as many hydrogen atoms as its saturated cyclic paraffin cousin cyclohexane (C_6H_{12}). This means that benzene is "unsaturated," and has three "double bonds" between the carbon atoms that can react with other elements. All aromatic organic molecules are arranged in rings and contain reactive "unsaturated" carbon bonds of a special type.

Crude oil is characterized as being "sweet" or "sour" depending upon its sulfur content and "heavy" or "light" depending upon its particular distribution of large and small organic chemical compounds, as measured by specific gravity or weight per unit volume. Oil is measured by the barrel, containing 42 gallons.

Most of the components of oil can be separated by fractional distillation, taking advantage of a wide range of boiling points. The distillate fractions that are made into reactive, unsaturated petrochemical feedstocks include the gaseous C_1 to C_4 components removed overhead, the C_5 to C_{20} naphthas and gas oil liquid fractions, the heavy residues beyond C_{20}, and the asphalt and petroleum coke residues.

Lubricating Oils.—Lubricating oils used in vehicles and in industrial machinery and processes are made from a relatively small number of crude oil-base stocks blended with several additives designed to achieve specific properties. Special additives allow for relatively constant or variable viscosity change with temperature, promote oxidation resistance, and regulate acidity and pour points.

Asphalt.—Asphalt, a product of petroleum refining, is generally the bottom product left after all other products have been taken out. It is always blended with cutter stock, similar to kerosene but with a lower flash point, into three grades: fast cure (less of the kerosene material added so that it sets up faster), medium cure, and slow cure, for use as road base at different ambient temperatures.

Not all refinery operations produce asphalt because it is a natural product only from heavy crude oils and the amount of asphalt produced will be in rough proportion to the specific gravity of the crude oil. Further processing is necessary to make the asphaltic material suitable for roofing applications.

Asphalt serves as a highly effective binder in roadway construction. Asphalt roadways typically consist of only 5% to 10% asphalt, filled with an enormous quantity of crushed stone and modified with hydrated lime to facilitate impact resistance.[6]

Petroleum Coke.—Petroleum coke is obtained by severe thermal cracking of the bottom residues remaining after petroleum refining. The feed is heated to about 560° C and charged to the bottom of a coking drum. The cracked lighter product is drawn off overhead; the heavier product remains and, because of the retained heat, cracks to coke, a solid coal-like substance. Coke yields may approximate up to 30% of the feed.

Coke comes in two principal forms—"sponge coke" and "needle coke." Sponge coke varies from a hard, porous, irregular-shaped lump to a fine powder. The main uses for sponge coke are in the manufacture of electrodes and anodes, as a carbon source for carbides, and for the manufacture of artificial graphite used for motor brushes. The strength of sponge coke is not sufficient for its use in blast furnaces for pig iron or in foundry work.

"Needle coke" derives its name from its microscopic elongated crystalline structure. Needle coke requires special coker feeds and more severe operating conditions. Its qualities make it the preferred material for graphite electrodes because of its lower electrical resistivity and lower coefficient of thermal expansion. Graphite electrodes are integral to the production of steel based on the electric arc process.

Carbon Black.—This significant carbonaceous black pigment is an extremely fine soot, primarily carbon (90% to 99% C), that contains some hydrogen and oxygen and is produced by the partial combustion or thermal decomposition of hydrocarbons in the vapor phase. Although carbon blacks are available as furnace black, thermal black, lampblack, acetylene black, and bone black, furnace black is the dominant commercial material of choice. Carbon black is one of the most important pigments in industrial use today; significant quantities are used as a reinforcing agent in tires and other rubber products and as the primary black pigment in printing inks, paints, and plastics.

Petroleum Waxes.—Waxes are also a natural product of the refining processes and are derived from the gas oil fraction in the distillation process. Waxes come out of all crude oils. If the crude oil contains a large proportion of wax, then the final "pull" becomes unsuitable for asphalt production, even if it is a heavy crude oil.

Natural Gas.—Methane (CH_4) must be separated from various components before sale as "dry gas" for fuel use and as chemical feedstock. According to recent DOE statistics, about 83% of the total process feed was recovered as dry natural gas, 2% was removed as nonhydrocarbon gases (carbon dioxide, helium, hydrogen sulfide, and nitrogen), with some of the remainder being injected for repressurizing. Substantial amounts of other natural gas liquids (ethane, propane, and butane) also may be recovered during methane processing. Natural gas is sold on a dollars per million Btu basis. Substantial amounts of elemental sulfur also may be recovered as a marketable byproduct depending on the hydrogen sulfide content of the gas.

Natural gas is used extensively in catalytic steam reforming processes to produce inorganic ammonia (NH_3) and byproduct carbon dioxide, which are subsequently used to synthesize organic urea (NH_2CONH_2) for fertilizer and industrial use. Ammonia is also integral to the production of nylons and other important polymers and synthetic organic chemicals. Methanol, or methyl alcohol (CH_3OH), also is produced from methane by a similar reforming process.

Coal.—Coal is a black or brownish-black combustible sedimentary organic rock that contains more than 50% carbonaceous organic material by weight. In popular usage, coal commonly is called a mineral because it was formed in the earth. However, the scientific use of the term "mineral" is reserved for a naturally occurring inorganic material that has a definite chemical composition and a regular internal structure. Coal has neither of these. Coal is called a fossil fuel because it is derived from plants that grew in vast swamps millions of years ago and was subsequently reworked and metamorphosed. Recoverable coal reserves in the United States are considered to be the largest in the world, and the U.S. ranks as the leading producer at about 1 billion tons per year.

Outside of fuel uses for electrical power generation, the most important use of coal is for the production of metallurgical coke from bituminous coals mined principally from the Appalachian region of the United States. Typically, a 1-ton charge of low-sulfur bituminous coal when heated in a high-temperature coking oven in the absence of air will yield about 700 kilograms of coke containing 97% carbon and a variety of organic byproducts, including about 32 liters of crude tar containing creosote, naphthalene, phenol, pitch, pyridine, and other aromatic hydrocarbons, and 10 liters of crude light oil containing benzene with smaller quantities of the aromatics toluene ($C_6H_5CH_3$), xylene ($C_6H_4(CH_3)_2$), naphtha, and related hydrocarbons.[7]

Products for Trade and Industry

Approximately 50% by weight of all U.S. polymeric materials derived from nonrenewable organics is currently fabricated into packaging and building and construction materials, while consumer and institutional products account for another 10%; transportation equipment, 5%; electrical and electronic goods, 5%; furniture and furnishings, 4%; adhesives, inks, and coatings, 3%; and other merchandise, 11%. Exports account for about 12% of the total.

Packaging materials include bottles, jars, vials, and food containers, refuse bags and film, and items such as tubes, tape, pallets, shipping crates, blister and bubble containers, buckets, and drums. Building and construction materials vary from pipe, conduit, and fittings—including drainage, irrigation, plumbing fixtures, and septic tanks—to siding, flooring, and insulation materials. Other construction materials consist of panels, doors, windows. skylights, bathroom units, gratings, and railings.

Consumer and institutional products encompass disposable food serviceware, dinnerware and kitchenware, toys and sporting goods, health care and medical products, hobby and graphic arts supplies, together with footwear, luggage, credit cards, and other items. Transportation equipment includes parts and composites for motor vehicles and bicycles, railroad equipment, travel trailers, campers, golf carts, snowmobiles, aircraft, ships, and boats.

Electrical equipment is composed of wire and cable coverings and industrial equipment, while electronic components include resistors, magnetic tape, records, and batteries. Furniture and furnishings include household and office furniture, bedding, carpets, rugs, backing, curtains, blinds, awnings, lamps, picture frames, and wall coverings. Adhesives, inks, and coatings consist of adhesives and sealants, printing ink, magnet wire enamels, core binders, foundry facings, paper coating and glazing, paints, varnishes, and enamels.

A variety of products ranging from pipe to window trim may be produced from PVC and PP resins. These rigid, high-strength polymeric products contain significant quantities of reinforcing fillers, extenders, and pigments that include varying combinations of organic pigments, titanium dioxide, calcium carbonate, talc, treated kaolin, wollastonite, mica, feldspar, alumina trihydrate, barite, silica, stearic acid, and derivatives.

Plastic coated handles on pliers, tin snips, scissors, and other items such as the coated wire trays in dishwashers, are derived from PVC dispersion resins processed into fluid plastisols or organisols that cure out or plasticize with heat. Plastisols are most commonly made by dispersing PVC resin in a suitable phthalate plasticizer. Organisols are made the same way except that an organic solvent is added to produce more solvation and fluidity.[8]

Phenolic thermosetting resins are used principally as an adhesive in pressed board products, etc. The material also is used in the production of foundry sand molds that withstand high temperatures associated with the molding of products such as engine blocks. Thermoset polymers also are used as a binder with organic and inorganic fillers in automotive brake linings, drum brake blocks, disk brake pads, clutch facings, and abrasives grinding wheels.[9] Synthetic rubber containing carbon black reinforcement pigment is used extensively in automotive components, including tires, motor mounts, nylon reinforced V-type drive belts, and high-temperature radiator, heater, and power-assist hoses. The modern-day radial tire comes equipped with steel-reinforced belts that span the tire circumference. Tire walls generally consist of tough, molded natural rubber vulcanized with sulfur and sulfur curing accelerators, while tire treads consist predominately of the more flexible molded and vulcanized styrene-butadiene synthetic rubber forms, which provide for better handling and wear characteristics.

Synthetic organic materials are integral to the construction of shingles and other roofing materials. Bitumen materials ranging from asphalt to coal tars comprise the major components of shingles, while protective roofing granules in shingles are derived from the minerals industry. "Built-up roofing" (BUR) systems are commonly employed in the industrial roofing sector. At the heart of the roofing system are two components, bitumens and felts. There are two types of roofing felts: organic and fiberglass-based. The roofing membrane is protected from solar radiation by a cap sheet of gravel embedded in bitumen.[10]

Technology

The production of petrochemical feedstocks, downstream intermediates, and end-use products encompasses an enormous array of organic chemical reactions and technologies as demonstrated by the descriptive flow diagrams contained in this report. *(See figures 1 through 9.)*

Oil Refining and Petrochemical Feedstocks.—The feedstocks for petrochemical plants are obtained from oil refineries and from light fraction hydrocarbon extracts of natural gas and from natural gas itself. Several industrial minerals and other minerals-related catalysts are used to effect the complex chemical reactions required to produce the essential petrochemical feedstocks shown in figure 1. The world's first fluid catalytic cracker using powdered catalyst came on-stream at Jersey Standards' Baton Rouge, LA, refinery in May 1942, only months after the Japanese attack at Pearl Harbor, and revolutionized the petroleum and petrochemical industries. By 1967, fluidized reactors were in commercial use for naphtha hydroforming, fluid coking, coal carbonization, coal coking, and chemicals production. Fluidization continues today as a major component of chemical engineering technology.

Cracking catalysts are used in oil refineries to facilitate the conversion of heavier molecules into lighter, more desirable products. High temperatures are needed, but pressures can be more moderate. Bentonitic clays in the form of granular pellets are typical natural cracking catalysts, while synthetic catalysts generally are silica-alumina, silica-magnesia, or silica-zirconia-alumina. One process uses a platinum catalyst to reform naphthas into petrochemical compounds. The catalytic cracking process uses operating pressures ranging from about 15 pounds per square inch (psi) to 700 psi [1 to 49 kilograms per square centimeter (kg/cm^2)] and temperatures ranging from 425° to 590° C.

Polymerization.—A number of highly complex chemical reaction mechanisms and technical processes are involved in the synthesis of polymers from petrochemical feedstocks. In 1929, W. H. Carothers subdivided polymers into two general groups, "condensation" and "addition" polymers. Polyester resins, for example, are formed by typical condensation reactions between bifunctional organic acid and alcohol monomers, with the elimination of water. Addition polymers, unlike condensation polymers, are formed by direct molecular linkup mechanisms in which no byproduct is generated. PE is an example of addition polymerization whereby ethylene molecules combine in large numbers to form continuous chains of high molecular weight polymer. The terms "step reaction" and "chain reaction" are used in deference to the more classical condensation and addition polymerization terminology whenever a more precise definition between reaction mechanisms is needed.

There are two basic types of polymers, "thermoplastic" and "thermoset." Thermoplastic polymers can be softened repeatedly at elevated temperatures and may be processed under pressure into a variety of products and recycled. PE, PVC, nylon, and PP are examples of thermoplastic resins. Thermoset resins, once processed, will not soften again as the temperature is raised, but eventually degrade or decompose at highly elevated temperatures. Phenol-formaldehyde, phenol-furfural, urea-formaldehyde, melamine, unsaturated polyesters, and epoxies are typical thermosetting resins.

Ethylene Synthesis.—Ethylene (C_2H_4) is the simplest unsaturated hydrocarbon, or "olefin," and is by far the largest of all the petrochemical feedstocks shown in figure 1 in terms of volume, sales value, and number of downstream derivatives. Figure 3 details the enormous family of downstream derivatives obtained from ethylene, the most important of which are the polyethylenes, PVC, styrene, vinyl acetate polymers, and ethylene-propylene elastomers. Other important derivatives include ethylene oxide and linear alcohols, such as ethyl alcohol (C_2H_5OH).

Thermal cracking of hydrocarbons in the presence of steam is the most widely used process for producing ethylene. Cracking is accomplished at about 1,600° C and 30 psi, followed by rapid quenching to below 1,000° C. Ethylene is recovered by low-temperature fractionation at 500 to 550 psi and purified by low-temperature (-65° C) gas-separation processes to remove hydrogen, methane, and ethane.

In the United States, hydrocarbon gases—ethane through the butanes—from natural gas condensates and petroleum refinery offgases dominate the feedstocks used to produce ethylene. With these clean feedstocks, yields may approach 80%. Liquid refinery products, such as naphthas and gas oils, also may constitute up to 25% of process feedstocks, but yields are less than 40%, and process costs are relatively higher. Ethylene also may be recovered by petroleum cat cracking, but the only practical source is from the hugh refineries in the United States owing to economies of scale.

Ethylene Polymerization.—Ethylene is a colorless gas that condenses to a liquid at -169° C. In high concentrations, it is a simple asphyxiant without other significant physiologic effects. Ethylene is commonly transported by pipeline to downstream processing facilities. About 50% of ethylene production in the United States is used to manufacture polyethylene polymers-high-density polyethylene (HDPE); low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE). LLDPE has made significant inroads relative to the other PE resins because of its unique properties derived from a number of copolymer derivatives, versatility of usage, and breakthroughs in synthesis technology. PE resin density varies between about 0.90 to 0.96 g/cm^3.

HDPE resins are produced by a variety of low-pressure processes. Since the introduction of novel LLDPE technology in the 1970's, also based on low- pressure processes, the classic process-based distinction between LDPE and HDPE has become obsolete. Many of the newer PE plants are designed with LLDPE/HDPE swing capabilities to meet changing market demands.

HDPE resins are characterized by greater toughness and by superior mechanical strength and high modulus, low gas permeability, coupled with higher service temperature limits. HDPE resins compete with PP resins in a variety of molding applications. Resin price and other factors affecting total conversion economics may favor one or the other material for a given end-use article. As a result, some back-and-forth substitution is always taking place. Most HDPE resins are converted to end products by various polymer processing technologies: blow molding, injection molding, and variations of the extrusion process.

HDPE manufacturing processes fall under three basic categories: gas-phase, fluid-bed, or stirred-bed reactor polymerization; slurry-phase polymerization using isobutane diluent or C_6 or higher diluents; and solution-phase polymerization processes using cyclohexane or a paraffinic hydrocarbon.

Major advances in polymerization technology have resulted from the introduction of innovative catalyst systems incorporating complex chromium compounds impregnated in silica or silica-alumina support or those based on complex titanium compounds chemically bound to a solid magnesium-containing support. Recently, single-site metallocene catalysts have been developed or are under development; these new catalysts allow precise control of molecular properties, enabling products to be specifically tailored to match the performance needs of a given application.

LDPE resins, conversely, are derived under high-pressure environments ranging from 15,000 to 50,000 psi using organic peroxide initiators. Two types of reactors are used: a continuous-flow stirred autoclave and tubular reactors. Autoclave reactors produce homopolymers with a high degree of long-chain branching, resulting in polymers useful for extrusion-coating markets and high-strength industrial heavy-duty film. In contrast, tubular reactors produce resins that have much lower degrees of long-chain branching. These resins are well suited for clear packaging film production.

Other commercial synthesis reactions include the palladium-catalyzed oxidation of ethylene to produce acetaldehyde (CH_3COH), or if synthetic acetic acid (CH_3COOH)—"vinegar" in nature—is used as the solvent, vinyl acetate. Chlorination and oxychlorination processes are used to make vinyl chloride monomer (CH_2CHCl), which in turn is polymerized to the industrially significant PVC and PVC copolymers like polyvinyl alcohol and polyvinyl acetate. Ethylene oxide, a ring compound containing oxygen (C_2H_4O), is produced by the silver-catalyzed oxidation of ethylene. About 50% of the ethylene oxide produced is converted to ethylene glycol ($HOCH_2CH_2OH$), most commonly sold as automotive "antifreeze" and used in the manufacture of polyester resins. Acid catalyzed hydration of ethylene produces ethanol (C_2H_5OH), ethyl alcohol, competitively priced with alcohol from traditional fermentation processes.

Methane and Propylene.—These petrochemical feedstocks are second to ethylene in terms of volume. The flow diagrams of figures 4 and 8 track the downstream synthesis products of propylene and methane, respectively. Some of the more familiar reaction products of propylene are isopropyl alcohol, used as a solvent and rubbing alcohol, acrylonitrile that goes into acrylic-based resin and fibers, and the significant polymer PP.

Methane (natural gas), as already described, is the feedstock for ammonia that is used to produce nitrogenous-based organic compounds: urea, organic nitration products such as TNT, amines ($-CNH_2$), and methanol; downstream polymers, nylon-6; urea-formaldehyde, phenolic, and melamine thermosetting resins; and many other important resin intermediates. Nickel and iron-promoted catalysts are used in the production of ammonia. Methanol is important to the synthesis of methyl methacrylate from which acrylics ("plexiglass") are made, together with polyester fibers and resins. Methanol is commonly used in automotive windshield washer and deicing fluids and in the production of the major fuel oxygenate MTBE.

Benzene.—This important petrochemical feedstock ranks fourth in terms of volume behind ethylene, methane, and propylene. Benzene is probably most notable for its use in the production of polystyrene, one of the more important resins in commercial use. It is also essential to the production of cyclohexane, cyclohexanol, and cyclohexanone, precursors of the important nylon polymers nylon-6 and nylon-6,6.

Properties of Organic Chemicals.—Organic chemicals are highly useful participants in chemical synthesis, in purification processes, and as end-use products themselves as solvents, etc., because of unique properties. Many organic synthesis processes require an aqueous-free environment and may be conducted in an organic solvent system. Organic solvents are important extractants in the purification of products owing to different affinities for contaminants and end-use synthesis materials. Some organic synthesis materials such as caprolactam, the monomer for nylon-6, may be cycled back and forth between organic and aqueous phases to effect purification.

Many separation processes use the azeotropic properties of organic compounds whereby two organic compounds boil at a constant temperature and composition, and may be removed by simple distillation. Undesirable organic carboxylic acid (-COOH) byproducts may be removed by countercurrent extraction using aqueous sodium hydroxide, and other undesirable ionic impurities may be removed by ion exchange resins—polymerized organic beads having cationic (positive charge) or anionic (negative charge) exchange properties—and new membrane technologies. Another interesting feature of organic chemicals is that separation may be more easily effected by distillation under reduced pressure, or vacuum conditions, creating a wider variation in the vapor pressures of the various organic components. Organic products may be further purified and decolorized by filtration through a medium of activated charcoal.

Materials Processing.—The processing of solid polymeric resin and rubber materials into marketable products is accomplished through a series of operations ranging from the initial compounding of ingredients to the final process steps of molding, calendaring, or extrusion. Liquid products or intermediates, such as paints and coatings, are commonly produced from an aqueous colloidal dispersion base of plastic or rubber, or organic solvent-based systems involving the incorporation of solid fillers by shear milling processes and special-high-intensity liquid mixing.

Both resins and rubber are compounded or blended with varying combinations of ingredients—fillers, extenders and pigments, processing aids, blowing agents, curing agents and accelerators, antioxidants, etc.—for processing into solid end-use products. Compounding usually is effected in high-intensity steel alloy pressure mixers containing a pair of rotating sigma, or Z-shaped, mixer arms and jacketed for temperature control. Following compounding, the formulated mixtures may be processed on an alloyed steel roller mill consisting of two horizontal rotating drums revolving at different speeds to provide shear to complete the mixing process, to sheet out the mix, and to remove moisture and other volatiles.

In rubber compounding, extra care must be taken to shear, or "break down," the elastomeric molecules into rheological forms suitable for compounding and to precisely control the mix temperature to prevent "kick-off" of sulfur and associated curing accelerators. Many rubber compounders prepare "master batches" containing premixed rubber, curing agents, and pigments that are added during the processing step to facilitate more exacting quality control.

Compounded plastics and rubber materials may be prepared for downstream processing by "dicing" or "extrusion chopping" to produce granules or pellets that provide uniform flow or by "calendaring" sheets through pairs of compression rollers that more precisely control thickness or gauge. Calendaring also may represent the final step in processing.

Extrusion, injection molding, and blow molding are the most popular methods of production of thermoplastic materials, in order of importance, while compression molding dominates the thermoset resin and rubber arena. Several important rubber items of commerce—hoses, gaskets, and pencil erasers, etc.—are extruded and cured under pressure in autoclaves.

Thermoplastic extruders are made of heavy-duty special alloy materials capable of withstanding high temperatures and pressures. The integral parts of a typical extruder consist of a feed hopper; high-alloy steel internal chamber or barrel; specialty feed/shear screw; a die of suitable geometry, together with a face plate. Plastic pellets or granules flow from the extruder hopper to the screw chamber where plasticization is effected through a combination of barrel temperature and screw shearing rheology. The plastic medium is then forced through a die, producing the desired profile. Typical marketable products range from writing elements, soda straws, plastic pipe and hose, to vinyl siding and window trim.

Coextrusion is a process in which two extruders facilitate the cojoining of materials in a mutual chamber, creating a two-component or multilayer system. The inner polymeric resin component is extruded through a die of desired shape and is then sheathed or coated by the second extruder system whose shape is determined by a mutual die exiting the mixing chamber. One unusual and commercially significant form of coextrusion involving metals and plastics is wire and cable coating, where a thermoplastic of suitable dielectric properties is extruded around a continuous feed of wire or cable that passes through an individual and common die. The coated wire is wound on drums after cooling.

In the production of wide film or sheeting, resin is extruded in the form of a tube that may be split as it comes from the die and then stretched and thinned to the desired dimensions of the finished film. An alternate method involves inflating the tubing as it comes from the die, with the degree of inflation regulating the thickness of the final film.

Injection molding is a process in which the hopper feed is pushed into a long heating chamber by a plunger, where the polymer is softened to a fluid state. The fluid resin is then forced at high pressure through a nozzle into a cold mold. As soon as the material cools to a solid state, the mold opens and the finished product is ejected from the press.

Blow molding is the most popular process for producing thermoplastic bottles. Blow molding consists of stretching and then hardening a polymeric resin against a mold. There are two general methods, direct and indirect, encompassing several variations of each. These processes basically involve the air blowing of a glob of resin or heated thermoplastic sheet into a mold or die of the desired shape.

Compression molding is simply the squeezing of a material into a desired shape by application of heat and pressure to the material in a mold. The three compression molding factors—pressure, temperature and time—vary with the design of the finished article and the material being molded.

Thermoforming of resin sheet has developed rapidly in recent years. This process consists of heating thermoplastic sheet to a formable state and then applying air and/or mechanical assists to shape it to the contours of a mold. Pressures of up to 14 psi may be obtained by evacuating the space between the sheet and the mold in a process called "vacuum forming," which is used in the majority of thermoforming applications. *(See table 2.)*

Operating Factors

Total industrial employment in the synthetic resin, fiber, and rubber sectors fell by about 4% to 166,000 workers in 1993, compared with about 173,000 workers in 1992. This was in line with cost cutting measures by major manufacturers of organic chemicals and resin materials. The average hourly workweek increased marginally, and wages of production workers fell $0.11 per hour to $15.26. Average hourly wages of employees engaged in the synthetic organic chemicals business, however, were 30% above the $11.76 per hour earned by employees in all manufacturing jobs, indicative of the high-tech skills required by employees in this industry. *(See table 3.)*

ANNUAL REVIEW

Legislation and Government Programs

The North American Free Trade Agreement (NAFTA) was signed into law by the President on December 8, 1993 (Public Law 103-182).[11] This act was designed to liberalize agricultural and industrial trade between Canada, Mexico, and the United States owing to a gradual phaseout of most tariff barriers.

Section 313 of EPA's Emergency Planning and Community Right-to-Know Act of the Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) required EPA to establish a national inventory of toxic chemical emissions from certain facilities, called the Toxic Release Inventory (TRI). EPA's 1992 TRI data released in April 1994[12], disclosed that organic compounds accounted for 31 of the top 50 TRI chemicals releases, led by methanol, toluene, acetone, 1,1,1-trichloroethane, and xylene. Organic compounds also predominated the reported emissions of suspected carcinogens, ozone-depleting chemicals, and bioaccumulators. EPA reported that about 17 million tons of toxic chemical waste continued to be generated by reporting facilities, about 80% of which was recycled, recovered, or treated on-site. Industrial releases to the environment were reported to have declined 6.6% from the previous year, and offsite transfers to treatment facilities, primarily for recycling, increased nearly 17%. EPA planned to double the list of TRI chemicals to about 600 compounds in 1994, including several pesticide materials.

The 1992 TRI indicated that for about 300 chemicals surveyed, a total of 3.4 million tons was released to the environment or transported to offsite facilities, including publicly owned treatment works (POTW's), of which about 1.4 million tons (42%) was released directly to the air, water, land, or injected underground. Based on available information, about 50% by weight of direct releases was attributable to organic chemicals, while organic compounds comprised about 30% of the 2 million tons transported offsite. Approximately 65% of total offsite transfers was recycled; 18%, treated; 11%, recovered as energy; and the remainder disposed of. *(See table 4.)*

TRI includes a voluntary industry toxic chemicals control program known as 33/50, implying an interim goal of reducing emissions of 17 high-priority toxic chemicals by 33% between 1988 and 1992, with an ultimate goal of 50% reduction by 1995. One of the more noteworthy findings revealed in the 1992 TRI was that emissions had declined more than 40% between 1988 and 1992, surpassing program objectives. Twelve of the seventeen high-priority toxic chemicals listed under the 33/50 program were organics: benzene, carbon tetrachloride, chloroform, cyanides, dichloromethane, methyl ethyl ketone, methyl isobutyl ketone, tetrachloroethylene, toluene, 1,1,1-trichloroethane, trichloroethylene, and xylenes.

On August 3, 1993, the President signed a new Executive order pledging the Federal Government to protect the environment by preventing pollution at the source. This executive order applies Federal Right-to-Know laws, including TRI reporting requirements, to all Federal facilities beginning in 1994.

On November 30, 1993, EPA finalized the addition of more than 30 chemicals to the TRI list. EPA added 11 hydrochlorofluorocarbons (HCFC's) because of their potential to damage the Earth's protective ozone layer, leading to adverse human health and environmental effects. EPA also added 21 chemicals and 2 chemical categories that were listed under the Resource Conservation and Recovery Act (RCRA). On January 12, 1994, EPA proposed the addition of 313 toxic chemicals to the TRI list, including hazardous air pollutants, carcinogens, ozone depleters, and pesticide active ingredients.

The Energy Policy Act of 1992 (H.R. 776) was signed into law by the President in October 1992. This comprehensive energy bill contained 30 titles covering nonrenewable and renewable energy resources and was underscored by environmental and energy efficient mandates for the implementation of new technology and for long-range research and planning. Under Title XIII—Coal—clean coal technology, the Secretary of the Interior was to provide consulting services to the Secretary of Energy for research and development of effective utilization of coal wastes and for the administration of mineral rights for coalbed methane projects on Federal lands.

Title XVI—Global Climate Change—included provisions for a 75% increase in energy derived from renewable resources over 1988 levels by the year 2005 and a reduction in the Nation's oil use from a level of approximately 40% of total energy consumption in 1990 to 35% by the year 2005.

The Clean Air Act of 1990 (Public Law 101-549) contains 11 titles that target 3 major forms of pollution: acid rain, smog, and toxic air pollutants. The most important facets of the act relative to nonrenewable, nonfuel organics deal with VOC emissions from industrial processing, industrial solvents, paints, and coatings, together with emissions from coke ovens.

Effective November 1, 1992, EPA's Oxygenated Fuel Program required gasoline marketers to commence supplying fuel oxygenates averaging 2.7% by weight oxygen during 4 inclusive winter months in 39 cities that did not meet Federal air quality standards for carbon monoxide. The major fuel oxygenates are MTBE, a nonrenewable organic material produced from the natural gas derivative methanol and isobutylene; and ethanol, a renewable organic material produced primarily through the fermentation of corn starch.

EPA's year-round reformulated fuel program will commence on January 1, 1995, wherein the nine worst U.S. ozone nonattainment areas (Los Angeles, New York, Greater Connecticut, Baltimore, Philadelphia, Chicago, Milwaukee, Houston, and San Diego) will be required to sell gasoline with a minimum 2% by weight oxygen, 1% maximum by volume benzene, 25% aromatics maximum by volume, and no heavy metals (e.g., lead, manganese). MTBE consumption in U.S. motor fuels is currently in excess of 2 billion gallons, and ethanol consumption is slightly less than 1 billion gallons.

Issues

On September 16, 1987, the United States, along with 23 other nations and the European Community (EC), signed the "Montreal Protocol on Substances That Deplete the Ozone Layer." As a result of this protocol and newer scientific evidence, Congress mandated in the Clean Air Act Amendments that the production of CFC's and halons (organic bromine/fluorine/chlorine compounds) be phased out by the year 2000. In 1991, however, the National Aeronautics and Space Administration's (NASA) conclusion that ozone depletion in the previous decade was far more severe than previously predicted, led to a new ruling banning the production of 11 organic compounds called Class I ozone depleters as of January 1, 1996.

CFC's and halons release chlorine or bromine in the stratosphere and may act as a catalyst to convert ozone to oxygen. An increase in ultraviolet radiation resulting from stratospheric ozone depletion has been linked to skin cancer, suppression of the immune system, cataracts, and respiratory damage. Interim substitutes such as HCFC's, more marginal Class II ozone depleters, must also be eventually phased out.

CFC's and halons are used widely as refrigerants in household refrigerators and freezers, cold storage warehouses, refrigerated transport systems, and air conditioning. Some CFC's are used as blowing agents in the manufacture of foam plastics, in combination with ethylene oxide to sterilize medical equipment, in pharmaceutical production, and in spice fumigation. Organic chemicals in this class also include the chlorinated hydrocarbons carbon tetrachloride and 1,1,1-trichloroethane, a significant solvent used in vapor degreasing of electronics components and precision cleaning, adhesives, inks, and coatings, including wood, metal, and aerospace.

On June 14, 1993, the President created a new White House advisory group called the President's Council on Sustainable Development. The goal of the council was to develop a national strategy for sustainable development that could be implemented by both the public and private sectors.

In late 1993, several national trade agencies expressed concern over an executive branch policy decision to develop a national strategy for substantially reducing or prohibiting the use of chlorine and chlorinated compounds, in conjunction with reauthorization of the Clean Water Act. Chlorine especially is an essential ingredient in the manufacture of PVC plastics. Products made from PVC include blood bags and many other medical device applications, plumbing, drainage pipe, and other building materials. Chlorine is also critical in the production of raw material for many other plastics, including polyurethane (PUR) insulation, compact disks, scores of automotive and electronic components, and adhesives.

On October 22, 1993, petitions were filed with the ITC by several U.S. firms, alleging that subsidized imports of phthalic anhydride (PAN) from Brazil, Israel, Mexico, and Venezuela threatened to materially injure the domestic industry. Furthermore, it was alleged that Brazil, Hungary, Israel, Mexico, and Venezuela were landing PAN at less than fair market value (LTFV).

The ITC published the results of an investigation into the matter in the Federal Register on December 16, 1993 (p. 65732), finding that there was a reasonable indication that Venezuelan imports were threatening material injury to the U.S. industry, pursuant to the Tariff Act of 1930. PAN is an aromatic synthetic organic chemical usually produced from the primary petrochemical orthoxylene, although it may also be produced from naphthalene. PAN is used predominantly in the production of plasticizers, unsaturated polyester resins, and alkyd resins, which, in turn, are generally used to produce plastics and paints.

The issue of renewables versus nonrenewables use in fuel oxygenates precipitated a major debate between the U.S. petroleum industry—proponents of nonrenewable MTBE—and the U.S. farm community—proponents of renewable ethanol and ethyl tertiary butyl ether (ETBE), a renewable/nonrenewable reaction product. The U.S. petroleum industry cited favorable production economics, ease of blending and transportation, and lower vapor pressures, especially during the summer months, as factors favoring MTBE use. The U.S. farm community countered by citing favorable environmental factors associated with the use of renewable ethanol, including the recycling of greenhouse gases; a reduction in U.S. dependency on foreign oil, methanol, MTBE, and domestic agricultural subsidies; plus the overall favorable energy balance aspects of ethanol or ETBE.[13]

Production

Organic chemicals production among the top 50 chemicals in the United States grew by 9%, to 129 million tons in 1993, compared with an overall nominal chemicals growth of 3%. MTBE production for fuel oxygenates was 12 million tons, more than double that of the previous year, making it the ninth largest volume chemical. Production of MTBE precursors methanol and isobutylene rose 30% and 20%, respectively. Methanol production was 5.3 million tons, ranking twenty-first in total volume, while isobutylene production was 0.6 million tons. Ethylene, MTBE, propylene, ethylene dichloride, urea, benzene, and ethylbenzene ranked in the top 20 volume chemicals, in respective order of importance, while cumulative output of 73 million tons accounted for 57% of subject organics production.[14]

All categories of plastics posted gains in production. Thermosets rose 8%, with the increase for individual resins varying from 5% for phenolics to 16% for melamines; thermoplastic resins were up 3%. Synthetic fibers and rubber each increased about 3%; paints and coatings, 4%; while pesticides were mixed. *(See tables 5 and 6.)*

According to the most recent ITC statistics, the United States produced 197.5 million tons of synthetic organic chemicals and related raw materials in 1992, valued at $155 billion, f.o.b. plant. Excluding raw materials, total synthetic organic chemicals production, plus coal tar and crudes, amounted to 141 million tons, valued at $137 billion, f.o.b plant. USBM estimates indicate that about 59 million tons of salable synthetic organic materials was produced at an f.o.b. plant value of $67 billion, after discounts for reaction intermediates and salable petroleum byproducts.

Plastics, resin, and plasticizer materials accounted for 55% of total tonnage; surface active agents, 5%; synthetic rubber and processing agents, 5%; pesticides, medicinal chemicals, dyes, organic pigments, flavor and perfumes, 1%; and miscellaneous organic chemicals, 34%. Although pesticides, medicinals, dyes, pigments, flavors and perfumes accounted for only 1% of salable tonnage, the products commanded premium prices amounting to 16% of the total value. *(See table 7.)*

Total U.S. nonfuel feedstock demand for nonrenewable organic chemical derivatives manufactured in 1993 was up about 1% to 123 million tons, according to DOE data. Nonrenewable organic fossil fuel feedstocks were derived primarily from crude petroleum, petroleum refinery derivatives, natural gas liquids, dry natural gas, and coal. About 60% of total nonfuel feedstocks was equally divided between synthetic resin, fiber and rubber manufacture, and numerous other organic chemical products. The remainder consisted of finished or semifinished organic materials, including lubricants and waxes, petroleum coke, asphalt, and road oil. Average feedstock values in 1993 fell about 9% to $12.5 billion, owing to a bottoming out of crude petroleum prices during the year.

A summary of producer activities and market trends occurring within the U.S. organic resins and chemicals industry during 1993 follows. *(See table 8.)*

Ethylene/Polyethylene (PE).—PE is the dominant resin produced in the United States. At yearend 1993, there were 18 U.S. producers situated primarily along the Texas and Louisiana gulf coast having a combined capacity of about 12 million tons per year. LDPE and LLDPE commanded about 62% of the market and HDPE, 38%. HDPE and LDPE producers continued to be adversely affected by overcapacity and low margins, while LLDPE supply and demand were more equally balanced. Capacity additions planned by several producers should add another 900,000 annual tons of PE, or 8%, to capacity in 1994-95.

Three major olefin steam crackers were coming on-stream shortly in the United States. Formosa Plastics was adding 700,000 annual tons of ethylene and propylene capacity at Point Comfort, TX, in late 1993 to mid-1994, split approximately 70/30% between HDPE and PP production. Dow Chemical was constructing another 700,000 annual tons of ethylene capacity at Freeport, TX, scheduled to come on-stream by early 1995. Dow had not reached a final decision on whether to shut down older units. Exxon Chemical Co. was constructing a 200,000-ton-per-year ethylene facility at Baytown, TX, scheduled to come on-stream in 1994. Exxon also completed a 75,000-ton ethylene debottlenecking project at Baton Rouge, LA, during the year.

In 1993, Union Texas Petrochemicals (UTP) of Houston, TX, contracted M.W. Kellogg to expand its 540,000-ton-per-year ethylene plant at Geismar, LA, about 4% to 561,000 annual tons. The expansion involved Kellogg's Millisecond ethylene furnace process based on ethane and propane feedstocks. Meanwhile, Hoechst Celanese was planning an ultra-high-density PE plant at its Bay City, TX, facility.

Occidental Chemical Corp. of Dallas, TX (OxyChem), discontinued HDPE production at its 120,000-ton-per-year Orange, TX, plant in late 1992, and announced its permanent closure in 1993. Oversupply and industry projections for a continued supply-demand imbalance led to the decision. The company has at least 650,000 tons per year of HDPE capacity elsewhere in Texas.

In July 1993, an agreement in principle was formulated for the purchase of Quantum Chemical—the largest U.S. PE producer—by the Hanson Group of London, England. The total transaction, including Quantum's debt, was to approximate $3.2 billion. Hanson's New York affiliate, Hanson Industries, looked for a strong recovery by Quantum owing to global economic recovery and steady absorption of capacity within the PE industry.

Polyvinyl Chloride (PVC).—PVC resin was the second leading polymeric material produced in the United States and continued to perform impressively during 1993. Output was up 3%, operating rates remained firm at about 95%, and there was upward movement in prices. There were 13 PVC producers in the United States with a combined annual capacity of about 5.2 million tons.

Because of the tight U.S. PVC market, producers were planning capacity expansions of about 13% during 1994 and 1995. Shintech, OxyChem, Formosa, Geon, Georgia-Gulf, Vista, and Vygen—in order of importance—announced about 680,000 annual tons of new capacity, in aggregate. B.F. Goodrich spun off its wholly owned 0.8-million-ton-per-year Geon Vinyl subsidiary into a new publicly owned firm called Geon Co.

Polypropylene (PP).—Propylene monomer is the second largest olefin produced in the United States, accounting for 30% to 35% of primary olefins production. At yearend 1993, there were 16 U.S. PP resin producers having a capacity of about 4.7 million tons per year. PP capacity ranks third in terms of production and capacity to PE, and is similar in volume to PVC, the second leading U.S. resin.

U.S. PP production was up only about 1% in 1993, however, and profit margins did not move to any extent. Formosa Plastic's new 210,000-ton-per-year PP plant coming on-stream in mid-1994 at Point Comfort, TX, should continue to hamper PP's performance during the next 1 to 2 years. Amoco Chemical, the second leading producer to Himont, brought a new 135,000-ton-per-year PP plant on-stream at Chocolate Bayou, TX, in 1992. Fina reportedly was planning a new 145,000 PP plant for 1995.

Huntsman Chemical contracted with the John Brown firm to carry out engineering design work for a 150,000 annual ton grassroots facility at Bayport, TX. At the same time, Huntsman was investing $30 million to debottleneck and expand its Woodbury, NJ, PP facility 18% to 180,000 tons per year by yearend 1993. In September 1993, Huntsman and a major firm in Australia acquired Texaco's worldwide petrochemicals business for $1.06 billion. The U.S. facilities purchased involved 3 plants in Texas. The Texaco Chemical facilities produced ethylene, propylene, and ethylene glycol, surfactants, and other specialty chemicals.

Polystyrene (PS).—PS was the fourth leading resin in terms of capacity and production in the United States. There were 15 U.S. producers having an aggregate capacity of about 2.9 million tons per year, including about 0.5 million tons of idle capacity.

In 1993, PS production increased about 6%, and operating rates, excluding idle capacity, were firm at 95%. There was an improvement in export markets and materials substitution markets, including engineering plastics, urethane foams, packaging and appliance, and computer disk housings. Huntsman, the leading producer of PS in the United States, planned aggregate expansions of 120,000 annual tons over the next 2 years. A retrofit project at Belpre, OH, will increase annual capacity by 20,000 tons in 1994, and a new unit for high-impact PS will be completed at Peru, IL, by late 1995. Huntsman also was planning to build a new crystal PS plant at an undisclosed location by late 1996.

Responding to growing demand in food packaging and other applications, BASF Corp. announced an expansion of low-residual, high-heat crystal PS at Joliet, IL. The expansion will raise capacity 8% to 235,000 tons, annually. Total BASF PS capacity in the United States was quoted at 300,000 tons per year, at three locations. BASF purchased the facilities from Mobil Chemical Co. in early 1992.

Chevron Chemical previously announced plans for a new $250 million benzene plant at its Pascagoula, MS, refinery in 1992 to supply feedstock to the downstream styrene market by 1994; Westlake Styrene also completed its 160,000 annual ton ethylbenzene-styrene plant at Lake Charles, LA, in 1992. Industry analysts projected PS demand growth in the United States at 3% per year.

Acrylonitrile-Butadiene-Styrene (ABS).—U.S. ABS production was up 12% in 1993, but global operating rates were only 70% and there was downward pressure on prices, with even more capacity increases slated in the Far East. General Electric Co., Monsanto Co., Dow Chemical Co., and Diamond Polymers, Inc., were the major producers of ABS resin, in order of importance. Monsanto completed a 36,000-ton-per-year ABS expansion in Addyston, OH, last year.

Basic applications in the automotive interior and business-machines housings businesses were meeting with resistance from PP and other lower priced resins. General Electric reportedly was countering automotive materials competition by installing a continuous mass capacity plant at Bay St. Louis, MS, due on-stream in 1994. The mass capacity process yields low-gloss ABS that can bypass painting in some uses, while minimizing chemical waste generation. Diamond Polymer's joint venture between Network Polymers of Akron, OH, and Marubeni and Mitsubishi Rayon of Japan planned to double its relatively minor capacity in early 1994.

Polyethylene Terephthalate (PET).—The U.S. PET bottle resin industry continued in tight supply during 1993, with overall PET resin consumption up about 6% to 0.5 million tons; the tight supply-demand situation could be alleviated somewhat in 1994 with new capacity coming on-stream. Also, rising demand in Mexico has prompted U.S. companies to construct plants there, while domestic producers anticipated increased trade with Mexico owing to NAFTA. Eastman Chemical Co. and Hoechst Celanese were planning to commence construction of PET capacity in Mexico.

As a result of the tight supply, several companies announced capacity increases. Shell Chemical Co. was adding 70,000 tons per year by early 1994 at Point Pleasant, WV, bringing nameplate capacity to 270,000 annual tons. Eastman Chemical planned to debottleneck plants at Kingsport, TN, and Columbia, SC, to increase capacity by 5%, from 410,000 tons per year to 430,000 tons per year; recycler Wellman was to bring 30,000 annual tons on-stream at Palmetto, SC, in early 1994. U.S. demand for bottle-grade resin in 1994 was expected to be about 0.7 million tons according to Eastman Chemical sources, just 10% below overall PET capacity additions in the United States. Total U.S. PET resin capacity was pegged at about 1.2 million tons per year

Toray Plastics America, a subsidiary of Japan's Toray Industries, planned to more than double its production of PET film to 20,000 tons per year at a cost of $100 million. The expanded facilities in North Kingstown, RI, were expected to begin production in March 1994 and will give the Toray group as a whole, 108,000 tons of annual capacity, making it the world's largest producer of PET film for audio and videotapes. The firm, John Brown, was awarded a contract by Goodyear for the design, engineering, and procurement of a 90,000-ton-per-year PET plant in Point Pleasant, WV. Construction commenced in late 1992, and, when completed, will increase PET capacity at the site to 295,000 tons per year.

Nylon.—U.S. production was up about 15% in 1993 and growth should continue into next year, fueled by a resurgence in the automotive and fibers industries. Industry leader DuPont reported a 30% increase in fiber production and a 40% reduction in inventories. DuPont's goal of strengthening its global presence in the nylon business was enhanced through the purchase of Imperial Chemical Industry's (ICI's) worldwide nylon fibers business for $475 million and the swap/sale of its acrylics business to ICI for $280 million. DuPont also was improving its position in Asia-Pacific. In the continuing shakeup of the worldwide nylon fibers business, AlliedSignal, Inc., and BASF Corp. agreed to combine their North American nylon carpet fibers and textile nylon businesses.

Hüls America planned to construct a multipurpose nylon polymer facility at Theodore, AL, to produce nylon-12 and copolyamide specialties. World demand for nylon-12 is estimated to be 40,000 tons per year, and it is expected to be increasingly in demand for use in pneumatic tubes for industrial robots and tubes and hoses for automobiles.

Polyurethane (PUR).—U.S. PUR production was up about 4% to 1.6 million tons, along with sales of isocyanates used in the production of PUR. Accordingly, diphenyl-methane-4,4'-diisocyanate (MDI) sales were up 11%, while toluene diisocyanate (TDI) sales increased 3%. The upturn was primarily attributable to the automotive, housing, bedding, and furniture sectors. Global operating rates for MDI and TDI were 90% and 85%, respectively. CFC's were being replaced by alternative blowing agents for PUR foam, including HCFC's and chlorine-free pentanes.

MTBE/Methanol.—At yearend 1993, DOE statistics indicated that there were 44 U.S. facilities capable of producing MTBE having a total capacity of about 200,000 barrels per day. Approximately 34,000 barrels per day, or 17% of total capacity, was idle. Large petroleum companies in Texas, Louisiana, and one location in Mississippi—in order of importance—controlled 87% of total capacity. Arco Chemical Co. was operating a swing train for MTBE/ETBE production at Corpus Christi, TX, that could produce either 12,000 barrels per day of MTBE, or 9,500 barrels per day of ETBE. Amoco Oil Co. was operating the only facility dedicated 100% to ETBE at Yorktown, VA, having a capacity of 815 barrels per day. Net imports of MTBE averaged 15,000 barrels per day, or 8% of U.S. capacity in 1993. MTBE was shipped primarily from very large plants—more than 10,000 barrels per day—in Canada, Saudi Arabia, and Venezuela. Imports came in duty free from Venezuela, while Canadian material will become duty free in January 1994 under NAFTA. All other countries except Argentina, Bahrain, Malaysia, and Trinidad, were required to pay a duty of 5.6%.

At yearend 1993, there were 13 U.S. methanol plants having a capacity of 126,000 barrels per day, or 1.8 billion gallons per year. Approximately 85% of total capacity was concentrated in Texas and Louisiana—in order of importance—and all plants were operating. Methanex of Vancouver, British Columbia, the world's largest methanol producer at more than 1.5 million tons per year, was involved in a joint-venture project to retrofit American Cyanamid's mothballed ammonia plant at Fortier, LA, while Terra Chemical was retrofitting its Woodward, OK, ammonia plant for methanol swing capacity. North American methanol supply-demand was tight in 1993 owing to an upswing in U.S. MTBE production for fuel oxygenates. Methanol growth was pegged at 6% to 7% per year for the 1991-95 period. The United States is believed to have an import dependency approximating 30% for methanol.

Other Organics.—DuPont started up the world's largest hydrofluorocarbon-134a plant at Corpus Christi, TX, during 1993, bringing total CFC substitute capacity to 50,000 tons per year, including facilities in Ponca City, OK, and Chiba, Japan. DuPont's 1993 Annual Report cited the firm as an industry leader in CFC alternatives, with a full line of refrigerant products marketed under the "Suva" trademark. These products were reported to have zero or significantly reduced ozone depletion potential.

OxyChem's new chlorinated isocyanurates business positioned the firm as the global leader in swimming pool sanitizers and a wide range of household and industrial disinfectants. Meanwhile, Elf Atochem North America was constructing a 10,000-ton-per-year liquid peroxide initiator plant at Crosby, TX, scheduled for completion by mid-1994.

Sun Co. of Philadelphia planned a 34-million-gallon-per-year cyclohexane plant at its Marcus Hook, PA, refinery, scheduled to come on-stream in late 1994. Cyclohexane will be produced as a downstream product of the firm's associated 60-million-gallon-per-year benzene project. Sun's announcement brought some relief to the tight market situation following the closure of the firm's Tulsa, OK, plant and the withdrawal of Texaco Chemical from the business. Additionally, Kerr-McGee Chemical Co. acquired a cyclohexane plant from Unocal and was relocating it from Beaumont, TX, to Corpus Christi, TX, in 1993. Meanwhile, Phillips Petroleum was expanding cyclohexane capacity by 15% to 50,000 tons per year at Guayama, Puerto Rico.

Texaco announced the shuttering of its 20,000-ton-per-year ethylenamines plant at Conroe, TX, after only 2 years of operation. The firm cited worldwide overcapacity, a 3-year downward trend in pricing, and slow acceptance of its material as reasons for the closure. Ethylene oxide feedstock complicated the process involving higher molecular weight linear material, which was new to customers. Industry leaders Union Carbide and Dow Chemical, on the other hand, have recently expanded capacity at Taft, LA, and Freeport, TX, respectively, and expect 4% market growth. Total industry capacity now stands at about 200,000 tons, annually. The strongest markets are for polyamines, used in lubricating oil and fuel additives and in specialty applications.

In early 1993, Monsanto signed a letter of intent to buy Chevron Chemical Co.'s Ortho business for about $400 million. Ortho is a leading merchandiser of more than 300 lawn and garden products, including insecticides, fungicides, herbicides, plant foods, and indoor household insecticides.

Consumption and Uses

Resins.—In 1993, U.S. plastic resin sales were up 5% to 31.2 million tons, reflecting an upturn in the domestic economy. Resins were valued at about $33 billion, f.o.b. plant. There was a general volume improvement across the board for all resins, although major thermoplastic prices did not follow suit, except for PVC. HDPE prices fell, indicative of continued oversupply, along with expanded PS bead, and downward price pressure continued to be felt in PP, ABS, and unsaturated polyester markets. Sales volume was driven primarily by improved demand for primary construction materials, automotive, and general consumer products. Within key markets, demand outperformed the average 5% growth in sales, indicating that consumers were no longer postponing the purchase of plastics-intensive products. Resin use in furniture was up 13% over 1992 levels; building materials, 12%; appliances, 10%; and marine applications, 8%. Demand and prices, in general, were perceived to turn up markedly for most commodity resins in the fourth quarter of 1993. *(See tables 9 and 10.)*

Packaging commanded about 30% of the U.S. resins market in 1993, followed by building and construction, 20%; and consumer and institutional use, 10%. The transportation and electronic industries accounted for another 10% in total; furniture and furnishings, 4%; adhesives, inks, and coatings, 3%; industrial and machinery, 1%; miscellaneous use, 10%; and exports, about 12%. *(See table 11 and figure 10.)*

Fiber.—U.S. synthetic fiber shipments were up 3% to 4 million tons in 1993, including a 2% increase in exports of 0.2 million tons. Approximately 95% of fiber shipments were noncellulosic synthetic materials, distributed to polyester, 40%; nylon, 30%; olefins (polyethylene-polypropylene), 25%; and acrylics, 5%; in respective order of volume. Cellulosics include rayon and acetates, produced by reacting cellulosic wood pulp with inorganic and organic chemicals. The majority of nylon and olefins was used for carpets, textiles, and industrial yarns and monofilament, with lesser amounts going into staple fibers and fiberfill. Polyesters were used more heavily for staple fibers, including nonwovens and fiberfill.

Approximately 1 million tons, or 25% of total fiber shipments, consisted of staple fibers, including nonwovens and fiberfill markets. Both nonwovens and fiberfill set new sales records in 1993. Nonwovens moved up 5% to 0.3 million tons, while fiberfill increased 2% to 0.2 million tons, representing about 50% of the total staples market. Olefin is the fastest growing fiber in nonwovens, and together with polyester, commands about 90% of the market. Polyesters, predominately PET, dominate the fiberfill market. The largest single market for polyester and olefin staple in 1993 was broad weaving, which absorbed 26% of total sales of the two fibers. *(See table 12.)*

Rubber.—U.S. synthetic rubber (elastomer) shipments moved up 3% to 2 million tons on the heels of surging demand for U.S. automotive products, including tire treads, hoses, belts, and other materials. Synthetic rubber was valued at about $3.7 billion, f.o.b. plant. Styrene-butadiene and polybutadiene rubbers accounted for approximately 60% of total synthetic rubber demand and were used primarily in tires. About 5% of styrene-butadiene was produced as latex for coating applications. Ethylene-propylene rubber accounted for another 10% of the total, followed by butadiene-acrylonitrile (nitrile), 3%; and silicone elastomers, 3%. Butyl rubber, polychloroprene (neoprene), polyisoprene, and miscellaneous elastomers accounted for another 15%. Thermoplastic elastomers accounted for the remaining 9% to 10%. These materials are primarily styrene-block copolymers, thermoplastic olefin elastomers, and thermoplastic polyurethane elastomers and copolyesters. *(See table 13.)*

Approximately 1 million tons of imported renewable natural rubber also was consumed in the United States during 1993 to fulfill the requirements for tire production and other demand. The United States is the leading global tire manufacturer and demand market for natural rubber. Securing a consistent supply of natural rubber for the United States has been a high priority of the rubber industry and the Federal Government because no synthetic alternative has been found to replace many of its unique physical properties. The majority of natural rubber is produced in Indonesia, Malaysia, and Thailand. Landed prices for natural rubber in the United States have ranged between $0.83 and $1.31 per kilogram during recent years.

Natural rubber is imported as latex (60% solids), sheet, or crepe, and approximately 80% is consumed in tire manufacture. The remainder is used mainly to produce footwear, gloves, contraceptives, thread, adhesives, foam, medical devices, hose and belting, and automotive goods. Many of these traditional applications for natural rubber have been replaced by synthetic rubbers and thermoplastic elastomers in recent years because synthetic materials offered a better variety of properties such as durability and chemical resistance.

The consumption of natural rubber in the rubber glove and contraceptive industries, however, has increased recently with the spread of Acquired Immune Deficiency Syndrome (AIDS). However, the overall demand for natural rubber is expected to be affected minimally by the AIDS epidemic, as gloves and contraceptives are low-volume end-use commodities, according to a recent ITC study. Thus, tire demand should continue to be the dominant driving force for natural rubber.

Solvents.—Organic solvent demand was pegged at 5.7 million tons in 1992, representing a $2.9 billion industry. Major solvent use was led by hydrocarbons (38%), followed by alcohols, esters, and ethers (33%), chlorinated solvents (11%), ketones (9%), and glycols (6%). Major end-use markets were in coatings, printing inks, and adhesives, where about 3.1 million tons, or 54% of the total, was consumed. Consumer markets accounted for 1.2 million tons (21%); manufacturing and process industries, 0.6 million tons (10%); industrial cleaning, 0.5 million tons (9%); and miscellaneous uses, 0.3 million tons (6%).

A multitude of environmental regulations ranging from the elimination of certain CFC's by January 1996 to forced reductions in VOC emissions, EPA's toxic release inventory and health concerns, are restricting growth of organic solvents. Many companies are turning to aqueous carriers or high-solid contents in paints and coatings, and to hot-melt, ultraviolet-cured, and waterborne adhesives. In the cosmetics and personal care markets, solvents have been dropped from some formulations because of concerns over VOC's; water-based hairsprays and solid deodorant sticks have captured market share.

Large-use chemicals, such as acetone, 1,1,1,-trichloroethane, and xylene, that could dissolve seemingly anything, are being replaced to an extent by myriad high-value specialty chemicals. Although 1,1,1-trichloroethane is being phased out in 1996, for example, only 20% to 30% of customers have been willing to change. Furthermore, perchloroethylene solvent used by the 25,000 dry cleaning facilities in the United States was the first to be regulated under EPA's 1990 Clean Air Act national emission standards for hazardous air pollutants (NESHAP). EPA has established a goal to reduce emissions of perchloroethylene, a suspected carcinogen and hazardous air pollutant, through a combination of tightening emissions standards in the dry cleaning industry and a gradual move to wet-based dry cleaning.[15]

Paints and Coatings.—Paints and coatings sales rose 4% to about $13 billion in 1993 and shipments climbed by more than 3% to 1.1 billion gallons, according to the U.S. Bureau of the Census. Architectural coatings led in all categories, commanding 55% of total industry volume and 43% of total industry value. Product coatings were 29% of total shipments and 35% of total value, while special-purpose coatings represented 16% of all shipments and 22% of total value. Architectural coatings include exterior and interior house paints, stains, undercoaters, primers, and sealers. Product coatings applications include appliances, automotive, electrical insulation, and factory-finished wood, marine equipment, metal containers, furniture, and pipe, in order of importance. Special-purpose coatings applications range from aerosols, arts and crafts, automotive, machinery refinishing, and bridge maintenance to multicolored, roof, swimming pool, and traffic marking, in order of importance.

Paint manufacturers are reformulating paints to reduce VOC's and hazardous air pollutants (HAP) in face of increasingly stringent air pollution regulations by EPA that will become effective in 1996. The paint industry has worked cooperatively with EPA for more than 2 years with the objective of establishing specific limits that would reduce VOC's emitted from architectural and industrial paints 25% by 1996; 30% by the year 2000; and 40% by 2004, based on 1990 emissions levels of about 0.5 million tons—an agreement had not been reached by yearend, however.

Whenever possible, industrial paint consumers have shifted to newer technologies, such as heat-curable powder coatings and radiation-curable coatings. Both of these technologies can eliminate VOC's because they are solvent free. However, these technologies are only practical on specially adapted, original equipment manufacturers' product-coating lines. Cost and practicality factors have led paint consumers to continue using newly developed low-VOC liquid coatings on their existing production lines. Some inroads have been made, for example, by replacing solvent containing urea alkyd coatings for kitchen cabinets with high-performance aqueous coatings. Waterborne systems to coat wood also are making inroads against the high-solvent nitrocellulose lacquers used widely for furniture.

Paint formulators are facing increasing regulatory pressure to reduce the use of older aromatic and aliphatic solvents—among them toluene, xylene, and mineral spirits—with oxygenated solvents such as butyl acetate and ethyl acetate; propylene glycol-based materials; and some ketone-based products and dibasic esters. In the industrial maintenance arena, formulators are shifting to higher solids, low-solvent coatings as well as waterborne coatings. Newly introduced propylene-based diether solvents have proven to be effective for use in both waterborne and solventborne urethanes.[16]

Recycling

According to the latest EPA figures, plastics account for 21.1% of the municipal wastestream by volume; paper and paperboard, 31.9%; metals, 11.1%; yard waste, 9,8%; food waste, 3.2%; and all others, 20.7%. Most municipalities in the United States have found that the only real solution to waste management is an integrated approach utilizing four basic methods: (1) source reduction, (2) recycling, (3) waste-to-energy incineration, and (4) landfilling.

On October 20, 1993, the President signed an Executive order requiring that Federal agencies purchase printing and writing paper containing 20% postconsumer material by the end of 1994. Federal agencies also are required to begin purchases of rerefined lubricating oil and retread tires by April 18, 1994. The Chief Executive's order was designed to emphasize to the Nation that recycling activities will protect the environment while providing the private sector with incentives to develop new market opportunities and technologies.

A brochure circulated by the U.S. Conference of Mayors' "Buy Recycled" Campaign, in conjunction with the Presidents new Executive order, suggested that instead of discarding used tires to waste—an estimated 3 billion tires litter the U.S. landscape—many may be retreaded. Retreading was said to require only 35% of the energy necessary to produce a new tire. It was also estimated that about 2 billion gallons of automotive lubricating oil was used in the U.S. annually, with about 10% known to be either dumped or burned. Thus, recycled oil was reported to make sense from both an environmental and nonrenewable resource conservation standpoint.

Recent data compiled by Modern Plastics on postconsumer recycling of thermoplastics indicate that recyclate volume increased by a significant 25% to 0.5 million tons between 1992 and 1993. PET and HDPE commanded equal shares of the market and, in combination, represented about 80% of total feedstock volume. LDPE held a 10% share of the market; PS foams, 5%; with PVC, PP, and other resins accounting for the remainder. Most of the recycled PET and HDPE feedstock was in the form of soda bottles and natural color bottles, respectively. PET was reclaimed predominately as fiberfill, with lesser amounts going to bottles, strapping, film, and export. HDPE was reclaimed as bottles and drainage pipe and transformed into a variety of construction and general consumer products. LDPE was reclaimed principally as film, PS as foam packaging and loosefill, and PVC as molded goods and miscellaneous items. *(See tables 14 and 15.)*

An independent study conducted for the American Plastics Council by R. W. Beck and Associates revealed that postconsumer plastics recycling increased significantly between 1991 and 1992. The recycling of plastics packaging was up 47% in 1992 to about 430,000 tons. Plastic bottles recycled in all forms increased from 14% to 19%. PET soda bottle recycling amounted to 170,000 tons, or 41% of total production between 1991 and 1992. Recycled HDPE milk, juice, water, and household chemical bottles and film bags was about 200,000 tons in 1992, up 67%, while colored HDPE bottle recycling rose dramatically to about 60,000 tons. Recycled PP was 100,000 tons, while LDPE, PS, and PVC, in combination, was about 60,000 tons.

In response to an ongoing nationwide survey conducted by the council, more than 6,850 cities and towns confirmed that plastics were being collected for recycling through either curbside, dropoff, or buyback programs during 1992.

Additional information on materials recycling is available, as noted.[17]

Transportation

Crude oil and natural gas were transported domestically through a network of major pipelines, while crude oil imports were landed at domestic ports primarily in supertankers. Newer, more modern supertankers were equipped with multiple hulls to prevent leakage in the event of accidents. In some instances, ethylene was transported through pipelines from petroleum refining and petrochemical facilities operated by major oil companies on the U.S. gulf coast. Large-volume synthetic plastic, resin, and rubber commodities were moved in bulk and bags by rail, truck, and barge. Selected synthetic fiber producers received monomers principally by rail, and subsequently polymerized and transformed the polymerized material into marketable fiber. Liquid organic chemicals and intermediates were transported principally by rail or barge.

Markets and Prices

An upturn in the U.S. economy during 1993 and improved consumer demand were the key factors leading to an approximate 3% to 4% rise in the large-volume organics commodity businesses, although margins were still negatively impacted by depressed petroleum prices and a sluggish recovery from recession.

PVC markets continued in tight supply as reflected by a steady rise in prices throughout the year. By yearend, PVC monomer prices were 18% above 1992 values and polymer prices were up 11%. Butadiene prices ended the year 22% above 1992, reflecting a tight supply-demand situation for styrene-butadine and polybutadiene synthetic rubbers. Polypropylene prices were down 8% in 1993, and HDPE declined 5%, reflecting continuing oversupply and downward price pressure. Polystyrene prices were mixed depending upon grade of resin. In general, there was dramatic improvement in HDPE, LDPE, and PS prices during the fourth quarter, but not enough to offset generally declining trends in the large-volume commodity thermoplastics during the preceding three quarters. *(See tables 16 and 17.)*

Foreign Trade

Organic chemicals are the single largest segment of U.S. chemical exports, accounting for nearly one-half of total chemical shipments to foreign markets. On a volume basis, 75% to 80% of organic chemicals are petrochemicals. The remaining 20% to 25% are pharmaceutical or drug products, which on a value basis comprise about 50% of organic chemicals. The trade surplus for U.S. nonfuel synthetic organic chemical materials derived principally from petrochemical feedstocks increased 1% to about $12 billion in 1993, according to the U.S. Department of Commerce. The trade surplus breakout includes $4 billion for organic chemical derivatives; $5 billion for plastics and resin materials; and $3 billion for synthetic fibers and rubber, in aggregate. According to the International Trade Administration (ITA), about 20% of U.S. petrochemical shipments by value in 1992 were to Canada and Mexico, 24% to the EC, 23% to the Far East, 9% to Japan, 10% to South America, and 14% to other countries.

Available data for U.S. large-volume thermoplastic resins trade in 1993 indicate that the traditional trade surplus declined 13%, from 2.4 million tons in 1992 to 2.1 million tons in 1993. Exports were flat at 3.5 million tons, while imports increased from 1.1 to 1.5 million tons. ITA estimates for 1993 indicate that the United States experienced a $4.6 billion trade surplus in plastics and resin materials, relative to $5 billion in 1992. Canada and Mexico accounted for about 30% of U.S. plastics and resin shipments by value; the EC, 23%; Asia, 21%; Japan; 6%, South America, 8%; and other countries, 12%. ITA also reported an estimated trade surplus of $0.4 billion in finished plastic goods, while a trade surplus of $2.5 billion was recorded for synthetic fibers, and $0.4 billion for synthetic rubber. *(See table 18.)*

DOE projections indicate that the U.S. MTBE trade deficit will probably increase threefold to 45,000 barrels per day in 1995, while domestic production capability will rise 48,000 barrels per day to about 250,000 barrels per day and operate at about 83%. Under NAFTA, MTBE will be allowed to come in duty free from Canada and Mexico effective January 1994, while MTBE imports from Argentina, Bahrain, Malaysia, Trinidad, and Venezuela were already duty free under existing trade agreements. All other countries must pay a duty of 5.6%. About 30% of U.S. methanol requirements were imported owing principally to a domestic capacity shortfall for the production of MTBE.

Under NAFTA, Canada and Mexico, and the United States agreed to create a free trade area under the existing General Agreement on Tariffs and Trade (GATT) provisions, designed to phaseout customs duties according to schedules established for each country. More specifically, the United States agreed to phase out existing duties on most plastics and resin materials effective January 1994. There was a provision to stage U.S. duties on LDPE from the existing 12.5% to 4% in 1994, with complete removal in 1998. Most duties were to be phased out shortly after the turn of the century. U.S. duties on petrochemical feedstocks are already free for the most part. The ramifications of the NAFTA agreement were published in five volumes and are available from the National Technical Information Service, Springfield, VA, 22161.

The ITC's recent report: "Potential Impact on the U.S. Economy and Industries of the GATT Uruguay Round Agreements;" concluded that the positive U.S. trade balance in plastics, resin, and rubber is likely to increase only marginally as a result of the Uruguay Round because U.S. rates are already low in comparison to other countries and will remain so, particularly in the developing world where future growth is anticipated. Because the U.S. industry is already multinational in flavor, ITC believes that many firms will opt to conduct business more aggressively in areas of the world where a competitive edge can be gained; GATT would not substantially alter these conditions.

The U.S. plastics and rubber industry position on GATT has generally been supportive. However, there have been concerns expressed with regard to market access in Latin American and Asian countries having relatively high tariffs and where no provisions have been reached to harmonize tariff levels to EC, Japanese, and United States levels. The U.S. industry is diverse, with some manufacturing sectors more affected than others by GATT provisions, but the general consensus has been that while exports may increase to an extent, imports probably will not be affected.

World Review

Global demand for selected synthetic resin materials in 1993 was up 1.5% to 69 million tons, largely on the strength of U.S. sales, which accounted for about 45% of the accountable total. In spite of improving conditions in the United States, recession in Europe and Japan and restructuring in the former U.S.S.R. and Eastern bloc countries continued to dampen global demand and prices. Overcapacity was the principal factor, especially in Europe and Japan, where rationalization measures were underway. Declining import demand in China further exacerbated the situation owing to inventory overhangs and economic pressures associated with currency devaluation. In the troubled global PE market, margins narrowed, overcapacity was rampant, and despite repeated attempts, price hike initiatives were unsuccessful. In Western Europe, prices also were undermined by a rise in imports from Eastern Europe and South America. Global operating rates ranged from a low of 79% to 83% for PP, HDPE, LLDPE, and PVC, in increasing order of importance, to a high of 87% for LDPE.

Industry Structure.—According to available statistics, the United States was the leading producer and distributor of global synthetic plastics resin, fiber, and rubber in 1992 and 1993, commanding more than 40% of the global resins market and about 30% of the synthetic rubber and fibers markets. Supply capability, excluding the United States, was generally concentrated in Europe, Japan, the Far East, former U.S.S.R. and Eastern bloc countries, Canada, and Latin America. *(See tables 19 through 21.)*

Capacity.—According to data reported by Chem Systems of Tarrytown, NY, world capacity for PE, PVC, and PP in 1993 increased more than 4% to about 85.5 million tons per year. Annual PVC capacity was 23 million tons, or 27% of total; PP, 20.1 million tons (24%); LDPE, 17.1 million tons (20%); HDPE, 14.9 million tons (17%); and LLDPE, 10.4 million tons (12%).

Asia and the Pacific Basin.—This region accounted for about one-third of world chemicals demand. The area's first major impact on the world chemical market was as a textile supplier, so chemical fibers were the first to undergo expansion. As a result, Taiwan and the Republic of Korea have larger polyester fiber production capacities than western Europe—each produces about 1.2 million tons per year of polyester filament yarn and staple fiber. This area has been primarily a market for Japan, which accounts for about two-thirds of the region's gross national product (GNP). Large multinational companies have been increasing their investment in the printstyle region; however, impending overcapacity has led to a slowdown in investments. China, Indonesia, and Taiwan have some room for growth. Other countries in the region are faced with overcapacity. Between 1990 and 1992, ethylene production capacity in Asia (China, Indonesia, Japan, the Republic of Korea, Malaysia, Singapore, Taiwan, and Thailand) grew from 10.6 million tons to 13.3 million tons, and in 1995 capacity is projected to reach 16 million tons. Polymeric resin production capacity growth in China from 1991 to 1995 is projected to grow by the following quantities: LDPE, 1.26 million tons; LLDPE, 330,000 tons; HDPE, 300,000 tons; PS, 300,000 tons; PP, 980,000 tons; and PVC, 480,000 tons.

Regional growth in the Far East led several companies to announce expansion plans for PVC. Tosoh Corp. (Japan) plans to expand production in Indonesia and Malaysia, while Thai Plastic & Chemicals also plans to increase its capacity in Thailand. Postwar reconstruction programs in Cambodia and Vietnam were cited as reasons for increased PVC demand.

Amoco Chemical Corp. and a local conglomerate formed a joint venture to build a 350,000-ton-per-year purified terephthalic acid (PTA) plant in West Java. Completion is slated for 1995. Amoco also formed a joint venture with several Japanese firms and completed a feasibility study for a 250,000-ton-per-year PTA plant in the Republic of Korea. The new capacity, to be completed by mid-1995, will bring the country's total capacity to nearly 900,000 tons per year, all to be used in the domestic market. The firm also was moving ahead on previously reported plans to build a wholly owned 500,000-ton-per-year PTA plant in Malaysia and is expected to invite bids in early 1994. Amoco's other regional PTA production is through joint ventures in the Republic of Korea and Taiwan; the latter is being expanded by 25%.

ICI commissioned its 350,000-ton-per-year PTA plant in Taiwan to serve the Asia-Pacific market, which accounts for about 60% of total world demand. The Far East market has been oversupplied following several startups in the past few years, and analysts do not believe this market will be able to absorb the additional capacity until 1993 or beyond. Between 1993 and 1995, at least six new PTA plants were planned in the region, increasing capacity by about 1.5 million tons per year.

In 1993, DuPont and Mitsui & Co. signed an agreement to jointly develop markets and sell DuPont's advanced composites in Asia-Pacific. Mitsui will be responsible for promotion and sales of the products, which are being targeted to replace metals in aerospace, automotive, industrial, and recreational applications. DuPont also signed a similar partnership agreement with Asahi Chemical to look for nylon synergies in Asia-Pacific. DuPont recently commenced construction of a major nylon-6,6 facility, including adipic acid, in Singapore.

China.—The Chinese Government approved construction of a 140,000-ton-per-year ethylene plant at Dongying, Shandong, and discussions began with foreign suppliers for an associated $600 million complex that also will produce 100,000 tons of PE, 60,000 tons of acrylonitrile, and 30,000 tons of acrylic fibers per year. China also started a new ethylene plant in Liaoning Province with a capacity of 120,000 tons per year. Toyo Engineering was awarded a contract to expand an ethylene plant for Yangzi Petrochemical at Nanjing. The present 300,000-ton-per-year Lummus Crest process plant, built in 1978, will be debottlenecked by 100,000 tons to 400,000 tons per year. The country plans to increase ethylene capacity from 1.8 million tons per year in 1990 to 3.7 million tons per year by 1995, and by at least another 1.5 million tons to 5.2 million tons per year by the year 2000.

The Italian firm Snamprogetti won an order to build a 120,000-ton-per-year LLDPE plant in China. The plant will form part of the Zhongyuan complex at

Puyang, Henan. Mitsui Engineering won a $35 million contract to build a 40,000-ton-per-year PP plant at the Daqing petrochemical complex in Heilongjiang Province. Chi Mei Industrial planned to build a 300,000-ton-per-year ABS plant and a 300,000-ton-per-year PS plant in China by mid-1995.

Snamprogetti won an order to build a 100,000-ton-per-year styrene monomer unit, and Mitsui Engineering won an order to build a 100,000-ton-per-year ethylene oxide/glycol unit at the Maoming petrochemical complex.

SNC-Partec was awarded a $55 million contract for a 60,000-ton-per-year styrene plant in Panjin, Liaoning Province. Two additional styrenics complexes were planned. One in Heilongjiang Province was to have annual capacities of 60,000 tons of styrene monomer, 25,000 tons of PS, and 50,000 tons of ABS. At Guangzhou, annual capacities will be 60,000 tons of styrene monomer and 50,000 tons of PS.

India.—India has experienced shortfalls in domestic capacity and production to meet petrochemical demand. With the Government's liberalization of the economy, official industry sources expected enough new petrochemical capacity to be installed to meet demand and perhaps provide some material for export. By the end of the decade, official industry sources projected an increase in ethylene capacity from 230,000 tons per year to more than 2 million tons. In 1992, production of LDPE, LLDPE, HDPE, PP, PVC, and PS was estimated to be 471,000 tons, with demand at 755,000 tons. By 1995, production is expected to be 1.1 million tons, with a demand of 1.06 million tons.

Simon-Carves of Manchester, England, was awarded a contract for the basic design and engineering of a 55,000-ton-per-year LDPE plant to be built in an undisclosed location in India. The plant was due on-stream in 1994.

Reliance Petrochemicals, based in Bombay, formed a joint venture with Mitsubishi Corp. to build a new 250,000-ton-per-year PP plant at the petrochemical complex in Hazira, Gujarat. Startup was scheduled for 1994, to coincide with the complex's 320,000-ton-per-year olefins cracker coming on-stream. Italy-based Tecnimont was awarded a contract to build a 75,000-ton-per-year PP plant for Indian Petrochemical Corp. Ltd. at Baroda, Gujarat; completion was scheduled for 1995.

ABB Lummus Crest of Bloomfield, NJ, was selected to build a 60,000-ton-per-year styrene monomer/PS complex in India. The company also will provide basic engineering and other services for a 100,000-ton-per-year ethylbenzene/styrene monomer plant. Both plants will be near Nagothane and were scheduled for completion in 1994.

Reliance Industries planned to build a 350,000-ton-per-year PTA plant at Hazira at a cost of $528 million. Also to be constructed were downstream facilities for the production of polyester filament, polyester staple, and PET, totaling 200,000 tons per year. Initial production was scheduled to begin at the end of 1993, and the complex completion date was scheduled for 1995.

Indonesia.—A new joint-venture company, PT Polytama Propindo, owned 80% by the local PT Tirtamas Majutama and 10% each by BP Chemicals (London) and Nissho Iwai (Tokyo), received permission to set up a $230 million, 100,000-ton-per-year PP Himont process plant at Balongan, Java island. The project will receive propylene feedstock from a new refinery under construction at Balongan for Pertamina and is scheduled for completion in 1995. This will be the third PP plant in Indonesia. Indonesia's existing PP plant is owned by Tripolita; the firm planned to double capacity.

P.T. Tripolita Indonesia will soon begin production of PP at its new 160,000-ton-per-year plant in Anyer, West Java. PT Styrene Monomers Indonesia completed its 100,000-ton-per-year styrene plant in West Java. Dow Chemical and the Salim Group were constructing a plant in Indonesia to produce 30,000 tons per year of styrene-butadiene latex. The plant came on-stream early in 1993.

In addition, Golden Key was building a 140,000-ton-per-year Unipol process unit at Serang, Java. Golden Key Group completed engineering for its $300 million styrenics complex at Serang. The project was expected to come on-stream in 1994 and included plants for styrene monomer, PS, high-impact PS, ABS, styrene acrylonitrile (SAN), styrene butadiene rubber, and styrene butadiene latex. BP Chemicals' PE joint venture, PT Peni, successfully started up a 200,000-ton-per-year LLDP and HDPE plant during 1993.

Indonesia has approved construction of the Chandra Asri petrochemical complex at Cilegron, West Java, as long as it is 100% foreign owned; the project was postponed in 1991. The first stage is a 450,000-ton-per-year to 500,000-ton ethylene plant, with downstream units to produce PE and PP.

Textile company P.T. Polyfin announced that it would build a complex with a capacity of 63,000 tons per year of polyester fiber to be completed by mid-1994. Total polyester filament capacity in Indonesia was 170,000 tons per year and was scheduled to double by 1993 when capacity expansions announced earlier are brought on-stream.

Japan.—Ethylene oversupply was substantial in 1993, and output was expected to drop by a further 7.9% in the first-half of 1994, to 2.7 million tons, according to a Ministry of International Trade and Industry (MITI) advisory panel. MITI projections indicated that ethylene equivalent demand was expected to decrease from those of 1992 and 1993 because of continuing declines in the automotive, construction, packaging, and electronics sectors. Several Japanese PE producers were extending shutdowns in 1993 owing to the downturn in the domestic market.

Because of the continued slump in

the Japanese petrochemical industry, where ethylene capacity currently approximates about 6.5 million tons per year, several projects were postponed or downsized. Maruzen Polymer delayed plans to build a 100,000-ton-per-year HDPE plant at Chiba, and Asahi postponed the April 1992 startup of its 40,000-ton LLDPE plant in Mizushima. Nippon Petrochemical postponed the startup of its 50,000-ton LLDPE plant from March until late 1992 to early 1993. Nippon Petrochemical postponed commissioning of its 50,000-ton-per-year LLDPE reactor until early 1993, and Showa Denko planned to cut back production of ethylene and derivatives into 1993.

Japanese manufacturers of PS were working to reduce high inventory levels, and plant operating rates decreased to less than 80%; total Japanese PS capacity was about 1.4 million tons, and 1993 demand was about 1.1 million tons. Exports for Japanese PS were not growing as expected because of competition from other producers in countries such as the Republic of Korea, where 300,000 tons per year of new styrene capacity competed in traditional Japanese markets. Several Japanese PS producers were considering closing outdated plants amid falling demand in 1993.

The Japanese styrene oversupply situation was further exacerbated by the startup of Idemitsu Petrochemical's 200,000-ton plant at Tokuyama in 1992. Sumitomo Chemical and Denki Kagaku reached an agreement to build a 250,000 annual ton $160 million styrene plant at Chiba by 1994. Nippon Polystyrene cut production of PS as a result of lower demand for electronic appliances and office equipment.

Idemetsu Petrochemical began limited production at its 80,000-ton-per-year PP plant, the output of which was destined for Malaysia; the company did not expect to start full-scale operations until the spring of 1993. Ube Polypropylene postponed startup of its new 80,000-ton PP plant from October 1992 until sometime in 1993, citing poor demand and overcapacity. An 80,000-ton-per-year PVC plant was completed at Sumitomo Chemical's Chiba complex in 1992, but startup was delayed by at least 6 months because of the depressed state of Japan's PVC market.

Tejin and DuPont reportedly reached an agreement to jointly develop polyethylene napthalate (PEN) films, an analog of PET. Tejin is currently the only commercial producer of PEN films with a plant in Japan. PEN films are stronger than PET films and are expected to see significant growth in the next few years. They are used in Japan for audiotapes and videotapes, and DuPont hopes to market PEN for thin-film capacitors and for insulating film used in motors, traditional PET markets.

Mitsubishi Kasel planned to raise its current xylenol capacity of 2.6 million annual tons, about 20% to 30% by 1994. The material is supplied to Yuka Shell Epoxy, a joint venture with Shell Oil, to produce epoxies for use in encapsulating advanced semiconductors. Mitsubishi Yuka announced the restart of a mothballed 25,000-ton-per-year acrylic acid plant at Yokkaichi, closed since March 1993, despite the local market slump. The company plans to export most of the material to the United States, under contract.

Idemitsu Kosan planned to construct a 100,000-ton-per-year MTBE plant at its Chiba refinery. Completion was scheduled for June 1993. In Japan, MTBE was approved for use in gasoline blending in 1991, which prompted several companies to build production capacity. In September 1992, Kashima Oil completed the first MTBE plant in Japan, with an annual capacity of 60,000 tons; the plant relied on imported methanol, supplied predominately by Methanex.

Korea, Republic of.—In the Republic of Korea, the Ministry of Trade and Industry banned construction of new ethylene plants and some derivatives through yearend 1994, including styrene and caprolactam. Ethylene capacity in the Republic of Korea was at about 20% above domestic demand; 2 years before, the deficit between MTBE capacity and domestic demand was about 20%; but, to meet upcoming clean air regulations, the Republic of Korea plans to increase its MTBE capacity. Sales of selected high-volume thermoplastics increased 13% in 1993.

Malaysia.—Titan Himont Polymers recently commissioned a 120,000-ton-per-year PP plant in Pasir Gudang. A 140,000-ton plant was under construction at the site and scheduled to come onstream during late 1993. Japan's Mitsui Engineering & Shipbuilding reportedly won an order to build Idemitsu's $50 million, 60,000-ton-per-year PS plant in Malaysia. This plant is a part of Idemitsu Chemicals' ethyl benzene/styrene monomer, PS, and ABS production facilities.

Singapore.—In 1993, DuPont broke ground for a new $100 million nylon-6,6 plant at Pulau Sakre. The unit, scheduled for mid-1995 completion, will form part of a major nylon complex; a $250 million adipic acid plant was under construction at the site. DuPont referenced the growing demand in Asia-Pacific for adipic acid, a key building block for nylon and polyurethanes.

Taiwan.—After a 6-year delay, Formosa Plastics, based in Taipei, received tentative approval from Taiwan's Environmental Protection Administration to begin construction of a $3.3 billion petrochemical complex. The complex will include the country's sixth ethylene plant and 24 downstream units, including styrene, MTBE, acrylonitrile, PVC, PE, polycarbonate, and ABS. Taiwan's Environmental Protection Administration mandated PS foam recycling beginning in late September 1993.

ICI formally commissioned a 350,000-ton-per-year PTA plant in Taiwan. This plant will bring the company's global PTA capacity to 872,000 tons per year. Taiwan is the second largest user of PTA, and if predicted growth rates materialize, Taiwan will be the largest user within a few years. ICI estimates demand will grow by an average of 8% per year during the 1990's, with 60% of that growth in Asia and the Far East. Prices were depressed in 1993, however.

Taiwan faces a significant oversupply of polyester filament. Demand has fallen to about 25,000 tons per month, while production is about 70,000 tons per month. Although exports fell in 1992, producers were reluctant to reduce production, resulting in a significant supply overhang in 1993.

Thailand.—Dow Chemical Co. and Siam Cement received a license to build a 75,000-ton-per-year PS plant at Map Ta Phut, at a cost of about $50 million. Completion was scheduled for mid-1995. Several other projects are underway at Map Ta Phut, including a 25,000-ton-per-year polyols plant; a 20,000-ton styrene-butadiene latex plant; and a 200,000-ton-per-year styrene plant.

Europe.—In PE, recent capacity additions in Europe have led to a significant oversupply situation for all three major product lines. In 1991, about 570,000 tons per year of HDPE capacity came on-stream and another 320,000 annual tons in 1992. New PE capacity represents a 7% to 8% increase, while the market has grown by a nominal 3%, at maximum.

In May 1992, Compagnie Industrielle des Polyethylenes de Normandie began production at its 220,000-ton-per-year LLDPE plant in France. The startup came at a time when PE markets were depressed because of overcapacity and economic recession. In October, because of the slump in Europe's PE market, the company temporarily closed its new LLDPE plant to correct "inventory imbalances." In addition, Dow Europe planned to close 55,000 tons per year of LLDPE capacity in Spain for at least 1 year and then reevaluate the market.

Shell Chemical Co. commissioned a new ethylene pipeline to feed downstream units in England. The company planned to have a 100,000-ton-per-year LDPE plant on-stream by yearend and to close 40,000 annual tons of existing capacity, leaving the company with a total of 170,000 tons per year of LDPE capacity.

PP was the healthiest of all polyolefins markets in Europe, growing by about 3% in 1993 and outperforming gross domestic product. Overcapacity, however, thwarted producers' attempts to raise prices. Even so, about one-third of producers were thought to have made a positive margin in the third-quarter of 1993, much better than the lackluster performance of the European PE industry. In fact, 1994 could prove to be a watershed for the European PP industry. Even if none of Europe's less efficient plants close next year, the forecast rate of growth should take plant operating rates from the current 85% to beyond 90%, leading to better operating efficiency and a decided reduction in capacity overhang.

Neste Corp. has been authorized to construct a $150 million PP plant in Porvoo, Finland, to be completed by 1994. The plant also will produce LLDPE and HDPE. The company may close one of the existing LDPE lines at the plant when the new capacity comes on-stream, because it is already balanced in ethylene.

Hoechst AG announced that it would close its old 135,000-ton-per-year PP plant at Kelsterbach, Germany, by early 1993. The company recently opened a 140,000-ton-per-year PP plant at Knapsack. BASF is investing $32 million in an expanded PP plant in Germany to be completed by 1994. Expanded PP will be used primarily for packaging and impact absorbing applications in the automotive industry.

In the first half of 1993, the 4.9 million annual ton European PVC market saw consumption decline 15%, mainly because of Germany's recession. European price increases were needed badly, because every PVC producer in Europe experienced losses in the third quarter principally because of high PVC production costs—according to Chem Systems in London. Solvay officials in Brussels, the world's third largest PVC producer, indicated that for the long term, the firm had no choice but to restructure to be competitive with the United States. With inventories well below normal by midyear, however, European producers could not look to North America to alleviate the shortage because of tight supplies in the United States. With U.S business tight and surplus capacity already absorbed by foreign markets, the European market has stabilized and plants were running at near capacity by yearend. Western Europe accounted for about 26% of global PVC demand in 1993.

Producer competition for European engineering polymers (EP's) share has resulted in price declines more dramatic than elsewhere. Lower car production in Western Europe, for example, led to a downturn in ABS resin demand, although polycarbonate demand was up 2% to 3%, largely because of healthy compact disk sales.

ABS prices have dropped, too, because of a large influx of imported material from the Far East and market share inroads by PP.

Eastman Chemical Co. plans to double PET capacity at its United Kingdom facility to 100,000 tons per year by early 1993. After the expansion, Eastman will share the title as the largest European producer with EniChem Elastomeri of Milan, Italy. European PET consumption is projected to increase from 465,000 tons in 1992 to 630,000 tons by 1995, and to 950,000 tons by the year 2001. Production is expected to increase as well, from 335,000 tons in 1992, to 560,000 tons in 1995, and 890,000 tons by the year 2001.

Melamine demand in Europe, which has dropped significantly in the past 3 years, has resulted in severe overcapacity in that sector. One new 50,000-ton-per-year plant in the Netherlands completed in 1991 has never come on-stream. In the past, eastern Europe was an important destination for melamine exports from western countries, but this region has severely curtailed buying because of a shortage in foreign exchange. Product also was being imported from the United States and Saudi Arabia. European melamine producers were projecting flat demand, with average annual growth rates of about 1% through 1995.

In 1993, EniChem Elastomeri started up its new $30 million neodymium polybutadiene plant for the production of a special elastomer, of which EniChem is the world's largest manufacturer, at Raveni, Italy. Product from the 30,000 annual ton plant is brand-named Europrene Neocis, and is used mainly in tires. EniChem already produces the product at Grangemouth, United Kingdom.

Following reappraisal, Statoil and Conoco will proceed with construction of an 830,000-ton-per-year methanol plant at Tjeldbergodden, Norway. Conoco will market its 18% (150,000-ton) share in the $423 million plant, scheduled to start up in late 1996, while Statoil's 680,000 tons will be targeted at European markets.

Latin America.—Petrochemicals integration and privatization in the Mercosur free trade zone linking Argentina, Brazil, Paraguay, and Uruguay were major topics addressed at the recent Asociacion Petroquimica Latinoamericana (APLA) meeting in Rio de Janeiro in late 1993. Delegates continued to express skepticism as to the feasibility of agreeing on zero tariffs in the next few months, however, because of the unbalanced economies between Brazil and Argentina. Increases in PP in South America from 1990 to the end of 1992 should allow the area to become a net exporter. Additional capacity in Brazil and Argentina, coupled with existing capacity in these countries, along with Colombia, Mexico, and Venezuela, should bring total capacity to 900,000 tons per year. Latin American PP consumption was estimated to be about 600,000 tons annually.

Argentina.—Argentina was struggling with the issues of privatization and consolidation, together with its significant cost disadvantages relative to Brazilian resins, and concomitant import reliance, especially on Brazilian HDPE. Argentina's HDPE domestic demand of 130,000 tons per year significantly outstripped the country's capacity of 85,000 tons per year.

Brazil.—Plans to privatize the Brazilian petrochemicals and resin businesses and restructure the chemical industry met with resistance in 1993 as Brazil's oil monopoly, Petrobras, was still unwilling to compromise on naphtha supplies. Petrobas officials continued to favor the importation of less expensive oil derivatives compared with the price of domestic product. Consequently, about 30% of the 6.6 million tons per year of naphtha needed for petrochemical crackers was imported in 1993.

Meanwhile, synthetic rubbermaker Petroflex was privatized successfully and given the go-ahead by the Brazilian Government to create a major styrene-butadiene rubber enterprise in South America. Petroflex was given the authority to handle details for a merger with the other Brazilian rubber producer, Coperbo.

Government-controlled styrene producer Estireno do Nordeste (EDN) halted production at its 45,000-ton-per-year PS plant at Camacari for 2 years. The company was planning to concentrate on production at its 90,000-ton-per-year plant in Sao Paulo. EDN officials reported that normal operation would continue at the company's 172,000 annual ton ethylbenzene plant and 150,000-ton styrene monomer unit at Camacari. The Sao Paulo PS unit will run at 95%, with one-half dedicated to the domestic market.

PE capacity was more than 1 million tons per year, with domestic demand estimated at less than 500,000 tons per year. Two new PE plants were added during 1992, with a total capacity of 240,000 tons per year. PP capacity was about 650,000 tons per year, and demand was estimated at 300,000 tons per year. This, together with Braspol Polimeros' recently commissioned 150,000-ton-per-year PP plant in Brazil, brings total Brazilian PP capacity to 700,000 tons per year, leaving a large surplus for export. The Brazilian PVC market performed slightly better during 1993, following a demand surge in the first half of the year. Brazilian officials estimated the market at 375,000 tons annually; imports accounted for 60,000 tons.

Mexico.—Hoechst Celanese planned to increase its PET capacity by 57,000 tons per year in Mexico in response to the country's increasing growth in the PET market. This is a part of Hoechst's plan to increase total North American capacity by nearly 227,000 tons per year by 1995.

In May 1993, Eastman Chemical of the United States confirmed plans to build a 60,000-ton-per-year PET resin plant in a joint venture with the Mexican firm Temex. The plant will be located at Temex's site in Cosoleacaque, Veracruz. Eastman will own the plant and be responsible for its operation, while Temex will supply purified terephthalic acid (PTA) feedstock. The unit will meet soaring demand for PET bottle resin in Mexico, the world's second largest soft drink market. PET refillable soft drink bottles were introduced to Mexico in 1991 and the market has enjoyed substantial growth, approximating 15% to 20% per year.

Trinidad and Tobago.—German contractor Ferrostaal and U.S. trader Helm signed a memorandum of understanding in June 1993 to build a $235 million methanol plant at Point Lisas having a capacity of 550,000 tons per year, based on ICI process technology. The two firms were expected to take a 31% stake in Trinidad and Tobago Methanol Co. (TTMC), which operates a 460,000-ton-per-year methanol plant at the site. The plant was scheduled to come on-stream in 1996. In addition, Caribbean Methanol Co. (CMC) was scheduled to bring a 500,000-ton-per-year methanol plant on-stream in late 1993 at Point Lisas. If financing is obtained for the new TTMC project, Trinidad will have 1.6 million tons per year of methanol capacity by 1996. The Canadian firm Methanex will market output from the CMC plant, while Helm was to market output from the TTMC plants.

Venezuela.—In 1992, ABB Lummus Crest was awarded a contract to build a 150,000-ton-per-year LLDPE plant in Venezuela. The plant was scheduled for completion in the first quarter of 1994.

***Mideast Region.*—Iran.**—Iran reportedly gave permission for 10 new private-sector chemical projects. These included a project to produce 30,000 tons per year of aniline; a project for 25,000 tons per year of isocyanates, 24,000 tons per year of acetic acid, and 10,000 tons per year of monochloroacetic acid; a project for 10,000 tons per year of melamine; a 70,000-ton-per-year PVC plant; a 15,000-ton-per-year ABS and styrene-acrylonitrile resins complex; a plant for 40,000 tons per year of dioctyl phthalate and 10,000 tons per year of petroleum resins; and two 10,000-ton-per-year plants for petroleum resins.

A new 1 million-ton-per-year MTBE plant was planned to be constructed in Iran by the third quarter of 1994. State-owned National Petrochemical Co. and an Iranian entrepreneur signed a letter of intent for the $300 million venture to be constructed in Bandar Imam. About 15% to 20% of the output from the plant was expected to be sold in the domestic market, with the rest to be exported.

Israel.—Israel's Carmel Olefins may begin shipments of PP to Egypt in 1994, according to senior Israeli energy ministry officials. Diplomatic negotiations between the two countries resulted in an agreement in principle whereby Egypt would provide Israel with caustic soda in exchange for PP. Carmel Olefins began PP production in the summer of 1993 at Haifa. Carmel was producing 100,000 tons per year, of which 60,000 tons was for local use.

Kuwait.—In 1992, Petrochemical Industries Co. reportedly revived plans to construct a petrochemical complex at Shuaiba that had been shelved since the war with Iraq. Along with an overseas investor, the company planned to build a 600,000-ton-per-year ethylene plant and include facilities to produce PE, PP, ethylene oxide, and glycol.

Saudi Arabia.—Dow Europe formed a joint venture in 1992 with a Saudi Arabian firm to manufacture and market styrene-butadiene latex in Saudi Arabia. The first 30,000-ton-per-year unit was due on-stream at the end of 1994, and a doubling of capacity was planned.

In 1993, a $225 million loan was extended by Mideastern banks for the construction of an oxo-alcohols plant planned by Al Jubail Fertilizer (Samad). Samad is a joint-venture between Taiwan Fertilizer and Saudi Arabian Basic Industries Corp. The Saudi plant was to produce 150,000 tons per year of 2-ethyl hexanol based on the Davy process, with the John Brown Co. serving as contractor. The loan also was to cover part of a project to produce annually 50,000 tons of dioctyl phthalate plasticizer. Both projects will require a total investment approaching $400 million.

Saudi Venture Capital Group (SVCG) confirmed that it was planning a 100,000-ton-per-year caprolactam plant at Al Jubail as a downstream unit from its recently announced aromatics joint venture with Chevron Chemical. SVCG's first project will consist of a 50-50 joint venture with Chevron to produce 420,000 tons of benzene and 270,000 tons of cyclohexane annually, using Chevron's Aromax technology. SVCG also planned to produce 50,000 tons per year of maleic anhydride, and eventually paraxylene and PTA.

United Arab Emirates.—The Abu Dhabi National Oil Co. announced plans to begin petrochemical manufacture. The first stage of the project was to include an ethylene and PE complex with an annual capacity of 300,000 to 500,000 tons. No timetable was given for construction.

North America.—Total sales of domestic Canadian resin in 1993 were about 2.3 million tons, level with 1992 values; net exports were 0.8 million tons. LDPE and HDPE accounted for 73% of sales, in order of importance. Other significant resin sales were PVC, PP, PS, and ABS, in order of importance.

Nova Corp. of Alberta acquired a 24% stake in Methanex of Vancouver, British Columbia, in exchange for its methanol assets plus $185 million. Novacor's methanol plant at Medicine Hat, Alberta, will add 370 million gallons per year to Methanex's 1.4 billion gallon per year capacity in 1994. Nova's methanol plant will provide Methanex with improved marketing and logistics flexibility. Methanex's Vancouver plant was well placed for serving the Far East and the Western United States, while Nova's Alberta site offered rail access to the Midwest and Eastern United States. Methanex is the largest global producer and distributor of methanol.

***Former U.S.S.R.*—Belarus.**—Eastman Chemicals and Pepsico International formed a joint venture with two Belarus companies to produce PET and PET bottles at Mogliev. PET resins were expected to be produced beginning in late-1992. One-half of the output will be used to produce bottles for use in the former U.S.S.R., and the remaining PET resin was destined for the western European market.

Kazakhstan.—The French company Litwin reportedly signed a contract with Shevchenkovski Zavod Plastmass to build a 370,000-ton-per-year styrene plant in Kazakhstan. The existing plant also will be modernized.

Russia.—Major Russian chemical

producers have formed a new company, A/O Neftek-Techno. This brought together some of the country's largest chemical producers, and the goal was to coordinate plans to improve earnings and profitability. For example, rather than selling excess propylene in western markets, the material was to be converted to value-added PP. Tecnimont signed a contract to supply a 100,000-ton-per-year PP complex for the Kapotnia Refinery in Moscow.

In 1993, a new company, Chem Bridge Corp. of Chicago, IL, was formed to help western companies gain access to Russian chemical science and industry. In custom products, the company will engage in complex organic, bioorganic, organometallic, and inorganic chemistry.

Ukraine.—The Chlorvinyl enterprise at Kalush, Ukraine, announced that it signed a $200 million contract with Linde (Germany) and Union Carbide Corp. of the United States, for the construction of a 100,000-ton-per-year LLDPE and an 80,000-ton-per-year PP plant. The plants could be completed as early as 1995. Uhde will expand capacity of vinyl chloride monomer and PVC in Ukraine. The monomer plant will be expanded from 250,000 tons per year, to 370,000 tons.

Current Research and Technology

In 1993, resin research was intensified in olefin polymerization technologies that would produce superior properties. Dow Chemical, for example, bypassed conventional Ziegler/Natta catalyst processes with its new Insite single-site metallocene catalyst technology to produce a new line of ethylene-based copolymers with densities as low as 0.864 grams per cubic centimeter (g/cm^3) and flexibility comparable with some rubbers. Dow's new polyolefin elastomers (POE's) incorporate 20% to 40% octene comonomer, higher than previously obtained with LLDPE, while modulus levels approximate those of ethylene-propylene-diene rubber (EDPM). Dow was targeting the new product for impact modification of PP to replace EDPM; for cross-linked, low-voltage power cable, under-the-hood automotive molding and profile, to compete with LDPE's; and textile calendared coating applications designed to compete with PVC.

In late 1993, Dow introduced its first line of metallocene catalyzed resins, containing up to 20% comonomer, and aimed primarily at film and sealant roles in packaging. The new resins were dubbed polyolefin plastomers (POP's). POP's demonstrate plastic and elastic properties, excellent for packaging, automotive, and consumer and industrial goods. Compared to polyolefins used now in these markets, POP's have lower and sharper melting points, excellent clarity, hot tack and seal properties, good recovery, and organoleptics.

Dow's Insite metallocene catalyst technology is based on group IV transition metals, like titanium, covalently bonded to a monocyclopentadienyl group bridged with a heteroatom such as nitrogen. The components are connected in such a way that a constrained cyclic structure is formed with the titanium center. Insite constrained geometry (CG) homogeneous catalysts produce highly processible polyolefins with a unique combination of narrow molecular weight distribution and long-chain branches, with useful properties across a broad range of densities and melt indexes.

Exxon Chemical Co. commercialized a new generation of metallocene-based specialty olefin elastomers for tire, automotive, pharmaceutical, and adhesive applications. Production commenced at a new plant in Baytown, TX. Additionally, seven grades of new resins based on proprietary technology were introduced. A total of 23 grades, one-half of them for the film packaging industry, have been introduced since commercial sales of these resins began in 1992.

Phillips Petroleum Co. commenced production of an ethylene-hexene-1 copolymer called low-density linear PE (LDLPE), using a new chromium-base Ziegler-Natta catalyst. The new material was said to be tougher and was designed to compete with traditional LLDPE materials in film, blow-molding, and injection-molding markets. The material has the advantages of swing production with HDPE, Phillips' major product, and direct interchange with HDPE film processing equipment. Premarketing production was being effected at Phillips' newest HDPE plant at Pasadena, TX.

Shell Chemical Co. introduced a new family of PP random copolymers that use butene as the comonomer. The firm reported that this is the first time that butene, a C_4 hydrocarbon, has been so used. Typically, suppliers offer PP copolymerized with ethylene or terpolymers employing a combination of propylene, ethylene, and butene. Shell's new products were reported to offer above-conventional levels of stiffness, clarity, and low heat-seal-initiation temperature as compared to traditional random PP copolymers. The higher heat-seal initiation properties of traditional products have been the key detriment to high line speeds. Union Carbide's gas-phase polymerization technology and Shell's 200 series super-high-activity catalyst were credited as being responsible for vast improvements in materials performance. Unipol technology allows high—up to 14%—levels of comonomer, versus conventional levels of 7% or less. The materials were also excellent for use in shrink films.

GE Plastics Co. commercialized a polybutylene terephthalate (PBT) resin grade that is designed to enhance optical fiber use in stringent aboveground environments. One resin is for use in buffer tubes, the brightly colored extrusions that jacket groups of eight optical fibers, which in turn are bundled to form a fiber optical cable. The key benefit of the new resin involves improved hydrolytic stability or the ability to retain integrity in humid, elevated temperatures. The material was reported to extend time to embrittlement by 500% over most existing PBT's at above 70° C. Projected growth of 20% per year over the next 10 years for communications technology requiring that optical fiber be employed in exterior and near-the-home uses is expected to drive demand for the new product. Additionally, a new Bell Communications Research standard (Bellcore TA20) has established generic requirements for increased hydrolytic stability. Flame-retardant and glass-filled versions designed for use in electrical connectors and plumbing were under development.

Georgia Gulf's PVC Div. entered the chlorinated PVC (CPVC) compound supply market through the launch of pipe and profile grades. The firm's new resin is a powder compound in tan and gray versions for extruded tubing and small-diameter pipe, respectively. The material combines excellent impact strength and processability, including the ability to readily utilize reworked material. The product is listed under the National Sanitation Foundation's Standard 14 code for hot and cold potable water pipe. A series of pelletized compounds offer a range of elevated heat-deflection temperatures for extruded profiles. Targeted markets include window glazing, components subjected to the "greenhouse effect"—dark-color window frames—and, construction profiles requiring high heat and chemical resistance properties, like skylights. Another CPVC grade is a pelletized injection molding grade targeted at pipe fittings and components in fire sprinkler and chemical transfer systems.

PPG Industries, Inc. is the world's leading supplier of automotive and industrial finishes and a major supplier of architectural finishes. PPG's most significant event reported during the year in terms of growth, however, was Transitions Optical, Inc., a joint venture with Essilor International of France. Transitions' new variable-tint plastic prescription lenses were well received worldwide, and sales increased dramatically throughout 1993. Transitions Optical has become the world's leading supplier of variable-tint plastic lenses for prescription eyewear, according to the firm's literature.

PPG's coatings products introduced in 1993, or that achieved broader consumer acceptance, were the environmentally compatible waterborne base coats for autos and the economical, high-quality automotive refinishes. PPG opened three new training centers for automotive refinishers during 1993. Also, a novel method involving externally coating glass bottles in lieu of blending colorants in situ was introduced at PPG's Monterrey, Mexico, plant. The external colorants and much of the coating equipment were supplied by Brandt Technologies of Windsor, NY. Coating the bottles rather than using tinted glass reduced costs and allowed for easier recycling.

In nonwovens, DuPont remained dominant worldwide in this rapidly expanding, high-technology, multi-billion dollar market. DuPont's nonwovens business was centered about spunlaced fabric, spunbonded olefins, and spunbonded PP—products designed to solve market needs in medical, apparel, construction, packaging, reinforcement, and absorbents. Spunbonded PP was the leading product growth nonwoven material in the United States and Europe for broadloom carpet backing. DuPont's new reinforced spunbonded olefins used for breathable roofliners that simplify construction techniques experienced strong growth in Europe. Spunlaced fabric maintained a strong position in the global health care industry as the preferred material for surgical gown and drapes. The material also continued to experience significant growth in diverse consumer applications, including window shades, specialty wipes, synthetic leather, and adult incontinence products.

The flame-resistant and high-strength aramid fibers businesses continued to expand, as DuPont opened new plants for each at Richmond, VA, and Asturial, Spain, respectively. A newly developed aramid fiber product provides the lightest and thinnest bullet-resistant vests currently available, while another grade provides protection against static electricity, as well as flame and thermal shock, for flight suits and in apparel for the oil, chemical, and munitions industries.

A major development in organic chemicals during the year involved the startup of DuPont's largest world-scale hydrofluorocarbon-134a plant at Corpus Christi, TX. The firm was reported to be an industry leader in CFC alternatives, with a full line of refrigerant products marketed under trademark. The new product had zero or significantly reduced ozone depletion potential. In a related development, OxyChem introduced a new product line, designed to replace certain ozone-depleting solvents widely used in the marketplace.

In other CFC-related industries, cyclopentane blowing agents were introduced as CFC substitutes for polyurethane in foam applications, particularly for refrigerator appliance insulation in Europe. In North America, pentane-blown PS foam also competed with urethanes, and high-impact PS competed with ABS for appliance liner markets.

Catalytica, of Mountain View, CA, was awarded a U.S. patent covering a direct catalytic methane-to-methanol synthesis conversion. Working with partners PetroCanada and a subsidiary of Mitsubishi Oil, Catalytica developed a low-temperature synthesis to foil one of the classic problems in direct methane oxidation—stopping the reaction at the methanol stage. Also, Pennsylvania State University (Penn State) chemists announced a novel acetic acid synthesis route based on the direct oxidation of methane, using a rhodium chloride catalyst. The reaction represents the first low-temperature catalytic oxidation of methane using oxygen, according to the Penn State chemists. Although the subject direct methane conversion efforts are currently in the early research stage, they suggest fundamentally new pathways to overcome methane's (natural gas) "notoriously fickle chemistry," according to the researchers.

Current technology involves high-temperature, energy-intensive, methane-steam-reforming-processes in which methane is oxidized to carbon dioxide, carbon monoxide, and hydrogen to form syngas for the production of ammonia, methanol, formaldehyde, and acetic acid. The new direct processes, thus, could pave the way to more economical, direct methods. If methanol could be produced more cheaply by direct routes, for example, the vast natural gas reserves of North America could potentially take their place alongside petroleum as a feedstock, and the use of C_1-C_2 feedstocks is inherently cleaner.

OUTLOOK

Steady upward growth has been generally experienced in U.S. synthetic organic chemicals and downstream products since World War II, interrupted only infrequently by disruptions in the economy or by supply-demand factors. Since 1967, the production of polymeric resins has increased at a compound annual rate of about 6% and sales and captive use by about 7.1%, although average annual growth has slowed to 4% and 5%, respectively, since the recessionary period of 1990 and 1991. Dynamic growth in the synthetic organics industry can be traced largely to increasing domestic demand for crude petroleum and the availability of petrochemical feedstocks for the production of a proliferation of synthetic organic consumer materials that have preferentially substituted for traditional materials. Other factors have involved growing consumer demand generated by technological innovations, together with international demand for U.S. basic and finished synthetic organic materials. *(See figure 11.)*

In 1993, the United States continued as the leading producer of polymeric resin materials, accounting for about 40% of global production, followed by Europe and Japan. The total U.S. synthetic organics industry was valued at more than $100 billion, including value-added products.[18] As the year progressed, there was a slow but steady recovery in the U.S. economy, as reflected by an upward movement of about 3% in the gross domestic product (GDP) and comparable growth in synthetic organic resins, fiber, and rubber products.

Although margins were less than desirable in 1993, the economic outlook for 1994 is encouraging, and nonfuel organics volume should rise at least 5% to 6%, along with a substantial rebound in prices. MTBE fuel oxygenates and associated methanol and renewable ethanol demand should continue to experience substantial growth in 1994, owing to the provisions of the Clean Air Act. Ethylene should begin to come back into balance, along with propylene and other large-volume petrochemical feedstocks and downstream commodity resins. PVC should remain in relative balance, and gradually absorb new ethylene cracker capacity coming on-stream, while demand for PET bottle resin and thermoplastic elastomers should remain firm.

The long-term outlook for the U.S. organics industry is positive, given its large-volume, competitive nature. This, in concert with projected near-term recovery in the EC and Japan, the growing multinational flavor of the industry, continuing growth potential in the developing world—especially Asia-Pacific—and favorable prospects for NAFTA further support this premise. Eastern Europe was reflecting early signs of recovery and, eventually, the former U.S.S.R. should complete the major economic restructuring necessary for recovery. Finally, the current prospects for long-term stability in both the supply and price structure of crude petroleum and natural gas are encouraging, barring any unforeseen events.

On the down side, a continuing buildup of petrochemical capacity in Asia-Pacific, the Middle East, Latin America, and in the former U.S.S.R., will probably result in declining market share in the long-term, and possibly cut into our Nation's current multi-billion dollar trade surplus for resin, rubber, fiber, and specialty organic products. In the United States, there are a variety of problems to contend with, including the elimination of CFC's and other chlorinated materials, in addition to suspected carcinogenic and VOC-emitting organic solvents widely used for specialty cleaning and in paints and coatings. Viable substitute materials and technologies will have to be developed at reasonable costs, including a large number of agricultural pesticides on EPA's toxic inventory list.

The evolving "Green Movement" in the United States and around the globe could potentially result in a significant reinvention and development of environmentally friendly renewable organic products targeted to replace or otherwise supplement nonrenewable organic materials in selected applications. Finally, prudent waste management and recycling will continue to challenge the U.S. organics industry, and support the Nation's drive toward sustainable development.

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TABLE 1
SALIENT U.S. ORGANIC MATERIALS STATISTICS

(Million metric tons, unless otherwise specified)

	1989	1990	1991	1992	1993[p]
Petrochemical industries:					
Production, domestic feedstocks[1]	[r]56.72	[r]55.71	[r]64.03	[r]66.61	66.00
Imports for consumption[2]	[r]9.31	10.11	[r]9.68	[r]8.92	10.20
Exports[2]	[r]2.22	2.17	[r]1.45	[r]1.55	.73
Consumption, apparent primary:	[r]64.16	[r]63.07	[r]71.24	[r]74.18	74.54
Resins[3]	31.76	33.23	33.55	35.70	36.87
Other[4]	32.40	29.84	37.69	38.48	37.67
Price, dollars per metric ton[5]	[r]$113.84	[r]$134.48	[r]$116.67	[r]$113.20	$103.40
Stocks, yearend	[r]4.16	4.74	[r]5.76	[r]5.56	6.49
Lubricants, miscellaneous products, waxes:					
Production	[r]14.24	[r]13.79	[r]13.42	[r]12.43	12.67
Imports for consumption[2]	[r].82	[r].82	[r].64	[r].82	.61
Exports[2]	[r]1.28	[r]1.31	[r]1.15	[r]1.09	1.21
Consumption, apparent primary	[r]13.76	[r]13.55	[r]12.92	[r]12.06	12.23
Price, dollars per metric ton[5]	[r]$119.22	[r]$152.90	[r]$130.24	[r]$123.45	$108.40
Stocks, yearend	[r]2.71	[r]2.46	[r]2.45	[r]2.55	2.39
Petroleum coke, coal byproducts:					
Production	[r]7.64	[r]9.87	[r]8.77	[r]12.71	12.89
Imports for consumption	[r].01	[r].03	[r].03	.04	.04
Exports[2]	[r]2.80	[r]3.46	[r]3.17	[r]4.34	5.05
Consumption, apparent primary	[r]4.83	[r]6.45	[r]5.54	[r]8.41	7.95
Price, dollars per metric ton[5]	[r]$83.39	[r]$104.80	[r]$85.94	[r]$87.54	$76.50
Stocks, yearend	[r].45	[r].44	.53	[r].53	.46
Asphalt and road oil:					
Production	25.52	25.02	25.85	[r]25.28	27.18
Imports for consumption	1.85	1.91	1.67	1.64	1.94
Exports	.19	.17	.19	.27	.31
Consumption, apparent primary	27.23	27.06	26.73	[r]27.41	28.57
Price, dollars per metric ton[5]	$110.40	$139.10	$115.23	[r]$110.69	$99.08
Stocks, yearend	3.39	3.09	3.69	2.92	3.17
Total organics:					
Production:					
Quantity	104.12	104.39	112.07	117.03	118.74
Value, dollars per metric ton[5]	$111.50	$124.01	$115.56	$110.96	$100.20
Value, millions	$11,609	$12,945	$12,951	$12,986	$11,877
Imports for consumption	11.99	12.87	12.02	11.42	12.79
Exports	6.49	7.11	5.96	7.25	7.30
Consumption:					
Quantity	109.98	110.13	116.43	122.07	123.28
Value, dollars per metric ton[5]	$112.32	$124.12	$116.38	$111.88	$101.16
Value, millions	$12,353	$13,669	$13,550	$13,657	$12,471

[p] Preliminary. [r] Revised.

[1] Feedstocks are composed of natural gas liquids and liquefied refinery gases, dry natural gas, naphthas, other petroleum oils, and still gas.

[2] Excludes dry natural gas and coal.

[3] Synthetic plastics, resins, fiber, and rubber.

[4] Pesticides, medicinals, plasticizers, solvents, dyes, pigments, other organic materials, process losses, and statistical discrepancies.

[5] Feedstock prices based on crude oil first purchase prices and natural gas at wellhead.

Source: Annual Energy Review (tables 2.6 and 3.1) and Petroleum Supply Annual (table 2), U.S. Department of Energy, 1993.

TABLE 2
PROCESSING OF SELECTED U.S. THERMOPLASTICS, BY PRINCIPAL METHODS[1]

(Thousand metric tons)

Year	Extrusion		Injection molding		Blow molding		Total sales
	Weight	Percent	Weight	Percent	Weight	Percent	Weight
1985[r]	7,066	53.7	2,421	18.4	1,184	9.0	13,157
1990[r]	9,725	55.1	3,178	18.0	1,549	8.8	17,656
1991[r]	9,407	54.1	3,107	17.9	1,566	9.0	17,374
1992[r]	10,390	55.0	3,510	18.6	1,679	8.9	18,900
1993[e]	11,000	55.1	3,800	19.0	1,800	9.0	19,961

[e]Estimated. [r]Revised.

[1] Polyethylenes, polypropylene, polystyrene, nylon, and PVC.

Source: Society of the Plastics Industry Inc.

TABLE 3
U.S. PLASTICS, FIBERS, AND RUBBER WORK FORCE CHARACTERISTICS

	1991	1992	1993[p]
Industrial employment (thousands):	178	173	166
Women employed	41.3	[r]40.1	39.8
Men employed	136.2	[r]133.9	126.2
Production workers (thousands)	110	[r]103.6	104.1
Average workweek (hours)	42.6	43.8	44.1
Average hourly earnings (dollars):			
Plastics, fibers, and rubber	14.79	15.37	15.26
All manufacturing	11.18	11.46	11.76

[p]Preliminary. [r]Revised.

Source: Chemical & Engineering News and U.S. Bureau of Labor Statistics.

TABLE 4
RELEASES AND TRANSFERS FOR THE TOP 50 U.S. CHEMICALS IN 1992

(Percent of all TRI chemicals)

	Total releases[1]	Total transfers[2]	Percent of total transfers recycled
First-level derivatives:			
Benzene	0.4	0.1	6.5
Ethylene	1.2	.3	—
Propylene	.7	.1	—
Toluene	6.1	3.0	22.9
Xylene	3.5	2.6	34.9
Other organics	32.2	18.6	33.3
Inorganics	52.2	64.4	78.9
Total[3]	96.1	89.1	65.7
Total for all TRI chemicals metric tons	1,443,186	1,977,247	1,287,519

[1] Releases include fugitive or nonpoint air emissions, stack or point air emissions, surface water discharges, underground injection, and releases to land.

[2] Transfers include transfers to publically owned treatment works, transfers to treatment, transfers to disposal, transfers to energy recovery, transfers to recycling, and other offsite transfers.

[3] Total represents the percentage for all TRI chemicals.

Source: 1992 Toxics Release Inventory, Environmental Protection Agency.

TABLE 5
U.S. PRODUCTION OF SELECTED THERMOPLASTICS AND THERMOSETS

(Thousand metric tons)

	1992	1993[p]
Thermoplastic resins:		
LDPE	[r]5,406	5,474
HDPE	[r]4,449	4,509
Polypropylene	3,819	3,914
Polystyrene	[r]2,312	2,441
Styrene-acrylonitrile	[r]51	48
Acrylonitrile-butadiene-styrene[1]	[r]1,184	1,327
Polyamide, nylon type	303	348
PVC	[r]4,531	4,653
Other vinyl resins	90	NA
Thermoplastic polyester	1,095	1,156
Total	[r]23,240	23,870
Thermoset resins:		
Epoxy	207	231
Melamine	105	122
Phenolic	1,326	1,396
Polyester	533	573
Urea	[r]702	791
Total	[r]2,873	3,113

[p] Preliminary. [r] Revised. NA Not available.

[1] Includes other styrenics.

Source: The Society of the Plastics Industry Inc., annual and monthly statistics.

TABLE 6
U.S. SYNTHETIC FIBERS PRODUCTION

(Thousand metric tons)

	1989	1990	1991	1992	1993
Noncellulosic fibers:					
Acrylic	247	230	206	199	196
Nylon	1,244	1,208	1,152	[r]1,159	1,208
Olefin	744	827	847	[r]908	970
Polyester	1,632	1,451	1,548	1,622	1,613
Cellulosic fibers	263	229	220	225	229
Total	4,130	3,945	3,973	[r]4,113	4,216

[r] Revised.

Source: Chemical & Engineering News.

TABLE 7

U.S. PRODUCTION AND SALES OF SYNTHETIC ORGANIC MATERIALS IN 1992[1]

(Thousand metric tons)

Material	Production	Sales[2]	
		Quantity	Value[3] (millions)
Plastics and resin	31,419	27,828	$28,210
Plasticizers	915	861	1,032
Pesticide products	492	406	4,174
Synthetic rubber	2,614	1,870	3,454
Rubber-processing chemicals	157	132	498
Surface-active agents	3,174	2,023	2,480
Medicinal chemicals	149	92	2,384
Dyes	148	137	912
Organic pigments	57	46	779
Flavor and perfume materials	101	92	882
Miscellaneous chemicals[e]	[4]19,927	[5]16,921	[6]12,518
Total[e]	59,153	50,408	57,323

[e] Estimated.

[1] Ranked in relative order of monetary significance by class.

[2] Excludes intracompany corporate transfers, shipments to wholly owned subsidiaries, resales, and toll agreements.

[3] Principally sales value f.o.b. plant or warehouse.

[4] Difference between reported primary products of petroleum, natural gas, and coal tar and crudes and finished materials.

[5] Estimated at 85% of production-basis-identified distribution.

[6] Based on average reported price of miscellaneous compounds.

Source: Synthetic Organic Chemicals, U.S. Production and Sales, 1992, U.S. International Trade Commission.

TABLE 8

U.S. PRODUCTION CAPACITY AND UTILIZATION RATES, SELECTED RESINS

(Thousand metric tons)

Resin	1989	1990	1991	1992	1993[p]
Polyethylene:					
High-density (HDPE):					
Capacity	4,119	4,333	4,902	5,406	5,406
Utilization rate (percent)	89.2	87.3	85.2	82.3	83.4
Low-density (LDPE):					
Capacity	3,524	3,562	3,556	3,563	3,563
Utilization rate (percent)	84.6	92.4	92.4	92.6	92.0
Linear low density (LLDPE):					
Capacity	1,891	2,289	2,350	2,498	2,500
Utilization rate (percent)	74.8	77.1	83.9	84.3	87.8
Polypropylene:					
Capacity	4,021	4,118	4,314	4,522	4,540
Utilization rate (percent)	81.6	91.5	87.6	84.5	86.2
Polystyrene:					
Capacity	2,74	2,544	2,671	2,551	2,551
Utilization rate (percent)	84.5	89.5	84.1	90.6	95.7
PVC:					
Capacity	4,213	4,257	4,390	4,664	4,950
Utilization rate (percent)	91.3	96.9	94.7	97.2	94.0

[p] Preliminary.

Source: Facts and Figures of the U.S. Plastics Industry, The Society of the Plastics Industry Inc., 1993 edition.

TABLE 9

U.S. PLASTIC RESIN SALES[1]

(Thousand metric tons)

	1989	1990	1991	1992	1993[p]
Acrylonitrile butadiene styrene (ABS)	561	527	510	[r]579	622
Acrylic	335	315	284	[r]286	291
Alkyd	147	145	143	145	148
Cellulosics	41	36	36	37	37
Epoxy	219	210	222	[r]235	246
Ethylene vinyl acetate (EVA)	475	497	506	NA	NA
High-density polyethylene (HDPE)	3,707	4,009	4,239	[r]4,586	4,775
Low-density polyethylene (LDPE)	2,975	2,770	2,827	[r]5,860	6,032
Linear low-density polyethylene (LLDPE)	1,763	2,160	2,175	NA	NA
Nylon	263	263	252	[r]313	329
Other styrenics	535	566	533	589	618
Other vinyls	408	[2]87	[2]81	80	82
Polyester thermoplastics (PBT/PCT/PET)[2]	951	1,060	1,153	[r]1,290	1,345
Phenolic	1,282	1,333	1,208	[r]1,294	1,393
Polyacetal	65	65	64	66	68
Polycarbonate	283	281	273	[r]252	280
Polyester, unsaturated	598	557	490	541	569
Polyphenylene alloys	89	90	88	93	95
Polyurethane (PUR)	1,462	1,492	1,427	1,510	1,577
Polypropylene (PP)	3,313	3,737	3,777	[r]3,841	4,065
Polystyrene (PS)	2,327	2,290	2,220	[r]2,365	2,485
Polyvinyl chloride (PVC)	3,849	4,080	4,180	[r]4,537	4,721
Styrene acrylonitrile (SAN)	49	61	52	[r]50	51
Thermoplastic elastomers	246	265	279	297	315
Urea/melamine	626	759	752	788	906
Others	141	150	156	162	167
Total[3]	26,712	27,805	27,651	[r]29,796	31,219

[p]Preliminary. [r]Revised. NA Not available; included in LDPE.

[1] Includes imports.

[2] Polybutylene terephthalate, polyethylene terephthalate, and polycyclohexane dimethylene terephthalate.

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

Source: Modern Plastics (annual resins review), Jan. 1990-94.

TABLE 10

U.S. CONSUMPTION OF SELECTED RESINS[1]

(Thousand metric tons)

Resin	1992[r]	1993[p]
LDPE	5,120	5,325
HDPE	4,009	4,241
PVC	4,022	4,260
PP	3,411	3,732
PS	2,221	2,331
ABS	571	610

[p] Preliminary. [r] Revised.

[1] Total U.S. resin sales, excluding exports.

Source: Modern Plastics (annual resins review), Jan. 1994.

TABLE 11

U.S. DISTRIBUTION OF RESIN CONSUMPTION IN SELECTED END USES IN 1992

(Thousand metric tons)

	Appliances	Building and construction	Electrical and electronic	Transportation	Furniture	Toys	Housewares	Packaging
ABS	106	63	50	149	3	16	—	3
Acrylic	5	96	—	32	—	—	—	—
Cellulosics	1	2	1	—	—	1	1	2
Epoxy	4	21	23	—	—	—	—	17
EVA	—	—	—	—	—	—	103	37
HDPE	—	—	67	—	—	91	209	2,240
LDPE	—	—	177	—	—	83	—	2,430
Nylon	—	—	41	67	—	—	—	—
PET	—	—	—	—	—	—	—	684
Phenolics	13	1,002	42	10	43	—	16	5
Polyacetal	6	—	2	16	—	—	—	—
Polycarbonate	24	55	17	27	—	—	—	10
Polyester	44	163	48	25	3	—	—	—
PUR	—	—	—	—	283	—	—	—
PP	85	13	15	13	53	31	134	770
PS	123	186	215	—	37	93	117	782
PVC	64	2,646	223	10	39	18	88	250
SAN	5	14	2	—	—	—	10	6
Urea/melamine	—	638	24	—	—	—	—	1
Others	128	891	35	774	26	48	38	265
Total	608	5,790	982	1,123	487	381	716	7,502

Source: Modern Plastics.

TABLE 12
U.S. SHIPMENTS OF STAPLE FIBERS, BY MARKET

(Thousand metric tons)

Fiber	1989	1990	1991	1992	1993p
Rayon:					
Shipments to nonwovens	44	33	32	32	32
All others	109	100	84	86	88
Total domestics[1]	153	132	116	118	120
Polyester:					
Shipments to nonwovens[2]	123	108	108	111	119
All others	902	805	858	888	860
Total domestics[1]	1,026	914	965	999	979
Olefin:					
Shipments to nonwovens	88	106	123	117	125
All others	76	70	75	83	86
Total domestics[1]	165	176	199	200	211
Total	1,344	1,222	1,280	1,317	1,310

pPreliminary.

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

[2] Polyethylene terephthalate.

Source: Nonwovens Industry, Rodman Publishing Corp., June 1994.

TABLE 13
U.S. SYNTHETIC RUBBER SHIPMENTS

(Thousand metric tons)

	1989	1990	1991	1992	1993
Ethylene-propylene	225	208	192	206	227
Nitrile	72	69	71	74	78
Polybutadiene	427	431	416	463	473
Polychloroprene	79	79	70	72	70
Styrene-butadiene rubber	827	791	727	796	817
Other[1]	295	329	298	315	328
Total	1,925	1,907	1,774	1,926	1,993

[1] Includes butyl-styrene-butadiene latex, nitrile latex, polyisoprene, and other synthetic elastomers.

Source: Chemical & Engineering News.

TABLE 14
U.S. SOURCING PATTERNS OF POSTCONSUMER FEEDSTOCK[1]

(Thousand metric tons)

Resin and product	1992	1993
Polyethylene terephthalate (PET):		
Soft drink bottles[2]	141	163
Custom bottles	9	14
Other[3]	27	27
Total PET	177	204
High-density polyethylene (HDPE):		
Natural color bottles[4]	84	111
Pigmented bottles	41	59
Base cups	20	16
Other[5]	14	18
Total HDPE	159	204
Low-density polyethylene	34	50
Polystyrene[6]	23	27
Polyvinyl chloride	9	14
Polypropylene	2	5
Other	11	14
Grand total	415	518

[1] Excludes typical 10% losses of collected volume that occurs during cleaning and reclaim steps.
[2] Base cups included in HDPE.
[3] Mostly X-ray film.
[4] Typically, natural bottles are homopolymer for milk and water use; pigmented are copolymer for chemical and detergent use.
[5] Primarily HDPE film.
[6] Mostly polystyrene foams.

Source: Modern Plastics, Jan. 1994.

TABLE 15

U.S. POSTCONSUMER RECYCLATE PATTERN OF CONSUMPTION[1]

(Thousand metric tons)

End-use market	1992	1993
Polyethylene terephthalate (PET):		
Bottle-grade:		
Fiberfill	86	95
Food bottles[2]	16	11
Nonfood bottles	9	14
Strapping	9	11
Export	14	11
Other[3]	43	61
Total PET	177	203
High-density polyethylene (HDPE):		
Bottles	27	45
Drainage pipe	27	29
Film	11	20
Plastic lumber	11	14
Pallets	9	14
Other[4]	73	82
Total HDPE	158	204
Low-density polyethylene (LDPE):		
Film	27	41
Other	7	9
Total LDPE	34	50
Polystyrene (PS):		
Foam packaging	9	10
Loosefill	7	7
Solid moldings	5	5
Other	2	5
Total PS	23	27
Polyvinyl chloride (PVC):		
Molded goods	5	7
Other	5	5
Total PVC	10	12
Other resins	14	18
Grand total	416	514

[1] Excludes typical 10% losses of collected volume that occurs during cleaning and reclaim steps.
[2] PET bottles converted by chemical processes back to monomer for reuse in virgin soft drink bottles.
[3] Includes bottles and nonpackaging film.
[4] Includes bottles, film, and base cups.

Source: Modern Plastics, Jan. 1994.

TABLE 16

U.S. PETROCHEMICAL FEEDSTOCKS (CONTRACT PRICES)

(Cents per pound)

	1992 average	1993				
		First quarter	Second quarter	Third quarter	Fourth quarter	Average
Acrylonitrile	26.3	26.0	26.0	26.0	27.0	26.3
Benzene	14.4	14.0	15.0	13.0	12.0	13.5
Butadiene	17.0	20.0	20.0	21.0	20.0	20.3
Ethylene	20.3	22.0	21.0	21.0	21.0	21.3
Propylene	14.4	14.0	14.5	14.0	14.0	14.1
Styrene	24.4	23.0	25.0	26.0	25.0	24.8
Vinyl chloride	16.0	17.0	18.0	20.0	20.0	18.8

Source: Modern Plastics, July 1993 and 1994 issues.

TABLE 17

BASIC THERMOPLASTIC POLYMER PRICES IN THE UNITED STATES[1]

(Cents per pound)

	1992 average	1993				
		First quarter	Second quarter	Third quarter	Fourth quarter	Average
LDPE, liner	33.3	33.0	32.0	31.0	34.0	32.5
LLDPE, hexene film[2]	32.0	32.0	32.0	30.0	33.0	31.8
HDPE, blow molding	30.0	27.0	26.0	29.0	32.0	28.5
HMW-HDPE, film	34.3	32.0	32.0	30.0	33.0	31.8
Polypropylene, molding	32.3	30.0	28.0	30.0	29.0	29.3
Polystyrene (PS), crystal molding	40.8	39.0	40.0	40.0	41.0	40.0
PS, impact extrusion	43.3	41.0	42.0	42.0	46.0	42.8
Expanded PS bead, construction	63.0	61.0	61.0	61.0	60.0	60.8
PVC, pipe grade	26.5	27.0	29.0	31.0	31.0	29.5
ABS, molding[3]	105.0	105.0	105.0	105.0	100.0	103.8
PET, bottle grade	62.0	62.0	62.0	62.0	63.0	62.3

[1] Market price, bulk basis.
[2] Primarily for grocery sacks.
[3] Natural high-gloss, high-impact ABS.

Source: Modern Plastics, July 1993 and 1994 issues.

TABLE 18

U.S. EXPORT AND IMPORT TRADE SUMMARY OF SELECTED RESINS

(Thousand metric tons)

	1992	1993[p]
LDPE:[1]		
Exports	[r]722	806
Imports	[r]430	546
Net exports	[r]292	260
HDPE:		
Exports	[r]659	602
Imports	[r]250	337
Net exports	[r]409	265
PP:		
Exports	[r]611	962
Imports	[r]122	99
Net exports	[r]139	863
PVC:		
Exports	[r]591	651
Imports	[r]92	145
Net exports	[r]499	506
PS:		
Exports	[r]171	195
Imports	[r]59	86
Net exports	[r]112	112
ABS:		
Exports	[r]205	140
Imports	[r]78	79
Net exports	[r]127	61
Other:		
Exports	576	173
Imports	89	189
Net exports	487	-16
Grand total:		
Exports	3,535	3,529
Imports	1,120	1,478
Net exports	2,415	2,051

[p]Preliminary. [r]Revised.

[1]Includes LLDPE and EVA.

NOTE.—Net exports = exports minus imports. All categories are independently rounded.

Sources: The Society of the Plastics Industry Inc. and U.S. Department of Commerce.

TABLE 19

WORLD SALES OF PLASTIC RESINS

(Thousand metric tons)

	1992	1993[p]
Belarus	629	474
Bulgaria	125	150
Canada:		
HDPE	[r]648	652
LDPE	[r]1,041	1,090
PP	201	NA
PS and ABS	206	158
PVC	[r]385	419
Total[1]	[r]2,481	2,319
China	[r]3,308	3,354
France:		
PE	[r]1,340	1,329
PP	[r]896	971
PS	507	481
PVC	1,095	1,173
Total[1]	[r]3,838	3,954
Germany:		
PE	1,452	1,621
PP	590	582
PVC	1,141	1,207
Total[1]	3,183	3,410
Hungary:		
PE	274	259
PP	148	136
PVC	176	183
Total[1]	[r]598	578
Italy:		
PE	925	948
PS	280	273
PVC	616	611
Total[1]	1,821	1,832
Japan:		
PE	2,980	2,762
Phenolic resins	356	328
PP	2,038	1,950
PS	2,005	1,966
PVC	1,981	1,980
Total[1]	9,360	8,986
Korea, Republic of:		
HDPE	1,019	1,189
LDPE	761	853
PP	[r]1,223	1,436
PS	754	809
PVC	[r]726	760
Total[1]	[r]4,483	5,047

See footnotes at end of table.

TABLE 19—Continued

WORLD SALES OF PLASTIC RESINS

(Thousand metric tons)

	1992	1993[p]
Mexico:		
HDPE	199	200
LDPE	[r]299	301
PP	110	111
PS	[r]100	102
PVC	[r]379	380
Total[1]	[r]1,087	1,094
Poland:		
PE	163	164
PP	96	109
PS	24	32
PVC	82	210
Total[1]	[r]365	515
Romania	267	254
Russia	2,644	2,205
Taiwan:		
ABS	569	642
PE	360	369
PS	522	587
PVC	1,043	1,078
Total[1]	2,494	2,676
Ukraine	555	294
United Kingdom:		
PE	314	NA
PP	327	414
PVC	293	244
Total[1]	934	658
United States	[r]29,796	31,219
Grand total[2]	[r]67,968	69,019

[p]Preliminary. [r]Revised. NA Not available.

[1]Country subtotals are for resins shown only.

[2]Total is for countries and resins listed only.

Sources: Modern Plastics and Chemical & Engineering News.

TABLE 20
SYNTHETIC FIBERS PRODUCTION, SELECTED COUNTRIES

(Thousand metric tons)

	1990	1991	1992	1993
Austria	173	157	169	168
Belarus	453	443	385	NA
Benelux countries[1]	311	326	321	314
Bulgaria	58	26	51	NA
China	[r]1,654	[r]1,910	[r]2,132	2,215
Czechoslovakia	200	137	142	—
Finland	69	58	67	68
France	156	118	122	118
Germany	1,019	980	982	993
Hungary	30	31	25	23
Ireland	93	95	109	109
Italy	694	708	725	656
Korea, Republic of[2]	730	780	778	NA
Poland	149	106	111	119
Portugal	64	64	74	67
Romania	209	144	112	45
Russia	673	529	472	NA
Spain	301	283	292	271
Switzerland	118	108	112	96
Taiwan	1,290	1,457	1,598	NA
Turkey	252	NA	NA	NA
Ukraine	179	136	NA	NA
United Kingdom	350	332	318	298
United States	3,945	3,973	4,109	4,217
Yugoslavia	148	101	—	—
Total[3]	[r]13,170	[r]13,002	[r]13,206	NA

[r] Revised. NA Not available.

[1] Belgium, the Netherlands, and Luxembourg.

[2] Polyester fibers only.

[3] Total is for countries listed only.

Source: Chemical & Engineering News.

TABLE 21
SYNTHETIC RUBBER PRODUCTION, SELECTED COUNTRIES

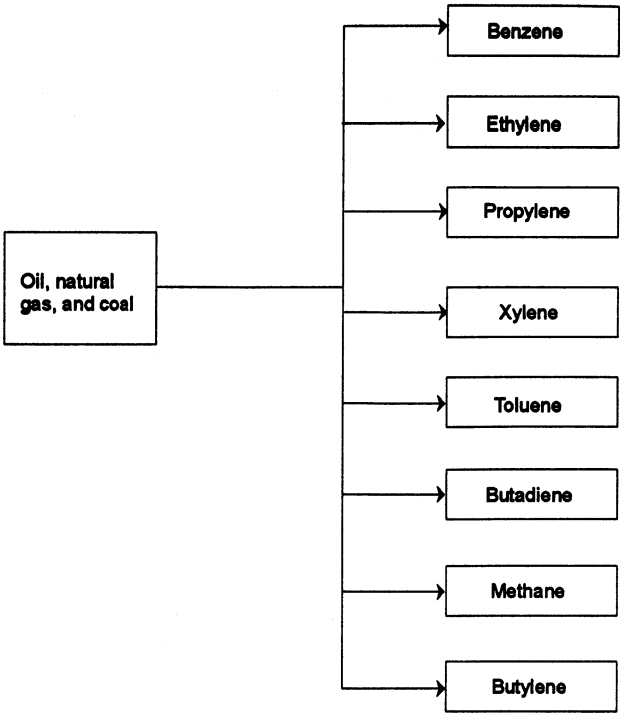
(Thousand metric tons)

Country	1992	1993
China	[r]373	385
Czechoslovakia	64	—
France	[r]498	485
Germany	490	582
India	55	47
Japan	1,388	1,310
Poland	89	75
Romania	36	30
Russia	[r]1,617	NA
United Kingdom	253	220
United States (shipments)	1,926	1,993

[r] Revised. NA Not available.

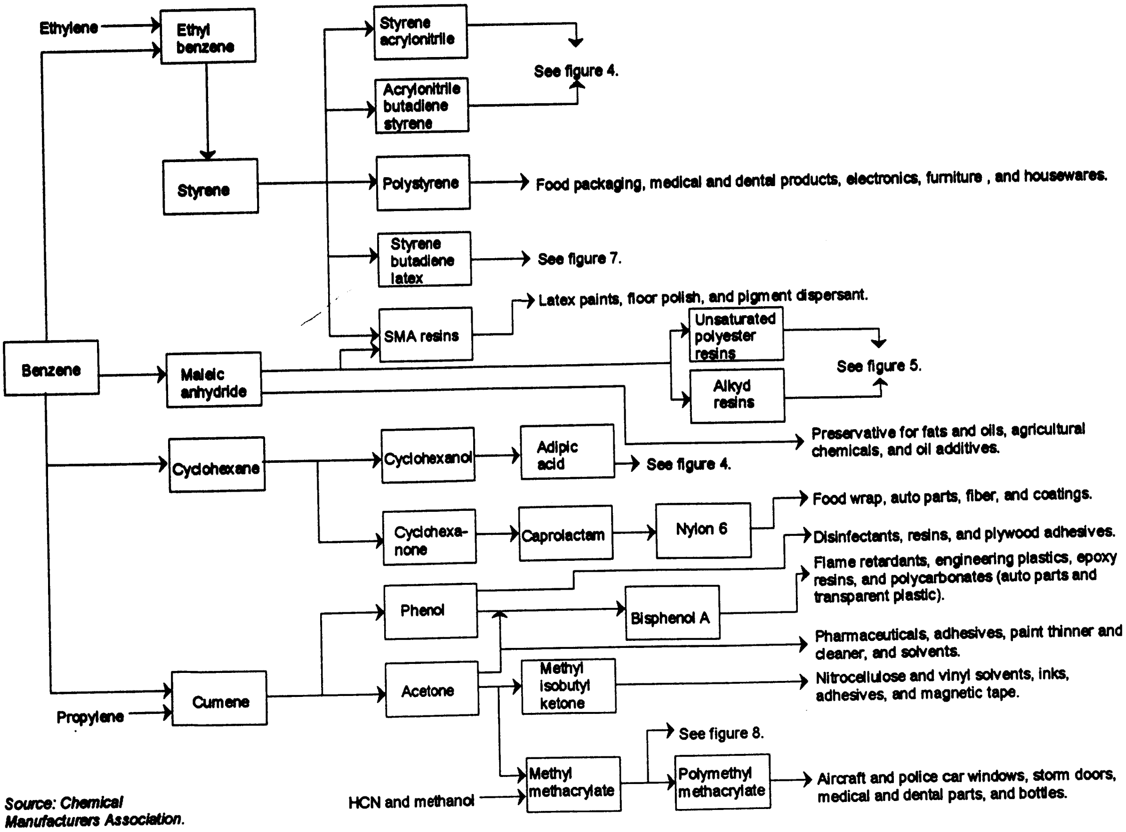
Source: Chemical & Engineering News.

FIGURE 1
FIRST-LEVEL DERIVATIVE ORGANIC CHEMICALS



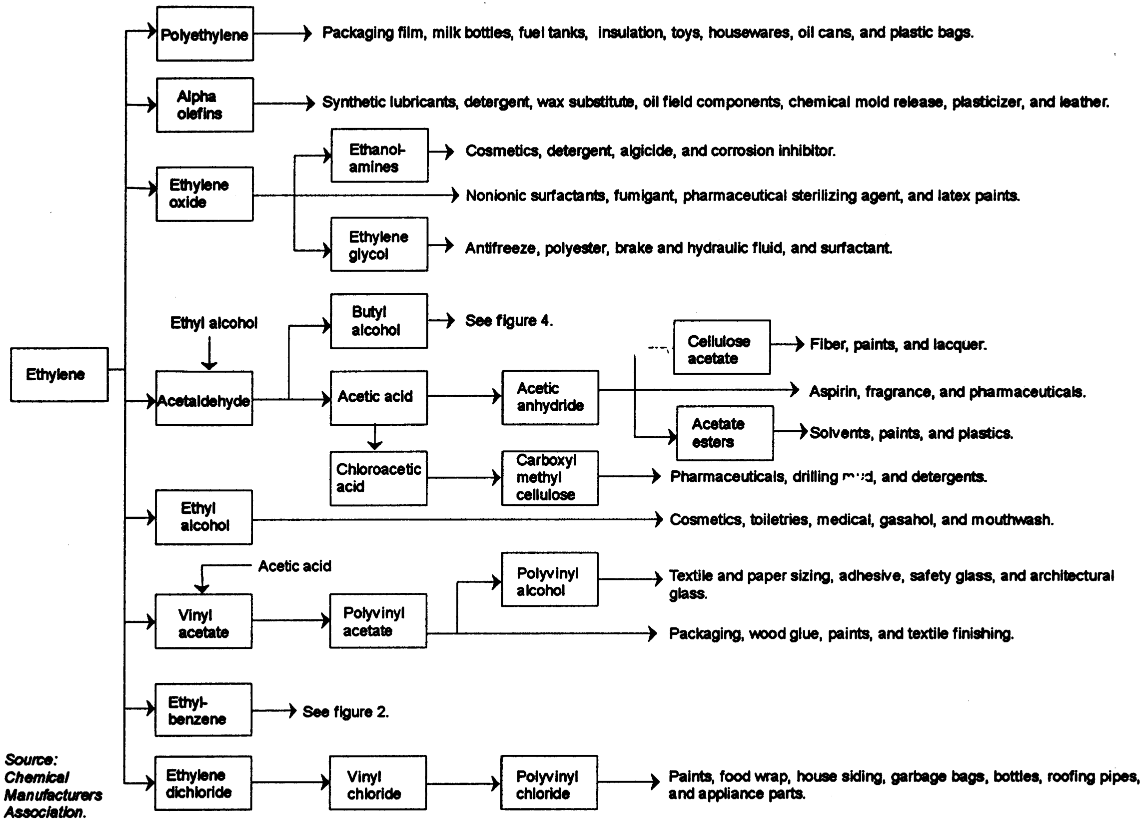
Source: Chemical Manufacturers Association.

FIGURE 2
BENZENE DERIVATIVES AND SELECTED END USES



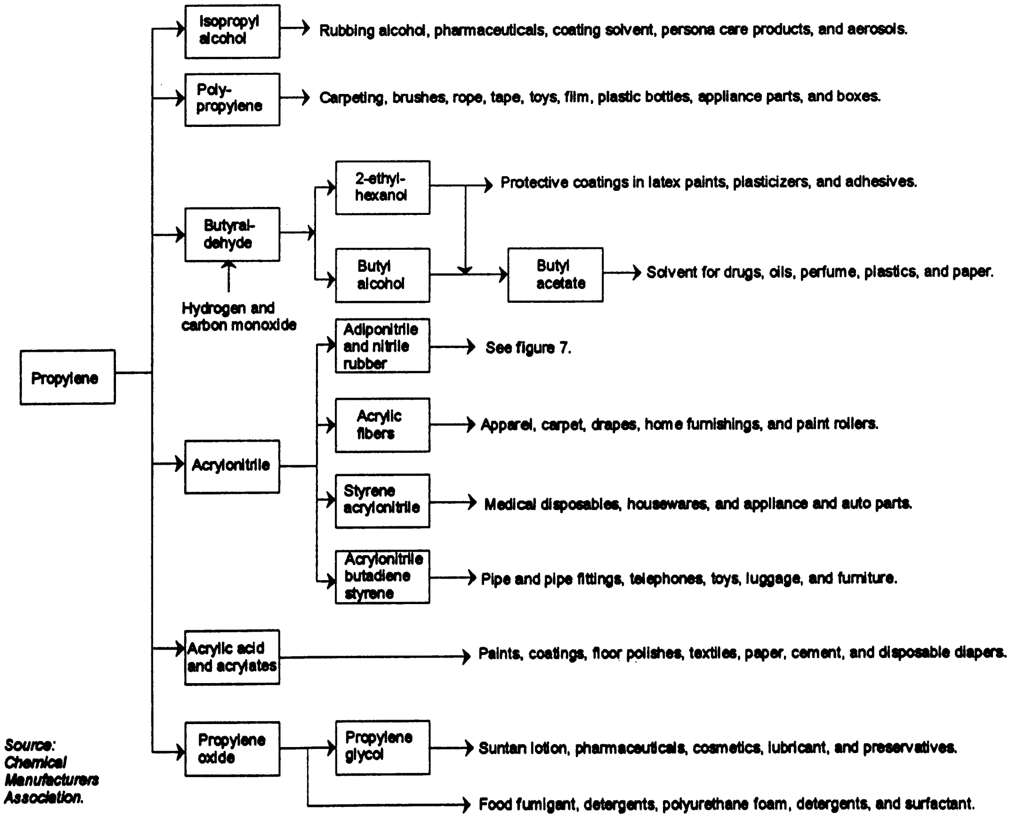
Source: Chemical Manufacturers Association.

FIGURE 3
ETHYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

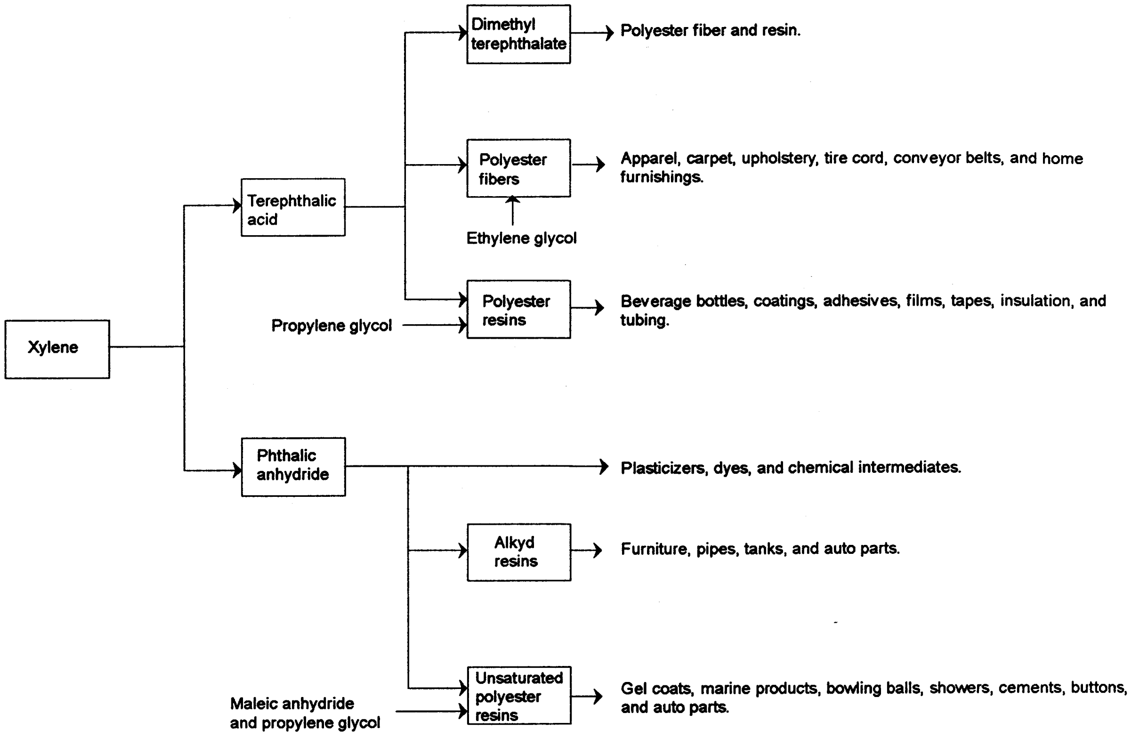
FIGURE 4
PROPYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 5

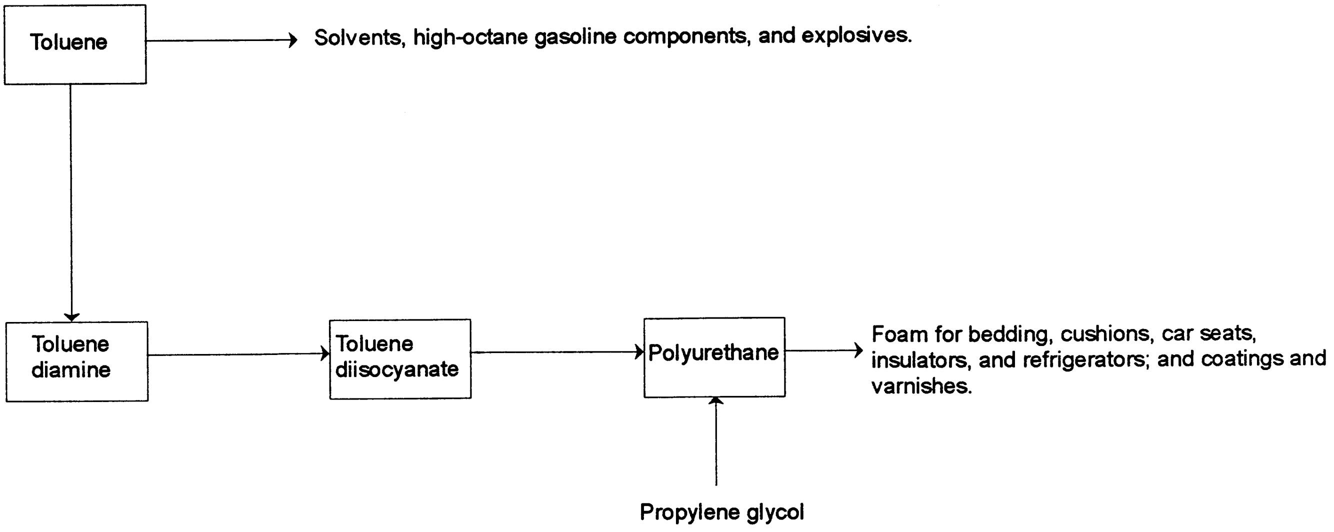
XYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

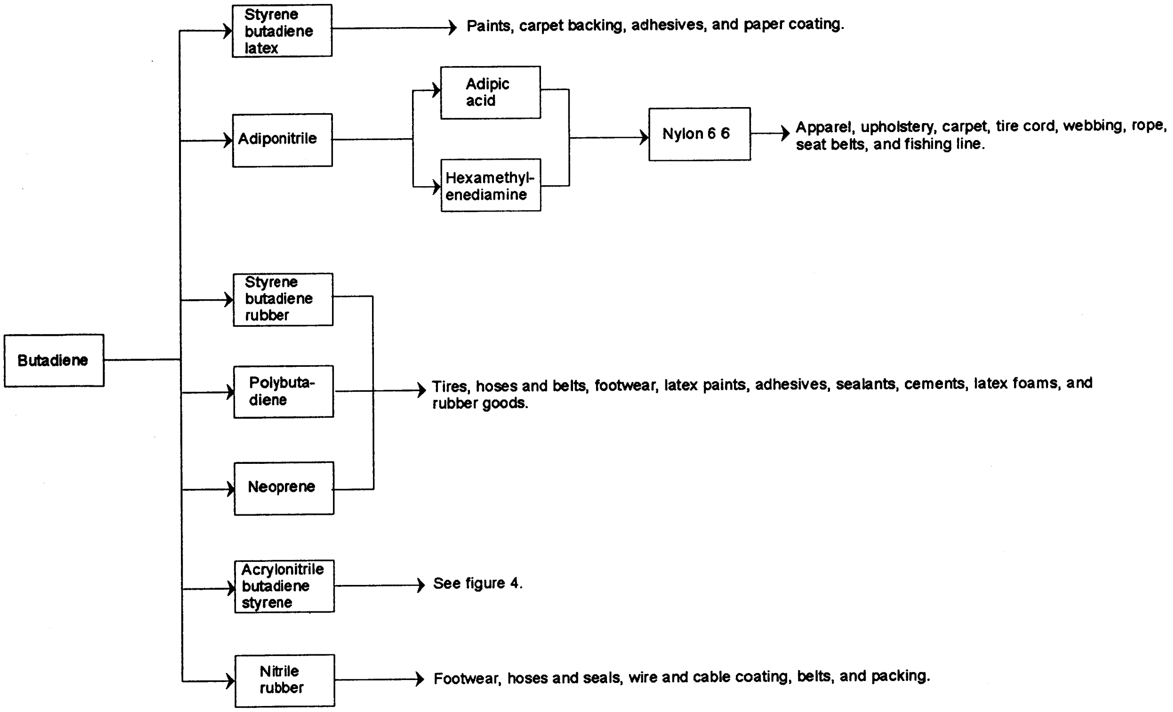
FIGURE 6

TOLUENE DERIVATIVES AND SELECTED END USES



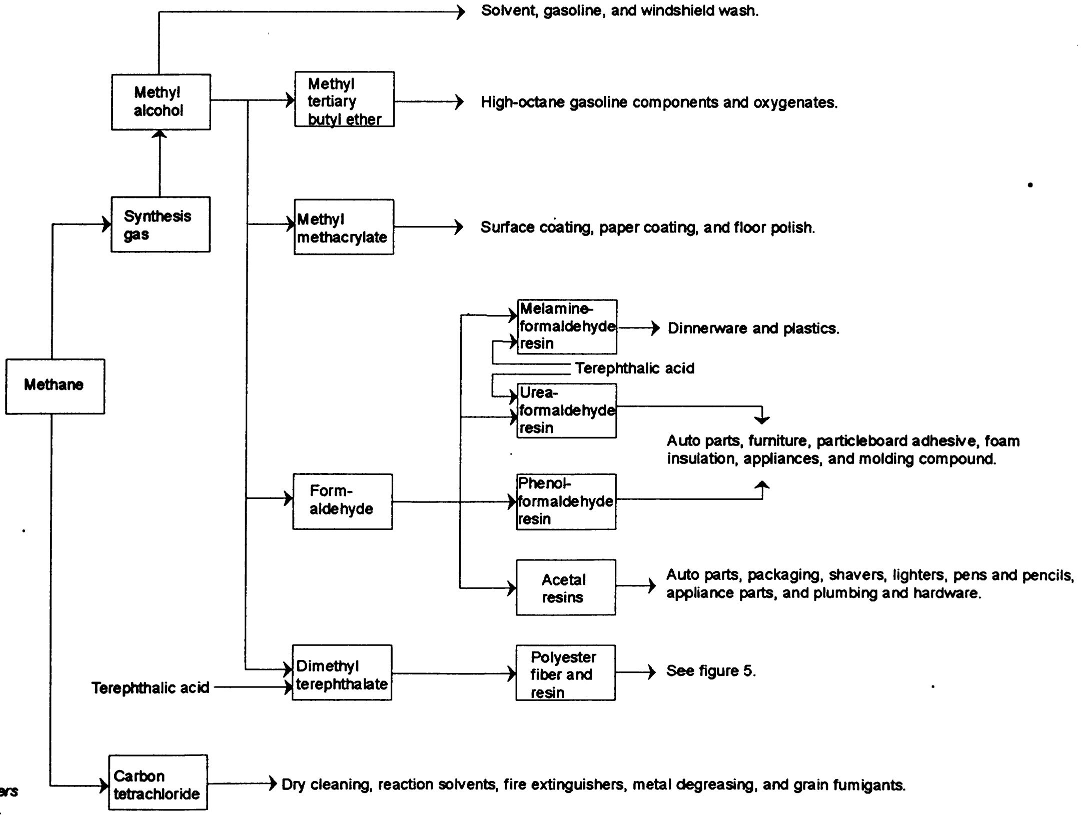
Source: Chemical Manufacturers Association.

FIGURE 7
BUTADIENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

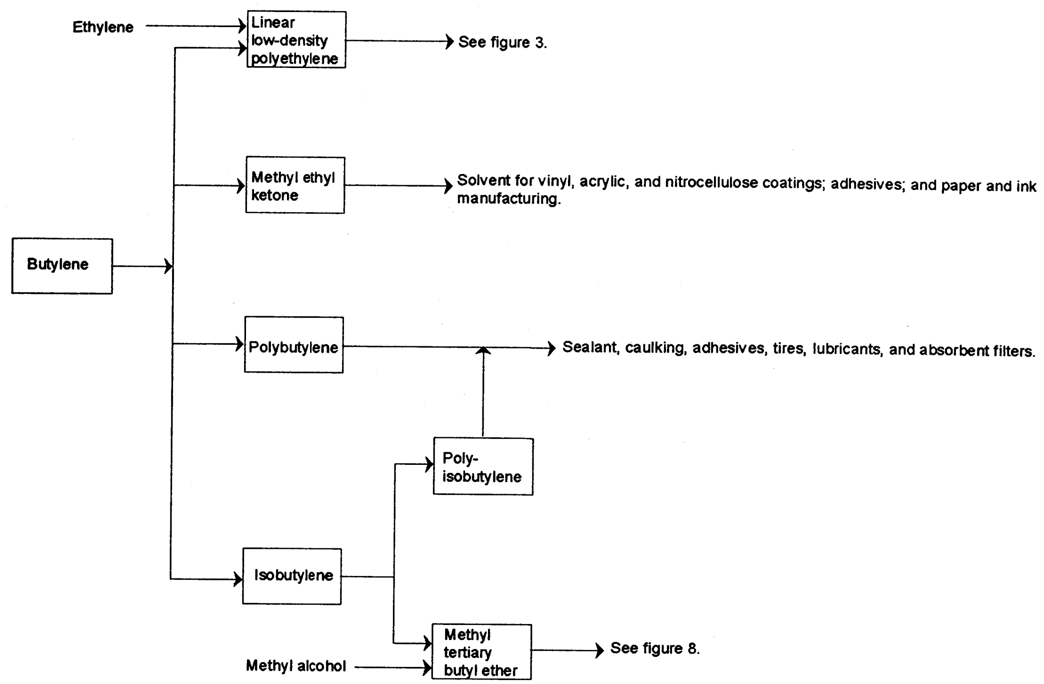
FIGURE 8
METHANE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

FIGURE 9

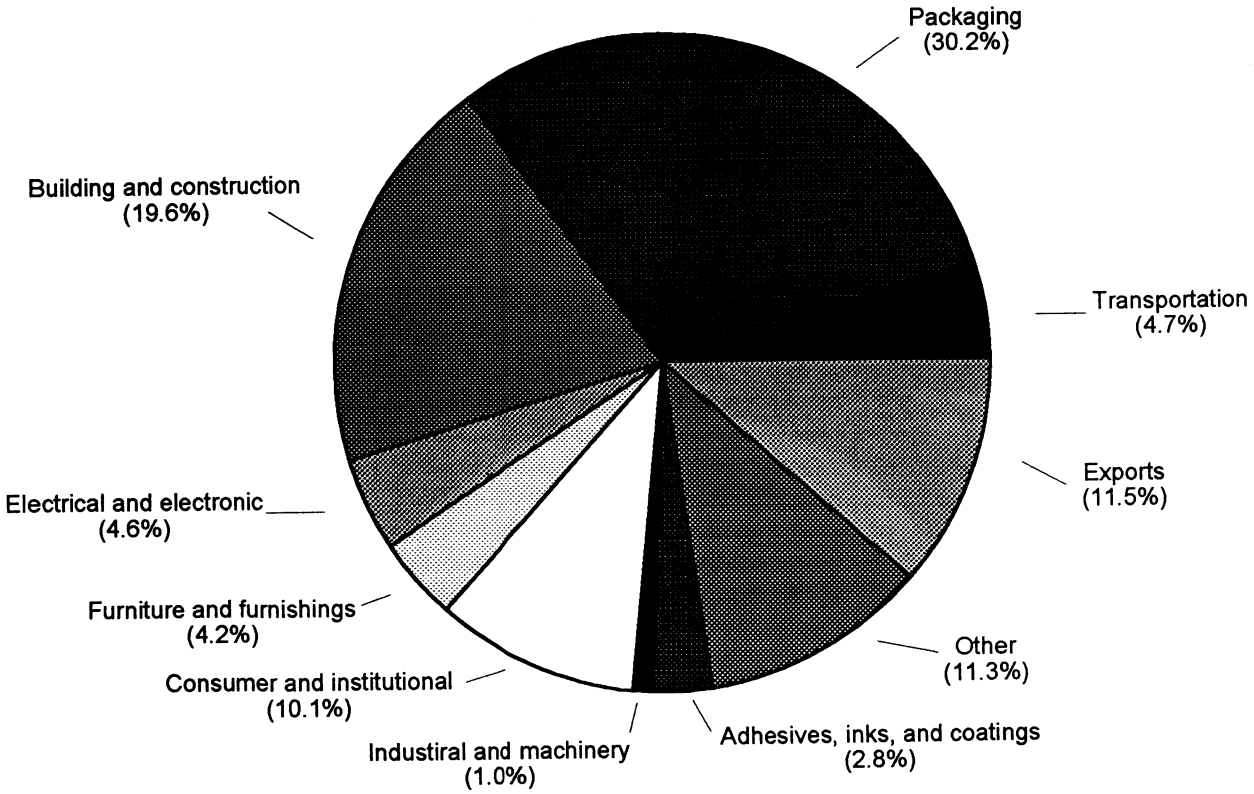
BUTYLENE DERIVATIVES AND SELECTED END USES



Source: Chemical Manufacturers Association.

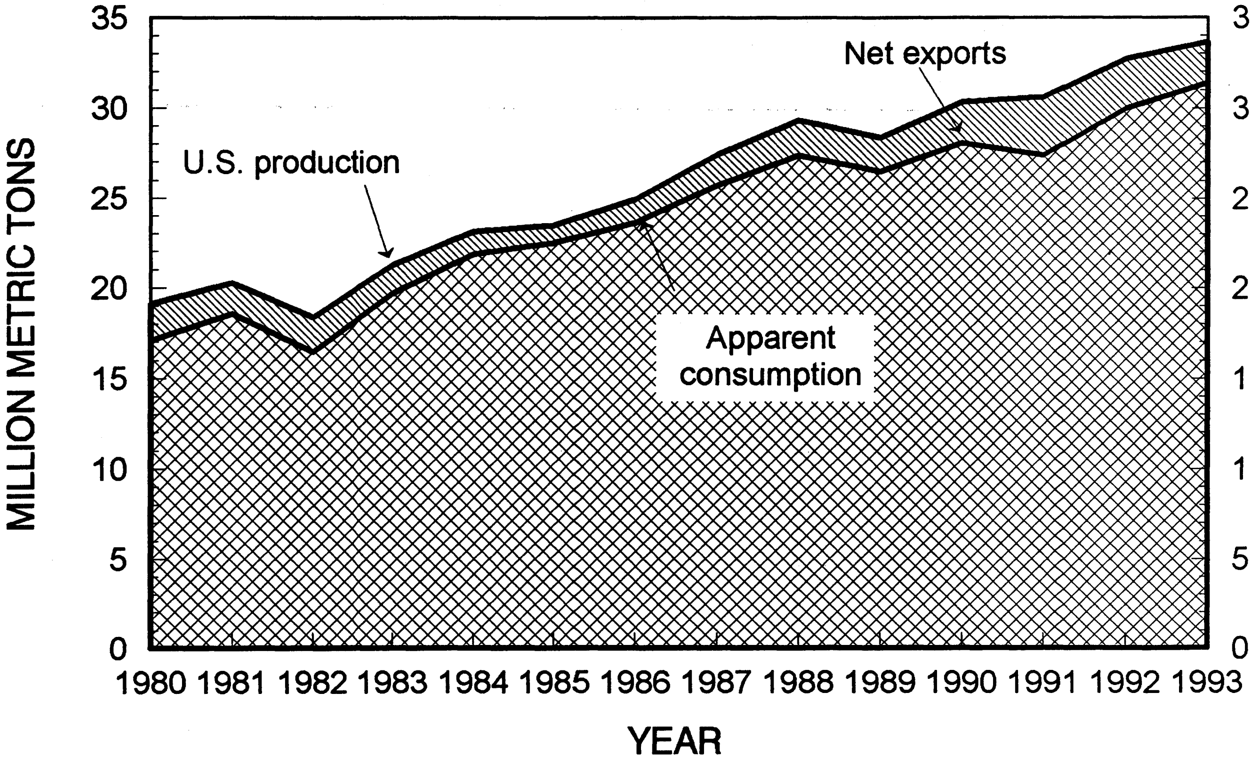
FIGURE 10

DISTRIBUTION OF RESINS IN MAJOR MARKETS IN 1992



Source: Facts and Figures of the Plastics Industry, 1993 edition.

FIGURE 11
U.S. SUPPLY-DEMAND RELATIONSHIPS FOR PLASTIC RESINS AND RUBBER



PEAT

By Wallace P. Bolen

Mr. Bolen, a physical scientist with 6 years as a U.S. Bureau of Mines commodity specialist, was assigned as the Bureau peat commodity specialist in the spring of 1994. Tony Roberts, statistical assistant, monitored the survey and also prepared domestic data tables. The international data table was prepared by Amy Durham, international data coordinator.

More than 90% of Earth's 450 million hectares (ha) (1.1 billion acres) of natural organic peat and peatland resources remain untouched, forming the basis for a continuous biological procreation mechanism for biomass. It is estimated that carbon stock in peat is approximately 300 billion metric tons, representing about 13% of the total carbon resources on Earth.

Significant quantities of peat are consumed by the global horticultural and agricultural sectors for use as a plant growth medium and soil amendment. In addition to its large volume use by the home gardener and professional nursery and landscape businesses, peat also enjoys substantial use in a myriad of industrial applications and consumer products, including potting soils, turf cultivation, golf course greens construction and course maintenance, mushroom cultivation and earthworm culture, poultry litter, fertilizers, composting, seed inoculants, humic acid extracts, toxic waste filtration, oil absorption, hygienic products, and fuel for electrical power generation.

In 1993, the U.S. peat industry continued to be disrupted by regulatory constraints, the large-scale recycling of yard wastes and other natural organic materials, and record imports of Canadian sphagnum peat, peat mixtures, and other articles of peat. Accordingly, 1993 was the second year in a row Canadian peat imports surpassed U.S. domestic production.

Several entrepreneurial domestic peat firms capitalized on the abundance of recycled yard and animal wastes by selling blends of composted natural organic materials and peat. The utility of U.S. sphagnum peat in specialty value-added applications also continued to generate new demand in the areas of oil sorption products and wastewater effluent treatment. Peat-based oil sorbents were accepted as environmentally friendly substitutes for clay sorbents in industrial and emergency cleanup applications in selected northeastern States and cities where clay has been banned from landfill disposal because of bulk, undesirable disposal economics, and potential health risks associated with clay dust containing crystalline silica. Minnesota's new sphagnum peat operations optimized capacity utilization and experienced improved competitiveness and profitability.

The U.S. Bureau of Mines (USBM) annual survey of domestic peat producers in the 48 contiguous United States reflected a 3% increase in production accompanied by the closure of two U.S. peat operations in the States of Maine and Michigan and the first full year of operations at a new Minnesota peat mine. Sales volume fell 6% to just more than 0.6 million tons, although the total value of producer sales increased slightly to $16.8 million, f.o.b. plant. Idled and discontinued operations continued to liquidate stocks.

Alaskan peat production in the Fairbanks vicinity was estimated at 55,000 cubic meters (m^3) by personnel of the State Division of Geological & Geophysical Surveys, Fairbanks, AK. The Alaskan peat carried a value of about $445,000, or $8.09 per m^3, representing an increase of 8% in unit value compared to that of 1992. Peat production from the Anchorage area was not available for publication.

Canadian peat shipped predominately from the Provinces of Quebec and New Brunswick, in eastern Canada, and from Alberta, Manitoba, and Saskatchewan, in western Canada, accounted for a record 51% of the total U.S. peat supply. Canadian import volume was a record 644,696 tons and was valued at $117.8 million, equating to a new record price of $183 per ton at U.S. Customs. Another $28 million of Canadian finished peat products was declared at U.S. Customs.

The total U.S. peat supply was valued at $135 million based on f.o.b. domestic plant and U.S. import Customs values. The monetary significance of peat as a value-added product at the retail level in the United States is many times greater and is estimated to be well in excess of $1 billion.

The metric system is the official system of measurement of most countries. The USBM, in an effort to provide statistical data on peat that are in compliance with Public Law 100-418, began, with the 1992 report, publishing in both metric units (metric tons, kilograms) and English units (short tons, pounds). This year's report uses all metric units with a total line in English units. Reports covering periods after 1993 will use only metric units with an occasional English reference, particularly for volume measurements, i.e. cubic yards. *(See table 1 and figure 1.)*

DOMESTIC DATA COVERAGE

The Division of Statistics and Information Services, USBM, conducts an annual survey of domestic peat producers in the 48 contiguous United States. Information obtained from the

USBM's voluntary canvass was used to develop data tables for publication. Of the 88 peat operations surveyed in 1993, 67 were reported to be active, 19 idle, and 2 to have closed permanently. Estimates were made for active operations that did not report data, based on past trends.

Alaskan peat producers were surveyed independently by the Department of Natural Resources, Division of Geological & Geophysical Surveys, Fairbanks, AK. In 1993, operations in the Fairbanks area reported active production.

BACKGROUND

Peat is a unique natural organic material of botanical origin and commercial significance that is found deposited in abundant quantities at the Earth's surface, where it plays an active role in the dynamics of our planet's ecosystem. Peat deposits function as natural hydrological control sources for vast areas of wetlands, provide an effective natural filtration medium for waterborne contaminants, and also serve as a biomass-related carbon link between the land and air. Today, peat deposits cover about 400 million ha (1 billion acres), or 4.4% of the Earth's total land mass, of which the United States ranks third in importance, eclipsed only by the large deposits found in the former U.S.S.R. and Canada.

The U.S. peat industry developed from small "mom and pop" operations that today comprise about 70% of all active peat operations and account for about 20% of total production. They provide essential peat supplies to surrounding communities that contribute significantly to cash-flow and liquidity within local economies. About 80% of U.S. peat is produced in high-volume operations by 30% of the producers. Large operations move peat in interstate commerce owing to economies of scale.

Peat deposits developed typically through the gradual decomposition of plant matter under anaerobic conditions in shallow aquatic basins. Most of the peat deposits in existence today lie at the Earth's surface and have formed since the last ice age approximately 10,000 years ago, although much older Pleistocene peats, typical of the deposits buried beneath the sands of Trail Ridge in Bradford and Clay Counties, FL, are known. Peat is a precursor of lignite and coal.

Peatlands, or mires as they are sometimes called, are more extensive in the temperate, boreal, and subarctic zones of the Northern Hemisphere and more limited in the cool and humid zones of the Southern Hemisphere. Peat deposits may be called bogs, fens, or "poor fens"—combinations of bog, fen, or swamp formations—depending on the aquatic mechanisms of the particular setting.

Most of the world's peatlands are classified as bogs. Bog is from the Celtic word "bocc," meaning "soft," which is an apt description for these waterlogged terrains. A bog is typically an acidic peatland that depends principally on rainfall to perpetuate the waterlogged conditions necessary for its survival. Because there is less decomposition in these nutrient-poor, acidic environments, the more fibrous peats—sphagnum moss, hypnum moss, and reed-sedge—may be found as the predominant species in the upper zone of the deposit.

The term "fen," as derived from the Anglo-Saxon language, translates to "mud" in modern day English. Fens are peatlands that depend mainly on ground water sources for their formation and survival and, thus, are less dependent on rainfall. Fens, unlike bogs, are found in less acidic nutrient-rich environments. Plant matter tends to decompose more rapidly under these relatively chemically neutral conditions, leading to a less fibrous, more mineralized material that in advanced stages of decomposition is known as muck or peaty muck. The majority of fens are over sites of sand and gravel deposits that are buried within more clayey glacial materials (intertill), providing a ground water seep over which the peat forms. It, therefore, is not uncommon to find fens situated on hillsides.[1]

Definitions, Grades, and Specifications

Methods adopted by the American Society for Testing and Materials (ASTM) find widespread use for the characterization of peat matter.[2] The ASTM Classification of Peats, Mosses, Humus, and Related Products requires the use of three parameters: ash content, fiber content, and botanical composition. Earthy organic materials must have an ash content of no more than 25% by dry weight to be classified as "peat." Botanical characteristics and fiber content govern peat types. Fibrous peat is defined as material retained on an ASTM No. 100 screen; that is, material 0.15 millimeter or larger.

Sphagnum moss peats must have a fiber content greater than 66%, all of which must be derived from the genus Sphagnum, as determined by screening and botanical analysis. Hypnum moss peats must have a 33% minimum fiber content, of which at least 50% must be derived from the genus Hypnum. Reed-sedge peats must have a 33% minimum fiber content containing more than 50% reed-sedge and other nonmoss fibers.

The U.S. Department of Agriculture Soil Conservation Service subdivides peat into three general categories: (1) fibric (peat moss), which is composed of sphagnum, hypnum, and other mosses; (2) hemic (reed-sedge), which is formed from reeds, sedges, swamp plants, and trees; and (3) sapric (humus), which is composed of materials that are decomposed beyond recognition of botanical origin.[3]

Fibric peats such as sphagnum and hypnum are relatively young moss species that are light in color in comparison to other peat varieties. Fibric peats, because of the lower order of decomposition, have a relatively high water-retention capacity and, in general, are quite acidic. Fibric peats have a low bulk density that averages about 150 kilograms per cubic meter (250 pounds per cubic yard) on an air-dried basis and very little ash. These peats are not suitable for fuel owing to the low degree of decomposition.

Hemic, or reed-sedge, peats are

somewhat older and more decomposed than fibric peats and originate from reeds, sedges, and other nonmoss-type plants. Hemic peats are considered to be intermediate between fibric and sapric in degree of decomposition, bulk density, and ash content. The average density of air-dried, reed-sedge peat is about 565 kilograms per cubic meter (950 pounds per cubic yard). Reed-sedge peats are usually slightly acidic and have a high energy value owing to fixed carbon content and low ash.

Sapric, or humic, peats, are the oldest and most decomposed peats, with color ranging from dark brown to black. Normally, sapric peats are the first peats formed in the filling of basins and are the most dense and colloidal. Sapric peats, because of their colloidal nature, take on less water, but retain it more strongly than other peats. Many sapric peats are excellent energy sources and are quite acidic. Sapric, or humus, peat, has an average bulk density of about 770 kilograms per cubic meter (1,300 pounds per cubic yard).

The von Post scale was developed in Sweden as a field method, or squeeze test, for determining the degree of peat humification or breakdown and is utilized by peat enthusiasts worldwide. According to the von Post method, peats are ranked on a scale from H 1 to H 10 relative to their degree of humification. A von Post of H 1, for example, would represent undecomposed peat that ejects colorless, clear water when squeezed, with the remainder containing easily discernible plant matter. At the opposite end of the scale, at H 10, the peat would be completely decomposed, with no plant remains recognized, and, upon squeezing, the whole amount would come out between one's fingers as a homogeneous material. In general, fibric peat mosses are in the von Post range between H 1 and H 3; hemic reed-sedges, H 4 to H 6; and saphric humus peat, H 7 to H 10.[4]

A typical proximate analysis for peat would yield a moisture content of about 50%; carbon, 26%; oxygen, 16%; hydrogen, 3%; nitrogen, 1%; sulfur, 0.1%; and ash, 4%. Fuel-grade peats may vary between 1,800 British thermal units (Btu's) per kilogram to as high as 4,500 Btu's per kilogram depending on moisture content and peat type.

Geology-Resources

In the United States, peat is deposited to some extent in all 50 States. About 10 million ha (25 million acres) of peatlands has been identified in the lower 48 States, representing an estimated reserve base of 6.4 billion tons. Alaska contains an enormous peat resource estimated at 51 million ha (125 million acres). Minnesota, Florida, Michigan, Wisconsin, and Maine, in order of importance, account for the major reserves that are available for commercial harvesting in the 48 contiguous United States. Peat reserves are also found in about 10 Western States, of which active harvesting is known to occur in Colorado, Montana, North Dakota, and Washington. At current mining rates, the U.S. permitted reserve base estimate of 4.5 million tons could theoretically be depleted within the coming 20 years.

Large peat resources are protected by Federal and State agencies in a vast area known as the Great Dismal Swamp near the southeastern coast of Virginia, extending south into northeastern North Carolina. Vast peat resources are also found in the sensitive wetlands areas of North Carolina's Pamlimarle Peninsula, Pamlico River Basin, and along the South Carolina Coast. Peat resources also are found along the east coast and southern regions of Georgia and along the U.S. Gulf Coast from Alabama to Texas.

Although Florida, Maine, Minnesota, and many other States have done a credible job in estimating individual State peat reserves, there has not been a comprehensive effort to consolidate individual State reports to establish the extent of U.S. peat resources since the 1922 U.S. Geological Survey (USGS) publication, "The Occurrence and Uses of Peat in the United States."[5]

As a result of the energy crisis in the mid-1970's, the Department of Energy (DOE) initiated a Peat Resource Estimation project in several States to provide information on the extent of our Nation's availability of peat resources for energy utilization, but the results were incomplete and never fully tabulated.

In the mid-1980's, the University of North Dakota and the USGS submitted a joint proposal to the U.S. Department of the Interior designed to survey the peat resources of the United States. The principal objective of the proposal was to systematically bring together and analyze the information obtained from DOE's Peat Resource Estimation program that had been conducted by the individual States. Other non-DOE-sponsored research in other States also was to be included. To date, a Federal program has not been established to research and publish a comprehensive report of U.S. peat reserves and resources.

This posture could change given that the Secretary of the Interior is currently formulating a proposed plan to conduct an extensive biological survey across the United States. The survey, which would be run by a new organization, the National Biological Survey, would map the country's ecosystems and biological diversity. Because peatlands or bogs are extensive, unique, and by nature biological, it was expected that a comprehensive survey would provide valuable and reliable information on U.S. peat reserves, resources, and locations.[6]

Technology

Mining.—Peat is mined or harvested by numerous methods in the United States dependent upon the prevailing conditions and the type of peat involved.

Sphagnum peat is mined through a combination of milling, aeration, and vacuum harvesting. A wide variety of equipment is required, including light and heavy power equipment; ditching machines to provide drainage; stumper, wood rake, and turner-aerator equipment to clear and aerate the surface; milling machines; vacuum harvesters; and wagons or trucks for transporting the harvested peat to the processing plant.

Reed-sedge peat may be harvested with conventional agricultural disking equipment, wide track bulldozers, and front-end loaders. Alternate methods involve milling or bulldozing, followed by windrowing and product pickup with a force feed loader equipped with a side-loading attachment. Smaller operations sometimes mine humus peat with power shovels, small draglines, and front-end loaders.

Fuel-grade peat, following conventional field preparation methods, is compressed into 10-centimeter-diameter cylinders with sod harvesting equipment. The cylinders break off at lengths ranging from 20 to 30 centimeters and drop to the surface for air drying. After windrowing to effect complete drying, the cylinders are picked up by a force feed conveyor loader and discharged into trailers for transport to the powerplant.

Processing.—All peat usually requires screening to remove debris and to produce a desirable marketable product. In state-of-the-art sphagnum operations, harvested peat is fed to a radar screen for sifting and the removal of large debris. The raw product is next discharged to a double-deck vibrating screen to effect sizing and to remove the smaller debris. Product oversize passing over the primary screens is hammermilled and recycled to the screening process. Processing is effected in a closed system equipped with an overhead vacuum takeoff for fine or dusty material. The fines may be recycled or conveyed to a closed waste bin outside the plant.

Product-grade material is discharged to a surge bin from which peat is processed in a four-step automated turntable process, wherein product is gravity metered into plastic containers, compressed into bales on a 2:1 volume ratio, sealed, and conveyed to storage. Four-cubic-foot bales (0.12 m^3) are the most popular size produced, but 2-cubic-foot (0.06 m^3) and 6-cubic-foot (0.18 m^3) bales also are produced in significant quantities.

Reed-sedge and humus peats are screened, packaged in bags, or sold in bulk. The materials also may be blended with perlite, vermiculite, sand, and sphagnum moss and packaged as potting soils, or for a variety of other uses. Peat-sand mixtures are popular bulk materials that are sold to golf courses for greens construction and for top dressing greens, tees, and fairway turf.

Economic Factors

U.S. peat prices, without adjustment for inflation, have increased at an average annual rate of 5% per year over the past 24 years (1970-93). Prices expressed in terms of constant 1993 dollars, however, have declined at an average annual rate of about 2% per year over the same period. The U.S. peat industry has overcome inflationary pressures principally through the rationalization of capacity, together with a move to higher volume modern and efficient plants, the proliferation of value-added consumer products, and the importation of more peat and finished peat products from Canada.

ANNUAL REVIEW

Legislation and Government Programs

The Environmental Protection Agency (EPA) issued final rules for Hazardous Waste Management; Liquids in Landfill, 40 CFR Parts 260, 264, 265, and 271. The rule was published in the Federal Register on November 18, 1992, and became effective on May 18, 1993. EPA's ruling addressed the final of three Congressional requirements developed under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA): "landfill disposal of containerized liquids mixed with sorbents."

This rule satisfies the statutory requirement that EPA issue a rule prohibiting the disposal of liquids in "hazardous waste landfills" that have been sorbed in materials that biodegrade or that release liquids when compressed, as might occur during routine landfill operations, and is intended to ensure the stability of materials in "hazardous waste landfills."

The Assistant Surgeon General, U.S. Public Health Service, clarified several points relative to EPA's seemingly complicated ruling. It was emphasized that the rule prohibits only the "direct" landfilling in "hazardous waste" landfills of liquids that have been sorbed into "biodegradable" sorbents. Thus, the rule does not in any way prohibit or restrict the use of sorbents (organic or otherwise) to address wastes or products going to a nonhazardous waste landfill (e.g., municipal or nonhazardous waste industrial landfill). Furthermore, it does not affect the use of sorbents with hazardous waste that is not landfilled—for example, that is burned for energy recovery, incinerated, recycled, or treated through bioremediation or land treatment.

EPA, in its rulemaking, did not conduct tests on the degradation of organic sorbents in an anaerobic landfill environment. Also, EPA did not test and made no judgment on the efficacy of different sorbents, including organic sorbents, in spill situations. Factors like absorption and retention—important considerations in the performance of sorbents in responding to spills—lay outside the scope of the rulemaking.

The U.S. Fish and Wildlife Service (FWS) continued to act as custodian for the preservation of a 38,000-ha (93,000-acre) peatland on the environmentally sensitive Pamlimarle Peninsula in northeastern North Carolina. About 32 million dry tons of high-energy, fuel-grade peat was deposited to an average depth of 2 meters over 28,000 ha (70,000 acres) of the property, formerly owned by First Colony Farms.

The FWS combined these lands with its adjacent 4,000-ha (10,000-acre) Pungo National Wildlife Refuge to form Pocosin Lakes National Wildlife Refuge. The development includes fire control, maintenance of drainage canals, provision of grain for feeding, and enforcement of wild game hunting. Deer, black bear, and wood duck were native to the area.[7]

The Pamlimarle Peninsula is the site of North Carolina's largest peat reserves. The peninsula is estimated to include 93,000 ha (360 square miles) of peatlands containing about 200 million tons of peat on a moisture-free basis. Only two small peat operations are currently active on the peninsula.

Large-scale commercial composting programs, fueled by environmental regulation, continued to proliferate in both the public and private sectors during 1993 and competed with peat in selected applications. Compost could lead to further growth in mulching and soil amendment activity dependent upon economic factors and consumer acceptance. In any event, several peat-compost product blends were marketed by major U.S. peat producers in 1993, representing a new trend that will most probably continue to increase in proportion to the availability of quality compost materials.

Issues

Major issues for the peat industry are uniquely intertwined with the very nature of peatlands, namely, peatland's location in wetlands and their contained ecosystems. Currently, debate on both ecosystem preservation and wetland regulations is increasingly concerning those involved with the harvest and consumption of peat.

In an article titled "Is Peat P.C.?" in the American Horticulturist, the preservation and mining of peat bogs is discussed with emphasis on activities in Canada. Ecologists contend that peat bogs contain many rare species and also fix carbon that is removed from the atmosphere. The article discusses the relatively tiny percentage of peatlands mined in Canada and restoration of previously harvested peat bogs.[8]

Peat deposits along the U.S. Eastern Seaboard, extending from Maine to Florida, are regulated by Federal, State, and local environmental agencies owing to population density and sensitive wetlands areas; this is also true in California along the U.S. west coast, and to an extent in several Midwestern and northeastern States. Conversely, the northern tier Great Lakes States are situated, for the most part, in more environmentally friendly surroundings. This is particularly true in Minnesota, where the prudent development of the State's tremendous peat reserve base—representing about 30% of total reserves in the 48 contiguous United States—is encouraged to generate employment and contribute to economic growth.

Since 1986, U.S. domestic peat sales have declined 35%, apparent domestic consumption has fallen by 8%, and 23 U.S. peat operations have been closed. During the same period, imports of Canadian peat have increased 29% and the U.S. import reliance has risen from 41% of total domestic consumption in 1986 to 51% in 1993.

Between 1986 and 1993, about 60% of the decline in domestic peat production and sales was in the leading States of Florida and Michigan, but equally disturbing was the fact that about one-third of the loss was attributable to 5 States in mid-America (Iowa, Illinois, Indiana, Ohio, and Pennsylvania). Many small operations, including some in Maryland, New Jersey, and New York, for example, have been shut down for an indefinite period by various regulatory agencies. In 1993, certain Michigan peat producers initiated litigation proceedings against the State Department of Natural Resources owing to new regulations that restricted peat mining.

In total, about 37 U.S. peat operations have been idled or have gone out of business since 1986. Many producers and consumers felt that a more equitable balance between environmental regulation and peat mining was needed, given the importance of peat to the U.S. economy and its value to the U.S. consumer. Industry sources were becoming increasingly cognizant of the role that Minnesota's tremendous sphagnum peat reserves will play in advancing future competitiveness and growth in the U.S. peat business.

Production

Peat was harvested and processed by 67 operations in 20 States, excluding Alaska. Florida and Michigan produced about 67% of the U.S. total, followed by Minnesota with 5%. The majority of U.S. peat production, about 80%, was conducted in high-volume operations that accounted for about 30% of the total number of active facilities. Geographically, about 50% of the total U.S. peat output by weight was from the Great Lakes region; 38% from 3 southeastern States; and the remainder from New England, the Midwest, and the West. The States of California, Georgia, and Maryland did not report production in 1993. *(See tables 2 and 3).*

On a weight basis, reed-sedge peat was 66% of total U.S. production; humus, 16%; sphagnum moss, 13%; hypnum moss, 4%; and other forms, 1%. On a volume basis, the product distribution may be altered dependent upon variations in peat bulk density, from sphagnum moss at the low end of the scale having a density of about 300 kilograms per cubic meter (500 pounds per cubic yard), to humus having a bulk density of more than 600 pounds per cubic meter (1,000 pounds per ton). Thus, reed-sedge was 60% of production by volume; sphagnum moss, 24%; humus, 12%; hypnum moss, 4%; and other forms, less than 1%.

In Alaska, A&A Services, The Dirt Co., and Landscape Supply Corp. produced peat in the Anchorage area, while Great Northwest, Inc. was active near Fairbanks. Alaskan peat demand increased dramatically during the early 1980's coincident with the economic boom precipitated by the development of the Alaskan Oil Pipeline. Production peaked at 100,000 m^3 (125,000 cubic yards) in 1984 and carried a value of $859,375, or $8.59 per m^3 ($6.88 per cubic yard). The potential for future development of Alaska's tremendous peat resources will be dependent upon Alaska's economic growth, peat's emergence as an effective filtration medium for the control of toxic waste effluents in mining, and logistical factors.

Domestic Operations.—Although Florida and Michigan were by far the largest producing States, Minnesota was thought to hold much promise for future peat production. Nine producers, including one new operation, were active during the year, of which there were major sphagnum producers in Carlton County and St. Louis County and one major bulk producer of reed-sedge in Aitkin County, all near Duluth, MN. It is useful to notice that Minnesota garnered 11.5% of the value of peat sales in the United States even though, by quantity, the State represented only 5.4% of the national tonnage. Minnesota's premium peat was valued at $60 per metric ton, f.o.b. plant, more than twice the U.S. average. This is a reflection of the higher quality of peat in Minnesota compared to the average peat in the Nation. It was anticipated that because of a favorable climate for job creation via peat operations and quality resources, Minnesota would continue to experience growth in peat production, sales, and number of operations.

Davidson Peat was harvesting reed-sedge peat from a 14-ha (35-acre) bog in Rice County, MN. Raw peat was extracted with a 3-m^3 (4-cubic-yard) swinghoe power shovel and stockpiled on-site. Following windrowing to effect drying and weathering, tractor-trailer rigs transported the peat to Davidson's processing plant at Kenyon, MN, near the town of Webster. Davidson sells fine-milled bulk peat and peat-sand bulk blends. The firm was operating under county mining permits because peat harvesting permits were not available, but was working with local officials to study the feasibility of introducing peat harvesting permits.

Aitkin Agri-Peat began harvesting and selling reed-sedge at its bog in Aitkin County in 1984. The operation was improved and expanded through the lease and later purchase of specialized equipment from the Natural Resources Research Institute (NRRI) at Duluth. Aitkin also designed and constructed unique harvest machinery that provides an efficient and economical method of harvesting bulk peat. Production capacity is about 15,000 m^3 (20,000 cubic yards) annually, from 40 ha (100 acres) of the 120-ha (300-acre) deposit. Aitkin Agri-Peat markets bulk reed-sedge to general contractors and golf courses within a 400-kilometer (250-mile) radius of the harvest site near McGregor, MN.

Minnesota Sphagnum, Inc. (MSI) commenced sphagnum harvesting in 1987. The first 5 years were devoted to improvements in processing facilities and field expansion. Expansion of this operation will continue for the next 2 to 4 years. MSI currently harvests peat from 100 ha (250 acres) and markets sphagnum peat in bale and bulk in the mid- and southwestern States. The MSI organizational structure is through Hyde Park Products and Conrad Fafard, Inc.

Peatrex Ltd. began sphagnum production in 1985 near the town of Cromwell, MN, in Carlton County. The operation is of Finnish design with good drainage. The fields are profiled for fast turnaround after heavy rains. In 1989, Peatrex was purchased by Premier Enterprises of Canada, and since, has constructed a state-of-the-art sphagnum processing facility on the property. Harvested sphagnum from the 100-ha (250-acre) operation is processed into 2-, 4-, and 3/4-cubic-foot bales or sold in bulk.

Michigan Peat Co. is a major supplier of retail soil amendments and professional grower horticultural products in the north-central States, providing a wide range of peat-based products to an area containing more than 40% of the Nation's population. Peat was harvested and processed in three locations, including sphagnum moss production at Cromwell, MN, and two facilities in the "thumb" area of Michigan, near Sanilac.

Michigan Peat is headquartered in Houston, TX, from which a $15 million annual business is coordinated. The firm has the capacity to harvest 135,000 tons of reed-sedge peat and sphagnum peat moss annually, or about 20% of current U.S. production. Michigan Peat products are marketed under the BACCTO and Garden.magic labels.

Hyponex Corp. harvested and processed reed-sedge peat from facilities in five States extending from Florida to Colorado. Hyponex markets peat and peat blends throughout much of the United States. The firm operates from parent headquarters, the O. M. Scott & Sons Co., in Marysville, OH, which is a recognized leader in the lawn and garden fertilizer market.

Hyponex also was operating 12 organic composting process facilities and a like number of additional sites across the country that were open to receive yard trimmings in line with the national thrust by the EPA and municipalities to recycle waste materials that otherwise contribute significantly to the overloading of landfills. Waste collection firms contracted by various municipalities transfer natural organic yard waste materials like leaves, grass, and hedge trimmings, which in turn are recycled into marketable compost materials. The composting/recycling approach has proven to be a win-win-win situation for municipalities, taxpayers, and the environment. Consumer demand for Hyponex organic products, such as Compost plus Organic Peat, Rich Dark Top Soil, and all purpose Potting Soil, ensure a steady market for composted yard trimmings. The firm believes that enough demand could be generated for its organic products to allow for the recycle of virtually all yard trimmings generated by the major metropolitan areas of the United States.

Domestic Projects.—New horticultural peat projects were reported to be under consideration in the States of Florida, Georgia, Maine, New Mexico, North Dakota, and possibly in North Carolina.

NorthWood Organics, a new Duluth, MN, subsidiary of Faulks Brothers Construction Co., Inc. of Waupaca, WI, opened its new sphagnum peat bog in St. Louis County, MN. Bog development began in early 1993, and production was underway later in the year. Full production at the 60-ha (150-acre) site, in the Toivola bog, is expected in 1994. NorthWoods Organics will provide technical support and new product development for Faulks Brothers while producing organic products for commercial landscape, horticultural products, and construction applications.

Power-O-Peat Co., with a bog near Eveleth, MN, has been closed since 1988. The owners announced plans to reevaluate the bog with the hope of reopening the operation of the reed-sedge/humus bog in the near future. Power-O-Peat has 120 ha (300 acres) available for harvesting and interest in an additional 800 ha (2,000 acres).

Folsom Marine Service Corp. reported the sale of its Saco Heath Property to the Maine Nature Conservancy in December 1993. The property is in York County, ME.

Fuel Peat Projects.—Plans by EcoPeat Co.—a U.S. affiliate of the Finnish firm Outokumpu—to develop 360 megawatts of peat-fueled electrical powerplants in cooperation with south-central Florida utility companies were postponed indefinitely. Central Florida utilities reportedly have opted to build powerplants based on natural gas fossil fuel.

The Down East Peat LP peat-fueled powerplant at Cherryfield, ME, was purchased in early January 1993 under the provisions of a reorganization that involved the formation of Worcester Energy Co., Inc., and Worcester Peat Co., Inc. The energy company acquired the 22.8-megawatt biomass powerplant, ancillary buildings, equipment, and 8 ha (20 acres) of adjoining land. The peat company, in turn, purchased about 360 ha (900 acres) of the adjoining Denbow Heath peat bog. At full capacity, the powerplant will require about 150,000 tons of bone-dry peat annually.

Worcester Energy Co. closed the powerplant in mid-January 1993 pending negotiations of a proposed power contract with Bangor Hydro-Electric Co. in which Bangor was asked to pay 2 cents above the normal 3-cent-per-kilowatt-hour "avoided" rate. Bangor Hydro was required by law to purchase the plant's power at the avoided rate, the cheapest price that the utility would pay for additional electricity. The new firms projected a good harvest season on the bog because the powerplant was back on-line in the second half of 1993.

Down East Peat LP of St. Petersburg, FL, originally brought the $51 million peat-fueled powerplant on-stream in June 1989 under the provisions of a 20-year supply agreement with Boston Edison, but the owners were ultimately faced with the prospect of continued losses and opted to allow the utility to buy its way out of the contract in mid-1992. The plant operated on a combination of woodchips and peat depending on the availability of peat. Former Down East Peat officials reported that the project could potentially become one of the more viable sources of power in the country were enough peat acreage available, given that peat can be harvested at a fraction of the cost of wood, oil, or coal. Down East Peat also cited technology problems, high transmission costs, and an oversupply of electricity in the northeast as other factors that had been detrimental to the project's success.

Humate Production.—Humates were mined from the San Juan Basin deposits in northwest New Mexico and sold primarily for use as soil conditioners and drilling mud additives. In 1985, the last year of available data, humate production was about 18,000 m^3 (23,000 cubic yards), with an f.o.b. mine value of $404,000. Mining and processing were conducted by three companies in McKinley, Sandoval, and San Juan Counties.

Humate and weathered coal occur in the Upper Cretaceous Fruitland, Menefee, and Crevasse Canyon formations in the San Juan Basin. All of these humate deposits—high in humic acid content—represent a facies in poorly drained swamps in nearshore deltaic and fluvial sequences accumulated during marine regression in the Cretaceous. Most humate occurrences consist of carbonaceous claystones rich in organic matter, or weathered coal ("leonardite"), having a high humic acid content.[9]

Humate is commonly associated with coal and lignite. When associated with lignite, humate is called leonardite, after A. G. Leonard of the North Dakota State Geological Survey. Through use, the term leonardite has been informally expanded to include coal-derived humate. Humic acid-rich deposits also exist in Arkansas, Florida, Louisiana, New York, North Dakota, Michigan Minnesota, Texas, and Wyoming. Alpine Humate, Inc. planned to start up a new humate mine near Denison, TX.

Consumption and Uses

Sales of U.S. peat products in 1993 continued a 3-year slide as U.S. peat continued to struggle against imports of Canadian peat and peat products. In 1993, domestic sales tonnage declined 6% from 1992 levels, while sales of imported peat rose slightly and maintained 50% of the total U.S. peat market for the second year in a row.

Packaged peat as a percentage of total domestic sales volume by weight dropped from 56% in 1992 to 44% in 1993. Packaged peat was valued at a 92% premium relative to bulk forms, according to the USBM annual survey. Approximately 90% of U.S. producer sales was for general soil improvement, horticultural, and agricultural use. In horticulture, peat was used predominately for general soil improvement, as an ingredient in potting soils, and in the nursery business. In agriculture, peat was used for general soil improvement, in mixed fertilizers, as a carrier and coating agent in seed inoculants, for vegetable cultivation, and as poultry litter.

Specialty applications included peat's use in golf course greens construction and course maintenance, as an earthworm culture medium, for mushroom cultivation, oil absorption and wastewater filtration, and for use in hygienic products. Minor quantities of peat were used as fuel for electric power generation. *(See tables 4 and 5.)*

Stocks

In 1993, primary producer peat stocks did not vary significantly from prior-year levels and stood at about 0.3 million tons at yearend, according to the USBM's annual survey of domestic peat producers. Producer peat stocks in all forms were about 50% of production, typical of the industry. Reed-sedge peat accounted for about 80% of total stocks by weight. *(See table 6.)*

Transportation

Peat was moved predominately by truck in both bulk and packaged form.

Small producers were restricted to local market areas because of the sensitivity of peat prices to transportation charges. High-volume producer costs were less sensitive to transportation charges, allowing for interstate movement of peat and peat products.

Lindqvist Business Development Corp. of Minnetonka, MN, was evaluating the feasibility of the CARGO 2000, an innovative side-dumping trailer developed by BURE VERKSTADS A.B. of Sweden for tractor-trailer or rail transport of peat, woodchips, beet pulp, and other bulk materials. During unloading, the roof, floor, and one side of the trailer are raised hydraulically. The lifting action of the floor and side wall will break up the cargo as it is dumped from the trailer, allowing even frozen cargo to be safely unloaded at rates in excess of 68 m^3 (90 cubic yards) per minute.

Markets and Prices

Domestic peat prices averaged $28 per ton f.o.b. plant in 1993, a 7% increase from the prior year. Packaged peat was quoted at a premium $38 per ton compared with $20 for bulk peat, although packaged forms captured only 44% of the total sales tonnage. Sphagnum moss sold at a premium $46 per ton, about 60% more than the national average. *(See table 7.)*

Foreign Trade

The United States has shipped minor quantities of peat offshore averaging about 18,000 tons per year during the past 5 years. In 1993, exports dropped significantly, to 8,000 tons from 22,000 tons in 1992. The exported peat was valued at $0.9 million f.a.s., or about $103 per ton, and went to 18 countries. Mexico, Saudi Arabia, Bermuda, Canada, Japan, Bolivia, and Argentina accounted for 83% of the total, in order of importance.

In 1993, Canada continued to provide more than 99% of total U.S. peat imports—principally sphagnum moss—and new records again were established for both volume and value. Canadian imports reached a record 645,000 tons, about 50% of the total U.S. peat supply, and carried a U.S. Customs value of $117.8 million, equating to $183 per ton. Another $28 million in Canadian peat merchandise was recorded by U.S. Customs under the "Articles of Peat" category. Peat pots and other specialty peat-based products, including some peat mixtures, were reportedly included under this category.

Under terms of the United States-Canadian Free-Trade Agreement, the Canadian tariff on U.S. peat was removed effective January 1, 1993. Prior to 1993, Canadian peat shipments in all forms entered the United States duty free, but a tariff of 10.2% was imposed by Canada on U.S. peat. The United States exported about 700 tons of peat to Canada in 1993, valued at $59,000 or $84 per ton, according to U.S. Department of Commerce trade statistics. A Canadian duty of 3.4% is currently imposed on U.S. "Articles of Peat," down from a maximum of 6.8%. This duty is scheduled to be gradually phased out at a rate of 10% per year over the next 10 years. The USBM could not find a record for U.S. articles of peat export shipments in the U.S. Department of Commerce trade data base.

The United States accounted for roughly 90% of total Canadian export shipments in 1993. About 70% of the total was shipped from central and Atlantic Canada, and the remaining 30% from western Canada. Officials of Natural Resources Canada in Ottawa, Ontario, reported that Canada's improved performance in the United States was largely attributable to a greater visibility brought about by an intensive national promotional campaign, together with more aggressive marketing by Canadian producers.[10] Canada typically exports between 75% to 80% of its total peat shipments. *(See table 8.)*

Natural Resources Canada reported that about 67% of all Canadian shipments in 1993, domestic and export, originated from Quebec and New Brunswick in eastern Canada. Alberta and Manitoba, in western Canada, supplied about 26% of the total. The remaining 7% was reported to originate principally from Saskatchewan in western Canada, with minor contributions from the eastern Provinces of Nova Scotia, Newfoundland, and Prince Edward Island.

World Review

After peaking at 197 million tons in 1989, global production is estimated to have declined by 57 million tons to current levels, representing a drop of nearly 29%. The major decline can be traced to the former U.S.S.R. where USBM production estimates indicate that production has fallen about 53 million tons, or 30%, during the period cited.

In 1993, global peat production declined to 140 million tons, a drop of nearly 9% from that of 1992, principally because of continuing geopolitical events in the former U.S.S.R. Finland's 1993 production pace slowed from the torrid production rate of 1992. The high 1992 production levels were a reaction to a poor 1991 season, which was attributed to restrictive wet weather. Finnish peat was utilized mainly for energy production as Finland, along with Ireland, are the leading western nations in fuel peat utilization and consumption. Production in all other countries was believed to be comparable to 1992 levels. The total value of world peat production, assuming an average f.o.b. plant value of $30 per ton, was about $4.2 billion.

Ireland and Finland, in order of importance, accounted for about 60% of the estimated 17 million tons of peat produced outside the former U.S.S.R. in 1993. In Ireland, greater emphasis was being placed on fuel peat technology transfer, environmental technology, and the marketing of horticultural peat, while in Finland, plans for additional peat-fueled powerplants were under consideration. Germany (Western states) provided 16% of global production outside the former U.S.S.R.; Sweden, 10%; Canada and the United States combined for 9%; and other countries, 5%.

Although peat was known to be deposited in the United Kingdom, tropics of Africa, Argentina, Brazil, China, Indonesia, Malaysia, New Zealand, Paraguay, and Uruguay, production data were not available. *(See table 9.)*

Industry Structure.—The former U.S.S.R. was estimated to account for about 88% of global peat production in 1993, followed by Ireland, 5%; Finland, 2%; Germany (Western states), 2%; Sweden, 1%; the United States and Canada combined for 1%; and all other countries, 1%.

Canada.—Natural Resources Canada, Ottawa, Ontario, reported that the total area of peatlands in Canada is estimated at 111 million ha (275 million acres) covering approximately 12% of the country's surface. Canada produces sphagnum peat for the most part typically from May to September, primarily in the eastern and southeastern parts of the Province of Quebec, in the eastern and northeastern parts of the Province of New Brunswick, and in the western Provinces near Edmonton, Alberta; Carrot River, Saskatchewan; and Giroux and Elma, Manitoba. Some peat production is also found in the Provinces of Nova Scotia, Prince Edward Island, and Newfoundland. Canada's massive peat resources can probably be harvested for centuries.

Production from about 73 operations improved about 12% in 1993 as Canadian producers sought to replenish depleted stocks. Shipments fell even as exports rose, indicative of a decrease in domestic peat demand. Production increased in Quebec (50%), Nova Scotia and Prince Edward Island (combined for 100%), and Alberta (4%). Production was down 13% in New Brunswick, 7% in Saskatchewan, 8% in Newfoundland, and Manitoba was practically unchanged. Production figures are confidential for the Provinces of Alberta, Manitoba, Nova Scotia, and Saskatchewan.

The fortune of Canadian peat is dependent on continuing exports, especially to the United States; therefore, various Canadian companies sought to maintain their markets via processing and packaging improvements and research. These activities continued in 1993 as various groups worked to modernize operations, researched peat use in horticultural and environmental protection, and developed equipment for peat handling and packaging. Research projects continued on restoration and reclamation of peat bogs and improving knowledge of the peat bog as an ecosystem.

The United States and Japan were Canada's principal export targets, in respective order of importance. A 1990 study supported by the Canadian Embassy in France indicates that substantial quantities of peat could be sold to France and eventually to other European countries if producers took full advantage of backhauling to reduce freight costs.[11]

The Newfoundland and Labrador Peat Association, in cooperation with many other Canadian agencies, held an international peat conference, Newfoundland Peat Opportunities, in the fall of 1993. The conference examined the current situation in Newfoundland and around the world, identified barriers to development, and formulated a plan of action aimed at appropriate development of the Province's peat resources. The island of Newfoundland is blessed with more than 1 million ha (2.5 million acres) of peatlands. These deposits represent a largely untapped natural resource offering significant business development opportunities. The resources of Labrador, while yet to be quantified, are likely to offer far greater potential.

Finland.—In 1993, Finland's peat production totaled 13 million m^3 representing a decrease of 60% compared to 1992 when production ran full throttle to make up for lost production time in 1991. Milled fuel peat production was 9.7 million m^3, 75% of the total, and sod fuel peat 2.2 million m^3, or 17%, bringing total fuel peat to 92% of total production. Horticultural peat was 1.1 million m^3, or 8% of total production.[12]

Peat production in Finland was very small in 1970, but grew to about 3 million m^3 by 1975 and to a record of about 22 million m^3 by 1986.[13] The potential for utilization of fuel peat in Finland is currently about 30% above actual use and is projected to potentially more than double during the next 10 to 15 years.[14]

Former U.S.S.R.—The peat resources in the former U.S.S.R. are commonly referred to as the largest in the world, and more than 90% are found in Russia. The total area of peatland in the former U.S.S.R. is about 80 million ha, and the quantity is on the order of 200 to 250 billion tons at 40% moisture. The western Siberian plain is a vast peatland covering about 30 million ha with a resource base in excess of 100 billion tons. The world's largest deposits lie here with Vasyugaskoe alone having an area of 5 million ha (12.4 million acres) containing about 10 billion tons of peat. The resource has been extensively exploited for fuel use for more than 50 years.[15]

In the former U.S.S.R., production was confined to the Baltic Republics, the Moscow-Gor'kiy area, Belarus, and the Ukraine, although peat was known to be deposited throughout much of the country. Peat was burned in thermal powerplants in European former U.S.S.R. and also was used to fire industrial boilers and large heating plants.

The use of peat in the former U.S.S.R. was reportedly declining because of insufficient reserves in the primary consuming areas around Moscow and St. Petersburg and restricted demand in the energy and agricultural sectors owing to a radical shift in sociopolitical and socioeconomic philosophy. The chemical industry produced methanol and synthetic natural gas from peat.[16]

A Finnish publication, ENERGY in Finland 1993, reported that the Baltic countries face serious problems related to their energy costs, which often consume 50% of an individual's income. However, all three countries have abundant peat and forestry products that could be harvested to help reduce their nations' reliance on imported oil and gas. Peat reserves were estimated at 1 million ha (2.4 million acres) in Estonia, 415,000 ha (1 million acres) in Lithuania, and 120,000 ha (300,000 acres) in Latvia.

Peat traditionally has been harvested in all three countries but has dropped off in the past few years. However, potential certainly exists for fuel peat production. History records Lithuania harvested about 2 million tons of agricultural peat from 25,000 ha (62,000 acres) at peak production and both Estonia and Latvia produced 1.5 million tons, each from 18,000 ha (45,000 acres). It was noted that 2 million tons of fuel peat represents an energy production potential of 4 million megawatt hours, roughly equal to 400,000 tons of heavy fuel oil.[17]

Estonian officials reported that in 1992, a total of 6.1 million m^3 of peat was produced, of which 4.0 million m^3 (66%) was horticultural peat and 2.1 million m^3 (34%) was peat fuel. Estonia exported 111,000 tons of peat, representing a volume of about 555,000 m^3. Peat was harvested from an area of 14,000 ha (35,000 acres). Estonian peat resources were reported to cover about 1 million ha (2.5 million acres).[18]

In Ukraine, annual agricultural peat use dropped sharply between 1991 and 1992, from 18 million tons to slightly less than 5 million tons per year. Fuel use has remained level at about 2 million tons of dried peat, about 50% of which was used to produce briquettes in about 20 factories.

In Belarus, fuel peat production was reported to be about 2 million tons, almost all in the form of briquettes. Lithuania has only three small briquette plants with a total annual capacity of 20,000 tons.[19]

Ireland.—For 1993, Irish peat production for fuel use was estimated to have increased 5% to 6.5 million tons. Peat used in agricultural uses remained about 300,000 tons. Ireland has a long tradition of using peat as an energy source and has been the largest producer of fuel peat in the world.

Bord na Móna, established by the Turf Development Act of 1946 to develop Ireland's peat resources, sells milled peat to the Electricity Supply Board for use in domestic peat-burning power stations, briquettes and machine turf on the domestic fuel market, moss peat and other growing media in the garden and horticultural industries on a worldwide basis, and manufactures pollution abatement products.

A reorganization in 1988 established four core business divisions. The largest of the new divisions is the Peat Energy Division, which is responsible for milled peat operations, with sales accounting for about one-half the group's turnover. Milled peat productivity has been doubled and unit costs dramatically reduced. The Division's principal objective was to continue to improve the comparative economics of milled peat relative to oil, gas, and coal. Gains in productivity have reached a point where milled peat costs are becoming more competitive in terms of world energy prices. The Division decided to conduct a prefeasibility study for a new 125-megawatt peat-fired power station that could take advantage of recent advances in technology.

The Solid Fuels Division is responsible for the production and sales of "briquettes and machine turf." The outlook for solid fuels has been clouded by a swing in demand to natural gas by industrial users of solid fuels as an inevitable consequence of the extension of the national gas grid and a significant rise in privately produced turf in the Midlands region, a traditionally strong market area for briquettes. Production of private turf—promoted by the Turf Development Act of 1981—rose to 1.5 million tons in 1990, representing a fourfold increase over that of the last decade.

The Horticultural Products Division is a major exporter with more than 90% of production being sold abroad, mainly to markets in the European Union. A minority holding in a Dutch cooperative was established in 1990 to enhance the Division's presence in what is regarded as Europe's leading market in horticultural products. Effective January 1990, the Division established its own distribution subsidiary, Du Móna France S.A., with offices in Lyon. This strategy, together with the previous acquisition of the French horticultural peat subsidiary, Pouget Solami, should further enhance the Division's competitive advantage in the French peat market.

The United Kingdom is the largest market for the Division's exports, and much effort was spent in restructuring marketing strategy to deal with declining disposable income in the United Kingdom and an increasing awareness of environmental considerations on the part of consumers. Shamrock Horticulture, a wholly owned subsidiary, was processing peat at a new plant in Liverpool. A new composting plant was successfully commissioned at Liverpool during the year in response to a growing trend in consumer preference for blended products (fertilizer and other).

Bord na Móna reiterated its opposition to the unacceptable practice of exploiting boglands of special scientific interest and continued to transfer environmentally sensitive boglands to the Wildlife Service. Ultimately, 3,400 ha (8400 acres) of boglands will be protected in accordance with Government policy.

Netherlands.—In the 11th and 12th centuries fuel peat cutting in the bogs was practiced throughout the country, and by the 15th and 16th centuries peat production also was active in the lowmoor deposits. The landscape was changed radically and land reclamation commenced, but extensive lakes also were formed that today contribute to the beauty of the surrounding countryside. After World War II, demand for fuel peat had been reduced to the small-scale production of activated carbon.

Sphagnum peat moss began to be harvested by 1880, and many mills were founded in the east of the country and in the neighboring German peat-areas, where Dutch producers bought bogs. The peat moss industry flourished until the end of World War I, when there were large-scale exports of sphagnum peat moss litter to Belgium, England, France, and many other countries.

Peat production in the Netherlands today is essentially nonexistent. There are still a few state-owned bogs reserved for conservation and a few thousand ha of boglands is managed by environmentalists. Demand continues to grow, however, and in addition to traditional black peat imported from Germany, supplies continue to increase from Scandinavian countries, the Baltic States, Ireland, and Russia. Canada also may become a future supply source.[20]

Sweden.—In 1993, Sweden was producing about 1 million m^3 meters of horticultural peat and about 3 million m^3 of fuel-grade peat, annually. Swedish peatlands were reported to cover an area of about 6.3 million ha (15.6 million acres), or about 15% of the total land area. About 865,000 ha (2.1 million acres) of peatland was available for fuel peat production. The overall area suitable for horticultural peat production has not been surveyed yet.

Sweden currently has about 50 producers of horticultural peat, mainly in the south and middle regions. Roughly 400,000 m^3 is produced as milled peat and 600,000 m^3 as sod peat, of which 30% to 35% is exported. More than one-half of the domestic consumption is used by amateurs for home and garden applications.[21]

After reaching maximum production and sales of about 2.5 million m^3 in 1950, fuel peat declined dramatically because of its economic disadvantages to cheaply priced fuel oil. By 1970, fuel peat production in Sweden was nonexistent. There was a subsequent revival in fuel peat demand beginning in the early 1980's, however, as an aftershock of the global energy crises of the 1970's.

Unfortunately, the Government's philosophy regarding Swedish fuel peat and peatland research has changed during the past 3 years. Environmental and ecological concerns apparently have dampened further progress in fuel peat output. So far, fuel peat has been taxed based on sulfur dioxide and nitrogen oxide emissions. The Swedish Peat Producers Association's recent promotional activities again have generated moderate optimism by Government agencies.

United Kingdom.—A private consortium of peatland conservationists, called the Commission of Inquiry Into Peat and Peatlands, held three public hearings between September 29, 1991, and November 27, 1991—two at the Natural History Museum, London and another in the Council Chamber, Strathclyde Regional Council in Glasgow, Scotland. The Commission was concerned primarily with the conservation of lowland raised bogs, because this was identified as the most immediately and seriously threatened of peatland types in the United Kingdom. The Commission also expressed concern for the conservation of blanket bogs, fens, and other British peatlands, but considered this issue to merit separate consideration.

The Commission reached several important conclusions and recommendations. Current data suggested that there was 1.4 million ha (3.5 million acres) of "blanket boglands" in England, Scotland, and Wales; 10,000 ha (25,000 acres) of "intermediate bog," and 67,000 ha (165,000 acres) of "lowland raised bog." The best available scientific evidence suggested that the maximum area of natural, undamaged raised bog remaining in Great Britian was less than 6,200 ha (15,000 acres), 10,000 ha (25,000 acres) in the United Kingdom; the predominate reduction resulted from forestation and conversion of peatlands to agricultural use.

It was recommended that Country Conservation Councils: English Nature, the Countryside Council for Wales, Scottish Natural Heritage, and the Department of the Environment (Northern Ireland) should adopt a rigorous policy to protect raised bogs and rehabilitate damaged bogs where necessary. The Commission also stressed the use of alternative natural organic composts.[22]

Current Research

Peat research and development continued during 1993, as several projects were reaching commercial fruition. Commercial ventures were established to produce and market peat-based oil sorbent products in significant quantities in the United States. Consumers of the peat-based products liked the superior absorbency and environmentally friendly aspects of disposal relative to clay-based products. Peat also was shown to be an effective filtration source for the removal of toxic wastes from secondary sewage effluents, urban stormwater management control, for the elimination of offensive odors, and as a superior bulking agent in the composting of natural organic waste products.

The Louisa County (VA) Housing Foundation issued a news release announcing the dedication of the Laurel Hill Project. The dedication, on November 15, 1993, was for a $100,000 neighborhood improvement project funded by Federal, State, and local governments as well as private donations. What makes this project unique is that for the first time in the United States, a septic system using biological filter will be used to treat wastewater from five homes. This system, which uses peat imported from Ireland, is being constructed by the Louisa County Housing Foundation under permit from the State water control board.

The peat system represents a major breakthrough in wastewater treatment. It is a low cost, effective, and environmentally safe solution to providing wastewater treatment in areas where the land will not support conventional septic drainfields and commercial systems are too expensive.

The Natural Resources Research Institute (NRRI), University of Minnesota at Duluth, continued to provide technical assistance to Mat Inc., a Floodwood, MN, peat firm that produced peat sorbents for D M S & D Associates, Inc. of Ocean, NJ, and Fisher Steven Inc. NRRI researchers reported that additional sorbent products were in the development stage, including peat-based socks, booms, and wood fiber pads. Mat, Inc. was already receiving orders for the new products although NRRI had just begun to identify tooling requirements for production.

According to a recent NRRI study, sorbents manufactured from the higher density, more decomposed Minnesota peats carry an optimal unit value that gives Minnesota product more than a twofold competitive transportation cost advantage over Canadian sorbents. NRRI researchers also reported that properly dried and processed Minnesota sphagnum peat performs as well or better than Canadian peat and surpasses clay, paper, sawdust, and corn. All peats tested were reported to exceed clay-type sorbents.[23]

During 1992, a 2-year commercial-scale turkey litter waste management project was initiated between NRRI, the Agriculture Utilization Research Institute (AURI), and Langmo Farms of Litchfield, MN, in association with Minnesota Technology, Inc. and Howe Chemical.

Traditionally, farmers have tilled turkey droppings into wood shavings litter that remain in the barn with the birds throughout the year. Heavy applications of turkey manure to agricultural lands can lead to an excessive buildup of fertilizer nutrients that may lead to serious water quality problems.

A novel feature of the landmark research was to incorporate turkey-friendly and environmentally sound sphagnum peat, oat, and sunflower hulls, with the traditional wood shavings litter. Peat is used in the litter to maintain low ammonia and odor levels and to control microorganisms that can cause disease in the birds. Additionally, sphagnum peat is low in dust—beneficial to the birds' health—and provides a low pH and high nitrogen content; ideal conditions for producing high-quality compost for horticultural applications. Howe Chemical planned to collect 1,000 tons of composted turkey litter produced during the project to manufacture and test market an organic-based, premium-grade lawn and garden fertilizer and a low-grade organic agricultural fertilizer.[24]

Michigan Peat Co. of Houston, TX, developed a unique compacted peat that served as a natural potting soil additive, providing improved aeration and drainage. Michigan peat representatives said that its particle size could be tailored to individual needs, while maintaining integrity and resistance to breakdown during watering cycles.

D M S & D Associates, Inc., Ocean, NJ, developed and test marketed a unique hydrophobic sphagnum peat moss product having superior hydrocarbon sorption properties. The firm reported that 1 pound of the product would effectively sorb 1 gallon of oil typically weighing about 8.2 pounds. D M S & D personnel said that the new product represented an advanced concept in spill cleanup.

The new peat product was reported to be cost efficient and safe to use compared with traditional products. Savings per gallon for the cleanup and disposal of a 1-gallon spill were favorable to traditional clay products, corn-based materials, and paper absorbents, in respective order of importance. In addition to its unique hydrocarbon sorbent properties, the product has disposal advantages. It is biodegradable, fuel blendable, EPA qualified as an alternative fuel with a low ash content, and is vapor suppressive. Thus, the product is environmentally friendly, helping to minimize waste going into diminishing landfills. Its native population of microorganisms assist in bioremediation, and it can be recycled as an alternative fuel. When used on water, it locks in the hydrocarbons, protecting wildlife and reducing environmental impact.

State transportation agencies in the northeastern United States, where clay sorbents have been banned, found that peat sorbents represent an environmentally friendly and economically viable clay substitute. In one northeastern State where clay has been banned since 1990, it was found that the use of peat sorbents was advantageous to employee health, represented indirect cost savings via disposal and less bulk, avoided landfills, and could be consumed in industrial fuel applications.

Research continued into "beads" made of peat moss and a common polymer. Researchers at the USBM Salt Lake City Research Center developed the beads to be used to clean rivers, streams, or other contaminated waters. These beads were effective in extracting toxic metal ions from a variety of wastewaters. USBM researchers developed porous polymeric beads that were prepared by blending sphagnum peat moss or algae into a polymer solution and spraying the mixture into water.

Batch and continuous tests demonstrated that the beads removed arsenic, cadmium, lead, and other toxic metals from acid mine drainage waters collected from several sites. Selectivity for heavy and toxic metal ions over calcium and magnesium was demonstrated. The sorption process was reversible, and metal ions were eluted from the beads using dilute mineral acids. Cyclic tests indicated that the beads continued to extract metal ions after repeated loading-elution cycles.[25]

STS consultants, Ltd., Minneapolis, MN, continued to develop a unique peat/wetlands treatment approach to acidic mine drainage abatement. The firm reported that peat wetlands demonstration plots constructed and operated over 2 years had effectively removed 80% to 95% of copper and nickel emanating from acid mine drainage streams. STS was constructing the first commercial peat wetlands system in Minnesota. The system will be designed to treat a flow of approximately 40,000 liters per day, constructed for subsurface flow utilizing 0.3 meters of limestone as a substrate, covered by about 1 meter of fibrous screenings and peat mixture.[26]

The Department of Environmental Programs of the Metropolitan Washington (D.C.) Council of Governments (MWCOG) was preparing study areas to determine if using peat-sand filter (PSF) systems to process stormwater would reduce waste entering regional bodies of water. Two study areas were chosen: the River Terrace PSF Project situated on a 63-ha (155-acre) drainage area in the District of Columbia and the East Springbrook Study Area (in the Paint Branch Watershed) in Montgomery County, MD. These PSF were chosen because it was not possible to use traditional urban Best Management Practices in these areas. After an extensive literature search, the staff of the MWCOG determined that the PSF system might offer a partial solution to the acute need for end-of-pipe water quality control.[27]

MULTITEK of Prentice, WI, introduced a modular system designed to separate and pulverize peat and other natural materials to desirable marketable consistency at rates up to 150 tons per hour. The unique tumbler screen rotates the material while 32 hammers pulverize to produce unequalled productivity. The system is totally portable and is hydraulically powered, permitting variable adjustment to peak performance speeds. This machine was reported to outperform a typical vibrator screen system. A portable unit was available that could be towed at highway speeds with a 1-ton truck. In addition to peat, the system can handle top soil, sand and gravel, compost, grade rock, composted manure, clays, woodchips, bark, coal, and composted sewage sludge.

Enviro Industrial Technology Corp. (E.I.T.C.) of Alberta, Canada, developed a novel line of peat harvesting and wetlands transport equipment. The products currently developed include a Field Profiler, Root Picker, Spoon and Rotary Harrow, Chain Miller, Ditcher, Vacuum Harvester, and Transport Wagons. E.I.T.C.'s equipment was designed to meet the rigorous durability demands associated with high production rates and low maintenance costs expected by the North American peat industry.

SaskPower and a Meadow Lake company in Saskatchewan planned to build a $22 million peat-burning powerplant at Jans Bay, north of Meadow Lake. It would reportedly generate 15 megawatts, enough to heat a community of 3,000 homes.

Peat Resources was planning a $4.5 million pilot plant to produce fuel-grade peat at a prime peatland 56 kilometers northwest of Thunder Bay, Ontario, Canada. Data collected from the pilot plant operation would be used for the potential design of a $95 million commercial plant capable of producing 1 million tons per year of peat fuel. The fuel would reportedly be used as an environmentally attractive alternative energy replacement for coal in electrical power generation plants.

The pilot plant would test a process for producing high-grade industrial peat fuel with a heating value comparable to bituminous coal. In a recent test burn completed by Ontario Hydro, the experimental peat fuel produced less than 5% ash, and a mixture of coal and peat fuel reduced sulfur emissions in direct proportion to the quantity of peat blended. Peat Resources, which had been developing the peat fuel process since 1984, applied for a Canadian patent.[28]

Peat also showed promise as a biodegradable medium in disposable diapers and in food packaging.

OUTLOOK

During the past 20 years, U.S. domestic peat production has grown at an average annual rate of about 2% per year and apparent domestic consumption by about 3.5%. The most recent upturn in the U.S. peat supply-demand cycle was experienced between 1981 and 1987. Domestic peat production hit the bottom of the latest cycle in 1981 at 0.7 million tons and gradually increased to a record 1 million tons by 1987, representing an average annual growth of about 7%. Total apparent domestic consumption during the same period followed the domestic production trend and grew at an average annual rate of 7%, from 1.1 million tons in 1981 to a record 1.5 million tons in 1987.

Between 1987 and 1993, domestic peat production and total apparent domestic consumption have declined 7% and 2%, respectively, owing to a downturn in the U.S. economy. Canadian imports as a percentage of the total U.S. supply, however, increased from 35% in 1987 to a record 51% in 1993.

The USBM forecast for horticultural peat during the next 5 years is based on a gradual recovery in the economy and a resultant rebound in domestic production and total apparent domestic consumption. Domestic production of horticultural peat is forecast to grow at an average annual rate of about 2% to levels approaching 0.8 million tons by 1998.

Total apparent domestic consumption for horticultural purposes is forecast to grow at an average annual rate of about 4% per year to about 1.6 million tons by 1998. Canadian imports are forecast to rise from a current 50% of the U.S. supply to about 55% by 1998. Per capita consumption is forecast to approximate 5.6 kilograms (12.5 pounds) by 1998 and approach the 5.7-kilogram (12.7-pound) average experienced during the peak years of 1986 and 1987.

The USBM's forecast for domestic peat production and demand could be optimistic in the event that Canadian competition becomes more intense, environmental regulations inhibit growth, composting captures an increasing market share, or a continued downturn in the economy persists. However, new uses for peat as a filtration medium for the cleanup of waste streams, oil absorption, composting natural organics, and for hygienic and other purposes could potentially drive U.S. peat demand to levels higher than forecast, regardless of the supply source, domestic or Canadian.

The outlook for future growth in domestic fuel peat demand for electric power generation has been deferred beyond the forecast period because of the loss of four 80-megawatt power contracts in Florida to the competitive economics of natural gas. Natural gas is currently in oversupply, and gas prices have declined significantly in recent years. Additionally, the capital costs associated with the construction of natural gas power plants are favorable to peat-based plants.

Florida Power and Light and Florida Power Corp. had previously signed letters of intent with EcoPeat—a U.S. subsidiary of the Finnish firm, Outokumpu—to purchase peat-fueled electrical power from proposed plants adjacent to vast peat reserves to the northwest and southeast of Lake Okeechobee in south Florida.[29] The plants were to be brought into production sequentially beginning in mid-1995 and at full capacity would have required about 2.5 million tons of peat annually, representing a threefold increase in current U.S. peat production.[30]

The global outlook for peat supply-demand is shown in table 10. This year's outlook, long-range, continued to be clouded by the downward trend in former U.S.S.R. production. If the projected downturn only impacts the former U.S.S.R.'s internal supply-demand situation, then the world outside the former U.S.S.R. should still anticipate reasonably balanced conditions during the next 5 years. If the former U.S.S.R. becomes pressured to move surplus product to the international marketplace, however, a global imbalance in peat supply-demand could be precipitated for an indefinite period. *(See table 10.)*

The USBM basic forecast methodology continues to include the assumption that peat production in the former U.S.S.R. will not return to 1990 levels in the foreseeable future. Otherwise, traditional methodology gauging global demand on the historic trend in per capita consumption has not changed. The long-term trend based on the current forecast shows that, between 1994 and 1998, global peat demand is projected to grow at an average 1% per year, about one-half of the projected 2% growth in population. This forecast is consistent with historic trends.

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TABLE 1
SALIENT PEAT STATISTICS

		1989	1990	1991	1992	1993
United States:						
Number of active operations		80	82	76	71	67
Production	thousand metric tons	690	692	632	599	616
Sales by producers[1]	do.	703	721	703	652	612
Bulk	do.	348	360	348	288	343
Package	do.	355	361	355	365	268
Value of sales	thousands	$17,703	$19,200	$17,773	$16,747	$16,841
Average per metric ton		$25.18	$26.63	$25.29	$25.68	$27.54
Average per metric ton, bulk		$20.92	$19.58	$20.22	$19.31	$19.62
Average per metric ton, package or baled		$29.35	$33.65	$30.26	$30.71	$37.67
Exports	thousand metric tons	30	12	13	22	8
Imports for consumption	do.	481	543	573	639	648
Consumption, apparent[2]	do.	1,182	1,232	1,251	1,226	1,291
Stocks, December 31: Producers'	do.	365	357	298	308	269
World: Production	do.	[r]197,115	[r]179,942	[r]164,742	[r]153,798	[e]140,288

[e] Estimated. [r] Revised.

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

[2] Apparent consumption equals U.S. primary production plus imports minus exports plus adjustments for industry stock changes.

TABLE 2
RELATIVE SIZE OF PEAT OPERATIONS IN THE UNITED STATES

Size in metric tons per year		Active operations		Production (thousand metric tons)	
		1992	1993	1992	1993
23,000 and over		7	8	295	363
14,000 to 22,999		9	6	153	92
9,000 to 13,999		6	5	61	57
5,000 to 8,999		8	8	54	53
2,000 to 4,999		8	13	19	38
1,000 to 1,999		9	6	10	7
Under 1,000		24	21	7	7
Total		71	67	599	[1]616
Total	short tons	XX	XX	660	679

XX Not applicable.

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

TABLE 3
U.S. PEAT PRODUCTION AND SALES BY PRODUCERS IN 1993, BY STATE

State	Active operations	Production	Sales		
		Quantity (thousand metric tons)	Quantity (thousand metric tons)	Value[1] (thousands)	Percent packaged
Colorado	3	W	W	$220	89
Florida	9	221	219	3,781	15
Illinois	4	W	W	W	99
Indiana	4	24	24	W	58
Iowa	1	W	W	W	71
Maine	1	W	W	W	—
Massachusetts	1	W	W	W	100
Michigan	10	189	186	6,114	80
Minnesota	9	30	33	1,931	39
Montana	2	W	W	W	5
New Jersey	2	W	W	W	81
New York	1	W	W	W	—
North Carolina	1	W	W	162	—
North Dakota	1	1	(2)	W	100
Ohio	3	W	W	W	—
Pennsylvania	7	9	9	249	11
South Carolina	1	W	W	W	85
Washington	3	W	W	W	—
West Virginia	1	W	W	W	—
Wisconsin	3	W	W	W	10
Total or average	67	616	612	16,841	44
Total short tons	XX	679	674	XX	XX

W Withheld to avoid disclosing company proprietary data; included in "Total or average." XX Not applicable.

[1] Values are f.o.b. producing plant.

[2] Less than 1/2 unit.

TABLE 4
U.S. PEAT SALES BY PRODUCERS IN 1993, BY TYPE AND USE

Use	Sphagnum moss			Hypnum moss			Reed-sedge		
	Quantity		Value (thousands)	Quantity		Value (thousands)	Quantity		Value (thousands)
	Weight (metric tons)	Volume[1] (cubic yards)		Weight (metric tons)	Volume (cubic yards)		Weight (metric tons)	Volume (cubic yards)	
Earthworm culture medium	45	80	$1	24	89	$3	771	1,500	$12
General soil improvement	30,710	133,477	2,391	6,831	19,034	487	248,353	577,952	6,485
Golf courses	1,191	7,500	154	6,984	21,485	191	2,683	5,564	58
Ingredient for potting soils	255	1,249	19	5,328	10,124	67	118,768	262,797	2,051
Mixed fertilizers	—	—	—	—	—	—	14,969	84,545	855
Mushroom beds	255	1,249	19	—	—	—	—	—	—
Nurseries	10,287	52,736	639	2,440	8,600	77	14,363	33,044	324
Packing flowers, plants shrubs, etc.	241	1,219	43	2,268	5,000	27	—	—	—
Vegetable growing	—	—	—	925	1,709	11	2,223	4,500	38
Other	38,270	185,828	476	—	—	—	—	—	—
Total[2]	81,254	383,338	3,741	24,801	66,041	862	402,129	969,902	10,182
Total short tons	89,567	XX	XX	27,338	XX	XX	443,271	XX	XX

Use	Humus			Other			Total[2]		
	Quantity		Value (thousands)	Quantity		Value (thousands)	Quantity		Value (thousands)
	Weight (metric tons)	Volume (cubic yards)		Weight (metric tons)	Volume (cubic yards)		Weight (metric tons)	Volume (cubic yards)	
Earthworn culture medium	1,045	2,230	$20	—	—	—	1,886	3,899	$35
General soil improvement	19,311	37,665	316	—	—	—	305,205	768,128	10,039
Golf courses	4,591	8,721	182	—	—	—	15,448	43,270	585
Ingredient for potting soils	57,047	115,006	968	—	—	—	181,398	389,176	3,104
Mixed fertilizers	257	515	7	—	—	—	15,225	85,060	862
Mushroom beds	—	—	—	—	—	—	255	1,249	19
Nurseries	11,597	21,801	212	—	—	—	38,687	116,181	1,251
Packing flowers, plants shrubs, etc.	726	1,500	10	—	—	—	3,235	7,719	80
Vegatable growing	1,009	2,022	24	—	—	—	4,157	8,231	74
Other	6,210	11,809	269	1,695	3,735	$47	46,174	201,372	793
Total[2]	101,793	201,269	2,008	1,695	3,735	47	611,670	1,624,285	16,841
Total short tons	112,207	XX	XX	1,868	XX	XX	674,251	XX	XX

XX Not applicable.

[1] Volume of nearly all sphagnum moss was measured after compaction and packaging.

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

TABLE 5
AVERAGE DENSITY OF DOMESTIC PEAT SOLD IN 1993

(Pounds per cubic yard)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other
Bulk	484	821	1,001	1,120	1,000
Package	440	841	855	1,056	—
Bulk and package	467	828	914	1,115	1,000

TABLE 6

U.S. PEAT PRODUCTION AND PRODUCERS' YEAREND STOCKS IN 1993, BY KIND

Kind	Active operations	Production (mertic tons)	Percent of production	Yearend stocks (metric tons)
Sphagnum moss	15	40,899	6.6	24,622
Hypnum moss	10	36,461	5.9	5,318
Reed-sedge	30	379,241	61.5	212,641
Humus	20	120,951	19.6	26,370
Other	3	38,662	6.4	—
Total	[1]67	616,214	100.0	268,951
Total short tons	XX	679,259	XX	296,468

XX Not applicable.

[1] Data do not add to totals shown because some plants produce multiple kinds of peat.

TABLE 7

PRICES[1] FOR PEAT IN 1993

(Dollars per unit)

	Sphagnum moss	Hypnum moss	Reed-sedge	Humus	Other	Average
Domestic:						
Bulk:						
Per metric ton	19.09	21.83	20.26	18.15	27.86	19.62
Per cubic yard	4.19	8.13	9.20	9.22	12.64	7.79
Packaged or baled:						
Per metric ton	93.55	60.89	29.37	40.90	—	37.67
Per cubic yard	18.69	23.24	11.59	19.59	—	13.30
Average:						
Per metric ton	46.04	34.77	25.32	19.73	27.86	27.54
Per cubic yard	9.76	13.06	10.50	9.98	11.75	10.37
Imported, total, per metric ton[2]	165.62	XX	XX	XX	XX	165.62

XX Not applicable.

[1] Prices are f.o.b. plant.

[2] Average customs value.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF PEAT MOSS,[1] BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Canada	637,052	$110,588	644,696	$117,753
Ireland	927	63	875	127
Other[3]	692	98	2,350	406
Total[4]	638,671	110,749	647,921	118,286
Total short tons	704,013	XX	714,210	XX

XX Not applicable.

[1] Poultry and fertilizer grade.

[2] Customs value.

[3] Includes Australia, Cameroon, Finland, France, Germany, Hong Kong, Japan, the Netherlands, Sweden, Switzerland, the former U.S.S.R., and Vatican City.

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

Source: Bureau of the Census.

TABLE 9
PEAT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Argentina: Agricultural use	2	[r]4	[r]4	[r]2	3
Australia[e] [3]	11	11	11	11	11
Belarus:[e] [4]					
Agricultural use	—	—	—	10,000	10,000
Fuel use	—	—	—	3,000	3,000
Burundi	14	12	10	[r]12	10
Canada: Agricultural use	[r]797	[r]716	[r]856	[r]740	830
Denmark: Agricultural use (sales)	259	225	[e]200	195	190
Estonia:[e] [4]					
Agricultural use	—	—	—	5,000	4,500
Fuel use	—	—	—	600	600
Finland:					
Agricultural use	451	[e]330	220	355	[5]252
Fuel use	4,590	[e]4,500	2,308	5,103	[5]3,035
France: Agricultural use[e]	200	200	200	200	200
Germany: Western states:[6]					
Agricultural use	2,836	[r]2,982	[r]2,876	[r]2,718	2,500
Fuel use	232	238	[e]225	[r]188	175
Hungary: Agricultural use[e]	70	65	65	65	65
Ireland:					
Agricultural use	265	229	249	[e]300	300
Fuel use	7,763	6,430	4,767	[r]6,200	6,500
Latvia:[e] [4]					
Agricultural use	—	—	—	5,000	4,500
Fuel use	—	—	—	300	300

See footnotes at end of table.

TABLE 9—Continued

PEAT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Lithuania:[e] [4]					
Agricultural use	—	—	—	5,000	4,500
Fuel use	—	—	—	100	100
Netherlands[e]	300	300	300	300	300
Norway:[e]					
Agricultural use	30	30	30	30	30
Fuel use	1	1	1	1	1
Poland: Fuel and agricultural use[e]	[r]50	[r]50	[r]50	[r]50	50
Russia:[e] [4]					
Agricultural use	—	—	—	80,000	70,000
Fuel use	—	—	—	5,000	5,000
Spain[e]	75	[r]77	[r]75	70	70
Sweden:					
Agricultural use	227	250	263	[e]260	250
Fuel use[e]	[6]1,450	1,400	1,400	1,400	1,400
Ukraine:[e] [4]					
Agricultural use	—	—	—	20,000	20,000
Fuel use	—	—	—	1,000	1,000
U.S.S.R.:[7]					
Agricultural use[e]	160,000	150,000	140,000	—	—
Fuel use	16,800	11,200	10,000	—	—
United States:					
Agricultural use	690	692	632	599	[5]616
Fuel use	—	W	W	W	W
Total in thousand metric tons[8]	[r]197,115	[r]179,942	[r]164,742	[r]153,798	140,288
Total in thousand short tons	[r]217,282	[r]198,352	[r]181,597	[r]169,534	154,640
Fuel peat included in total in thousand metric tons	[r]30,886	[r]23,819	[r]18,751	[r]22,942	21,161
Fuel peat included in total in thousand short tons	[r]34,046	[r]26,256	[r]20,669	[r]25,289	23,326

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

[1] Table includes data available through July 7, 1994.

[2] In addition to the countries listed, Austria, Iceland, and Italy produce negligible amounts of fuel peat. The Eastern states of Germany and Venezuela are major producers, but output is not officially reported, and available information is inadequate to make reliable estimates of output levels.

[3] Excludes data from some States.

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

[5] Reported figure.

[6] Production in eastern states has historically been confidential; no basis exists for reliable estimation.

[7] Dissolved in Dec. 1991.

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

TABLE 10
WORLD PEAT SUPPLY-DEMAND RELATIONSHIPS[1]

(Million metric tons)

	1988	1989	1990	1991	1992	1993[e]	1994[2]	1995[2]	1996[2]	1997[2]	1998[2]
Capacity[3]	198.5	198.5	199.3	199.4	199.6	200.0	200.3	200.5	200.9	201.4	201.5
Demand:											
Agricultural	169.0	[r]166.2	[r]156.0	[r]145.9	[r]130.9	119.1	119.5	119.9	120.5	120.9	121.6
Fuel	26.8	[r]30.9	23.9	[r]18.8	[r]22.9	21.2	23.4	23.6	23.6	23.8	23.8
Total	195.8	[r]197.1	[r]179.9	[r]164.7	[r]153.8	140.3	142.9	143.5	144.1	144.7	145.4
Operating rate, percent[4]	90	99	90	83	77	70	71	72	72	72	72
Consumption kilograms per capita[5]	38.4	37.9	33.9	30.5	28.0	25.1	25.1	24.7	24.4	24.5	23.8
Population, billion[6]	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1

[e] Estimated. [r] Revised.

[1] Calender years.

[2] Forecast.

[3] Effective production capability.

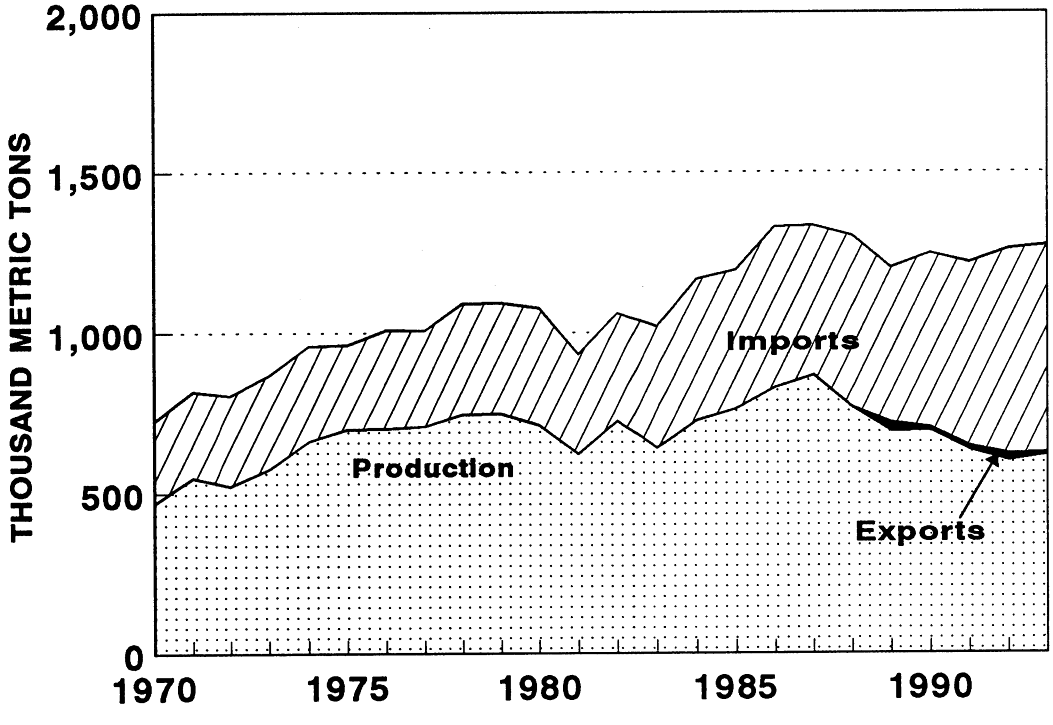
[4] Total demand as a percent of capacity.

[5] Peat demand expressed in pounds per person.

[6] Statistical Abstract of the United States, 1992; Bureau of the Census.

Source: Division of Mineral Commodities, Branch of Industrial Minerals, U.S. Bureau of Mines.

FIGURE 1
PRODUCTION AND IMPORTS OF PEAT IN THE UNITED STATES



PHOSPHATE ROCK

By Thomas O. Llewellyn

Mr. Llewellyn, a physical scientist with more than 30 years of industry and U.S. Bureau of Mines experience, has been a commodity specialist since 1987. Domestic survey data were prepared by Christopher Lindsay, statistical assistant; and the international data table was prepared by Jeremy Tidwell, international data coordinator.

Phosphate rock, the only significant commercial source of the element phosphorus, is vital to the agricultural sector worldwide. Phosphorus is a basic element that is essential to life. Phosphorus is not usually very abundant in soils because it is removed by crop and natural losses. To maintain high crop yields, fertilizers containing the major plant nutrients phosphorus, nitrogen, and potassium must be applied to the soil. The world requires that agriculture be highly productive to feed its expanding population. In the United States, nearly 90% of the phosphate rock consumed is for the production of fertilizers with the remainder consumed in a variety of phosphate chemicals used by industry and the general public.

U.S. production of phosphate rock dramatically decreased in 1993 compared with that of 1992 as sales of phosphate fertilizer products declined. The phosphate industry, faced with lower demand and prices for fertilizer products, was forced to idle and/or close some mines and fertilizer plants in an effort to control production to ensure competitive selling prices. Domestic and world production of phosphate rock decreased 24% and 10%, respectively, compared with output in 1992. Preliminary estimates showed that world phosphate rock trade decreased again in 1993 by about 7%, reaching only 27 million metric tons, from the almost 29 million tons traded in 1992; U.S. phosphate rock exports decreased from 3.7 million tons to 3.2 million tons primarily because of reduced consumption in Western Europe and the loss of exports to India.

The historical breakup of the former U.S.S.R. and the significant changes in the socioeconomic structures of countries in Eastern Europe is expected to continue affecting the demand for phosphate fertilizers in that region and across the world markets for the near future. Producers of phosphate products from the former U.S.S.R. and the Eastern Europe countries have been dumping phosphate fertilizer inventories on the world market to obtain needed hard currency.

The year 1993 produced significant changes in international trade. The North American Free Trade Agreement (NAFTA) was approved by the Governments of Canada, Mexico, and the United States. After 7 years, the Uruguay Round of multilateral trade negotiations were closer to reality. The United States intended to enter into the trade agreements by April 15, 1994. These agreements will not have domestic legal force until the U.S. Congress has approved them. *(See table 1.)*

DOMESTIC DATA COVERAGE

Domestic production data for phosphate rock were developed by the U.S. Bureau of Mines from two separate voluntary surveys of U.S. operations. Of the 14 operations to which a survey request was sent, all responded, representing 100% of the U.S. production data shown in table 1.

BACKGROUND

Phosphate rock deposits occur as marine phosphorites, apatite-rich igneous rock, and guano. Guano deposits are a result of animal waste accumulation, mainly sea birds. Current world phosphate production from guano deposits is insignificant. *(See table 20.)* All U.S. production was from marine phosphorites. The U.S. industry reports production in terms of a beneficiated phosphate rock concentrate and reserves in terms of an economically recoverable phosphate rock concentrate product. The grade of phosphate rock may be reported as percent of phosphorus pentoxide (P_2O_5) or as tricalcium phosphate, $Ca_3(PO_4)_2$, which also is referred to as percent bone phosphate of lime (BPL). Conversion factors are: $P_2O_5 = \%BPL \times 0.4576$; $\%BPL = P_2O_5 \times 2.1853$; and $P = P_2O_5 \times 0.436$. The phosphate ore bed or the zone of phosphorus-bearing material is known as matrix in Florida and North Carolina.

Marketable phosphate rock was produced by 14 companies in the United States. Six companies in Florida and one in North Carolina produced about 85% of the phosphate rock. The balance of 15% was produced in Idaho, Montana, and Utah. Approximately 82% of the phosphate rock sold or used by U.S. producers was consumed domestically to produce fertilizers and feed supplements; about 8% was exported and 10% was used to produce a variety of industrial chemicals.

Sedimentary apatite has a range of chemical compositions. The general formula for marine carbonate-apatite is $Ca_{10}(PO_4CO_3)_6F_{2-3}$. Apatite is host to many cation, anion, and anionic radical substitutions for PO_4. Accessory elements may be associated minerals or those that are chemical substitutions in the phosphate mineral.

The part of phosphate resources that can be economically recovered is called reserves. Reserves may increase as new deposits are discovered and as technology is improved. Estimates of phosphate rock reserves are made for a specific date and are subject to changing economic or environmental conditions. Operating companies and companies holding phosphate lands estimate the recoverable tonnages based on current and future economics. Estimated reserves for Florida and North Carolina deposits are about 1 billion tons for each State.

The phosphate rock bed of the Pungo River Formation in North Carolina is a primary marine phosphate 6 to 12 meters (20 to 40 feet) thick, overlain with 27 to 40 meters (90 to 130 feet) of sand, clay, and marl overburden. The underlying aquifer was depressurized by pumping water to the surface to ensure a dry pit. Currently, bucket wheel excavators have replaced dredges to strip the top 12 meters (40 feet) of overburden. Large-capacity draglines with buckets as large as 55 cubic meters (72 cubic yards) were used to strip the remaining overburden and mine the matrix. The matrix was slurried with high-pressure waterjets, pumped to the beneficiation plant, washed, and classified to produce a minus 16-mesh, plus 200-mesh flotation feed. Flotation concentrate was either calcined or dried.

Most of the phosphate mines in central Florida recover phosphate rock from the Bone Valley Formation. Overburden averages about 6 meters (20 feet). The overburden consists of a clay sand and a leach-zone material that overlays the matrix. The materials were selectively strip-mined with large electric draglines. The matrix was slurried in a sump and pumped to the washing plant. Cleaned, screened material from the washer that was plus 14 or 16 mesh was separated and may be a salable pebble product. The minus 16-mesh fraction was deslimed at a 150-mesh, and the plus 16- minus 150-mesh fraction was floated to produce a phosphate concentrate. The minus 150-mesh fraction, called slimes, is discarded by pumping into impoundment areas. Phosphate slimes contain 6% to 17% P_2O_5, which in some cases amount to almost one-third of the phosphate content in the matrix. Over the years, many unsuccessful attempts have been made to economically recover phosphate values from the slimes. Recovery of phosphate values from this waste product would lengthen the life of domestic phosphate reserves.

Improved recovery of phosphate rock concentrate from deposits in the United States was accomplished with the introduction of the flotation process in 1927 and 1928. Values in the 14 mesh by 150 mesh became recoverable, adding to the coarser plus 14-mesh pebble fraction. Conversion of phosphate rock with controlled quantities of sulfuric acid to single superphosphate, which contains about 20% P_2O_5, was the major phosphate fertilizer through the 1950's and into the 1960's. High analysis triple superphosphate, which contains more than 40% P_2O_5, is manufactured by acidulating phosphate rock with phosphoric acid. Ammonium phosphates, which contain 46% to 54% P_2O_5, are produced by reacting phosphoric acid with anhydrous ammonia. The ammonium phosphates and triple superphosphate have become the preferred fertilizers for domestic consumption and international trade. The intermediate chemical for these preferred fertilizers, phosphoric acid, is produced by acidulating phosphate rock with sulfuric acid. Phosphoric acid itself may be used as a fertilizer and is traded internationally; importers of phosphoric acid may manufacture fertilizers from the acid or use it to produce other phosphate chemicals.

In the past few years, experimental farming has determined more efficient use of mineral-based fertilizers. Farmers have learned to follow recommended application rates, timing, and use of efficient spreaders. These advances in the use of fertilizers significantly increased crop yields and decreased fertilizer consumption per planted acre.

ANNUAL REVIEW

Legislation and Government Programs

On September 30, 1993, the U.S. Department of Commerce notified the public of its determination not to revoke the antidumping duty on industrial phosphoric acid from Belgium, as was proposed the month before. Special dumping duties were established on August 20, 1987.[1] In Florida, new phosphogypsum stacks are required to be lined to prevent ground water from becoming contaminated with heavy metals. Heavy metals such as arsenic, cadmium, chromium, and phosphorus are found in waste phosphogypsum. New stacks must be constructed using a thick plastic sheet. The cost to build a 160-hectare (400 acre) lined stack site was estimated at more than $80 million.

The U.S. Environmental Protection Agency (EPA) announced the establishment of the Dialogue Committee on Phosphoric Acid Production Wastes (DCPAPW) in November 1992. The committee included the EPA, various State agencies, industry representatives, the Fertilizer Institute, and public interest groups. As required by the Federal Advisory Committee, the DCPAPW held two meetings in Arlington, VA, one in March and the other in November 1993, to continue reviewing information regarding existing or potential risks to human health or the environment from generated phosphoric acid wastes by identifying technically and economically feasible changes to the current production process of phosphoric acid.[2] The committee plans to publish a report on its findings in 1994.

The U.S. President, by Executive Order 12850 of May 28, 1993, announced the renewal of China's most-favored-nation (MFN) trading status without conditions. Each year MFN trading status for all nations expires. Therefore, the President recommended renewal of China's MFN status for an additional 12-month period beginning July 3, 1994, but future renewal would be subjected to its progress in human rights and weapons proliferation improvements.[3] U.S. exports of phosphate fertilizers are among the Nation's principal sales to China.

The North America Free Trade Agreement (NAFTA), between Canada, Mexico, and the United States, becomes effective January 1, 1994. Under this agreement most fertilizer products tariffs were eliminated, except for the following: phosphoric acid and anhydrous ammonia were assigned a 10-year phaseout and diammonium phosphate (DAP) and ammonium sulfate were assigned a 5-year phaseout.[4] The fertilizer industry is expected to benefit directly and indirectly from this agreement. The United States has no duties or tariffs on fertilizer imports. As Mexico eliminates duties under NAFTA, the U.S. industry is expected to directly benefit from an increase on fertilizer sales and, indirectly, from a potential increase in U.S. grain export.

On December 15, 1993, the President notified the U.S. House of Representatives and the U.S. Senate of his intention to enter into the trade agreement resulting from the Uruguay Round of multilateral negotiations under the auspices of the General Agreement of Tariffs and Trade (GATT). The Administration planned to enter into the GATT by April 15, 1994. Signed agreements will be submitted for congressional approval together with legislation and administrative actions required to implement the agreements in the United States. Fertilizer products are included in a chemical harmonized tariff system adopted in the market access of the GATT agreement.[5]

Issues

Phosphate rock mining and beneficiation processes require huge volumes of water. Transporting the matrix to the beneficiation plant, desliming it, and producing a high-grade phosphate concentrate by flotation consumes large volumes of water. The matrix is slurried with high-pressure hydraulic jets and pumped via a pipeline to the beneficiation plant. During beneficiation the minus 150-mesh slimes, mainly clays, are removed from the matrix by hydrocyclones and discarded by pumping into settling areas, called slime ponds. The Florida Department of Natural Resources, Bureau of Mine Reclamation, indicated that as of December 1991 there were about 40,000 hectares of active and inactive slime settling areas. Slime pond reclamation was a long-term operation requiring about 15 years for the clays to settle from an original 5% solids content to about 20% solids. Now reclamation time, after the slime pond becomes inactive, has been reduced to about 4 years by dewatering the pond using flotation tractors to dig the drainage ditches. For the past 30 years the phosphate industry, government institutions, and private research organizations have investigated methods of dewatering slimes instantaneously using flocculants. To date, an economic process to dewater slimes has not been discovered.

In the wet phosphoric acid process, phosphate rock is digested with sulfuric acid to produce dilute phosphoric acid. The process generates a solid waste of mainly calcium sulfate, called phosphogypsum. This waste also contains quartz, phosphates, fluoride, and radioactive minerals as well as minor amounts of heavy minerals, such as cadmium and cobalt. The water-slurried phosphogypsum is pumped to impoundments where the solids settle and the water is recycled to the process. The use of phosphogypsum is restricted because its radium content emits the radioactive gas radon. The National Emissions Standards for hazardous air pollutants of the Clean Air Act Amendments of March 15, 1990, requires that phosphogypsum be disposed of in stacks or mined-out areas. It is estimated that the Florida phosphate industry generates about 30 million tons of phosphogypsum per year at the present operating rates and there are about 600 million tons of this material in the existing stacks. It is technologically feasible to remove the harmful impurities from phosphogypsum, but the purified phosphogypsum is not economically competitive with natural gypsum.

Runoff from excessive application of fertilizer can contaminate ground water and receiving waters. The concern over negative environmental impacts frequently dismisses the importance of mineral fertilizers. Without providing and replenishing soil nutrients by increased use of fertilizers, production of food to satisfy an increasing world population will not be possible. The World Bank estimates that by the year 2025 the world population will reach 8.3 billion compared with the current population of about 5.4 billion, a 54% increase in a period of only 31 years.

Production

Production of marketable phosphate rock in the United States dramatically decreased from about 47 million tons in 1992 to about 35 million tons in 1993. Some mines and fertilizer plants were either closed or temporarily idled because of a low demand for phosphate rock and phosphate fertilizer products.

Florida and North Carolina.— Phosphate rock was produced in central Florida by Cargill Fertilizer, Inc. (CFI); CF Industries, Inc.; IMC-Agrico Co.; Mobil Mining and Minerals Corp.; and U.S. Agri-Chemicals Corp., owned by Sinochem (USA) Inc.

CFI closed its North Pasture Mine in June 30, 1993. CFI was buying phosphate rock from IMC-Agrico as feedstock for its phosphoric acid production through a contract expiring by the end of 1995. CFI also hired Jacobs Engineering Group Inc. to provide all engineering services related with the expansion and relocation of its beneficiation plant from the closed North Pasture Mine to a site near the new South Pasture Mine in Hardee County, FL. Startup for both the new South Pasture Mine and the expanded beneficiation plant was scheduled for late 1995.

IMC-Agrico Co. closed its Kingsford Mine in June and the Payne Creek Mine in October 1993. Both mines are in Polk County, FL. In July, the company also was forced to make additional adjustments in production of both fertilizers and phosphate rock concentrate as a result of large inventories in relation to low demand for fertilizers. DAP production was shut down at the Taft, LA, plant and production was reduced at one of the New Wales, FL, plants. To accommodate this lower fertilizer production level, the Four Corners Mine operation in Polk County, FL, was reduced from a 7-day to a 5-day week schedule. The closures and cutbacks in phosphate rock production were generally attributed to continued low prices for chemical fertilizers in the world market. The mines were expected to remain idle until market conditions improve. However, Clear Springs Mine, closed since November 1991, was reopened in October 1993. Company officials indicated that despite the sustained decline in phosphate prices the high-grade phosphate concentrate produced from Clear Springs had higher demand.

On December 2, 1993, IMC-Agrico announced the reopening of the DAP Taft fertilizer plant before the end of the month and returned the Four Corners Mine to a 7-day, three-shifts-per-day scheduled operation by January 1994, in response to the increased demand and higher prices for fertilizer products from domestic and international consumers. According to the company, this action was taken in anticipation of an expected increase in fertilizer demand for the coming spring season and to offset their lower fertilizer stocks.

Mobil Mining and Minerals Co. of Florida was told to go ahead with its projected mine development at South Fort Meade property. Mobil Corp., the parent company, agreed to fund the project cost of $200 to $300 million. Startup production of about 3 million tons per year was scheduled for 1995.

In northern Florida, Occidental Chemical Agricultural Products Inc. (Oxy) produced phosphate rock for production of phosphoric acid, superphosphoric acid, and diammonium phosphate. Oxy operated two mines north of Lake City, FL. As a result of the prevailing economic conditions affecting the phosphate fertilizer business, the company's Swift Creek phosphate mine was temporarily closed in May and remained closed through the end of 1993. In north-central Florida, low-fluorine soft phosphate rock was recovered from hard phosphate rock tailing ponds.

Texasgulf Chemical Co. (TG), a division of Texasgulf Inc., a subsidiary of Elf Aquitaine Inc., produced phosphate rock from the Aurora Mine in eastern North Carolina. TG employed bucket wheel excavating systems to remove the top 12 meters of overburden. Draglines were used to remove the remaining overburden and mine the 10 to 12 meters of matrix.

During 1993, the phosphate industry was affected by lower demand and prices for fertilizer products, and an important way to remain in business was through consolidation or joint ventures. Thus, in May 1993, Cargill Fertilizer, Inc., a subsidiary of Cargill Inc. of Minneapolis, MN, bought the assets of Seminole Fertilizer Corp., which was formerly owned by Tosco Corp. of Stanford, CT. The transaction included Seminole's Bartow phosphate fertilizer production plant, the phosphate mine Hookers Prairie, and two ammonia-storage tanks at Port Sutton, FL. Seminole's DAP plant in Fort Meade, FL, which is jointly owned (50%) by Agri-Chemicals, was not included in the deal.

On July 1, 1993, IMC Fertilizer Inc. and Freeport-McMoRan Resources Partners L.P., two of the largest domestic phosphate producers, finalized a joint agreement that combined both companies' phosphate rock mining and phosphate fertilizer businesses, as well as their uranium extraction operations. The new company name, IMC-Agrico Co., was expected to generate an overall operational cost savings of about $95 million in 1993.

Western States.—Phosphate rock was mined in Idaho by J. R. Simplot Co., Monsanto, and Rhône-Poulenc Basic Chemicals Co. Simplot produced phosphate rock from the Gay Mine on the Fort Hall Indian Reservation; however, the Gay Mine was closed in July 1993 because of phosphate rock depletion. Mainbed ore was used by Simplot to manufacture phosphoric acid, and the lower grade shale was used in FMC Corp. electric furnaces in Pocatello, ID. Simplot also produced phosphate rock from the Smoky Canyon Mine in the Caribou National Forest. The concentrate was pumped from the mine to Simplot's fertilizer plant west of Pocatello, ID. FMC produced phosphate rock from the Dry Valley facility for its Pocatello plant; Dry Valley material replaced shale from the Gay Mine, which closed during 1993. Monsanto supplied its electric furnaces in Soda Springs, ID, with phosphate rock from its Enoch Valley Mine in the Caribou National Forest. Rhône-Poulenc produced phosphate rock from the Wooley Valley Mine, Caribou National Forest, ID, and shipped to its electric furnace plant in Silver Bow, MT. Conda Partnership produced phosphate rock from the Mountain Fuel Mine and Maybe Canyon Mine, Caribou National Forest, ID. The Mountain Fuel Mine closed at the end of December 1993. The phosphate rock was shipped by rail to Conda, ID, beneficiated, calcined, and used to produce phosphoric acid. In March 1993, Cominco American closed its Warm Springs Mine near Garrison, MT. This was the only operating underground phosphate rock mine in the United States. The Cominco announcement stated that with scaled down production at its smelter complex at Trail, British Columbia, Canada, owing to environmental problems, the need for phosphate rock from the Warm Springs Mine was substantially reduced. SF Phosphates Ltd., formed in April 1992 by Simplot and Farmland Industries, produced phosphate rock from a mine near Vernal, UT. *(See tables 2 and 3.)*

Consumption and Uses

The demand pattern for phosphate rock was similar to that of 1992. In 1993, nearly 89% of the phosphate rock sold or used by U.S. producers was for the manufacture of wet-process phosphoric acid, single superphosphate, triple superphosphate, and deflourinated rock;

the balance was used to produce elemental phosphorus. Most of the phosphate rock imported was used to produce wet-process phosphoric acid. *(See tables 4 and 5.)*

Stocks

Phosphate rock stocks were maintained in wet rock piles in Florida and North Carolina and, after drying or calcining, were stored in silos. In the Western States, phosphate rock was stockpiled during the nonfreezing months of the year near electric furnaces or wet-process phosphoric acid plants to avoid railroad car or truck unloading problems in the wintertime. Phosphate rock inventory levels are of interest to analysts who follow inventory levels to indicate the strength of the demand for phosphate rock. In the United States, ending stocks in 1992 were 12.6 million tons. In 1993, phosphate rock ending stocks were 9.2 million tons, indicating a decrease of 3.4 million tons. *(See table 6.)*

Transportation

From production centers in central and north Florida, phosphate rock was moved by rail to terminals on Hillsborough Bay, FL, and Jacksonville, FL. In central Florida, CSX Transportation Railroad moved phosphate rock to terminals on Hillsborough Bay. The Rockport terminal was owned and operated by the CSX Railroad. Big Bend terminals and Port Sutton were owned and operated by IMC-Agrico Co. Eastern Associated Terminal (E.A.T.) was owned and operated by E.A.T.

In North Carolina, barges were used to transport phosphate rock from the Aurora Mine to the port at Morehead City for export. Railroad facilities were also available at the Aurora Mine to move phosphate rock to the port or domestic markets. Both railroads and trucks were used in the Western States to move phosphate rock from mines to plants. Two pipelines were used to move slurried phosphate rock from mines to plants. One pipeline was used to pump slurried concentrate from Vernal, UT, to Rock Springs, WY, and another was used to pump phosphate rock from the Smoky Canyon Mine in the Caribou National Forest to Pocatello, ID.

Markets and Prices

The price or value of phosphate rock, f.o.b. mine, was obtained from a semiannual survey of producing companies. The data from the survey were used to develop the weighted average price or value for each grade of phosphate rock sold or used in the domestic market or exported. The average annual price for phosphate rock in 1950 was $5.67 per ton and gradually increased to $7.42 per ton by 1966. In 1967, the average price started to decline progressively and, by 1972, bottomed out at $5.62 per ton. In 1973, the average price of phosphate rock followed a slight upward trend, reflecting the variation in supply and demand. In 1974, the price of phosphate rock continued a 2-year trend of sharp increases and averaged four times greater than the 1973 level, reaching the $25-per-ton mark for 1975. The dramatic increase in price was attributed to an arbitrary price increase by Morocco's Office Cherifien des Phosphate for exported phosphate rock. Although the price declined to $17.39 per ton in 1977, cost increases caused the price to level off at more than $20 per ton in 1979; the price peaked again in 1981 to $26.63 per ton, reaching a record-high level due to a strong demand. The price gradually declined to $19.37 per ton in 1987 and increased to $23.20 per ton in 1990. The price for phosphate rock followed a slight downward trend throughout 1991 and 1992 and for 1993 was $21.38 per ton. *(See tables 7, 8, and 9.)*

In 1993, prices of phosphate-based fertilizer products were low. DAP, the main phosphate fertilizer traded commodity, was selling at about $120 per ton in central Florida compared with about $150 per ton in January 1992. By mid-April, the price reached $110 per ton, the lowest in two decades. Low prices were attributed to lower demand for fertilizer products, an international market flooded with fertilizer products from the former U.S.S.R. in search of hard currency, and a compounded effect resulting from fewer fertilizer products bought by China and India.

Low prices and demand forced the phosphate industry to consolidate operations, close plants, and/or cutback on fertilizer products. Production cuts were necessary to turn depressed prices around. Since July, prices followed an upward trend, and at the end of December, DAP was quoted at more than $150 per ton in central Florida. The rise in fertilizer products prices did not trickle down to the phosphate rock prices. It usually takes more than 6 months of firm prices for the end products before the prices for raw materials gain ground.

Foreign Trade

Total exports of phosphate rock decreased about 14% from those in 1992. The major factor on exports of phosphate rock continued to be a lower demand for raw material, mainly triggered by closures of a number of phosphoric acid plants in Western Europe during 1992. These closures continued to affect the phosphate rock market in 1993. Exports of DAP, phosphoric acid, triple superphosphate, and elemental phosphorus decreased. Exports of monoammonium phosphate, however, increased by about 23% compared to those of 1992.

Imports of phosphate rock into the United States remained at about the same level in 1993 compared with those of 1992. The Bureau of the Census, however, supressed data on imports from Morocco into one U.S. customs district, which resulted in the artificially low import data shown in tables 1 and 17. The Moroccan Office Cherfien des Phospahtes reported exports of 1.46 million tons to the United States in 1993. *(See tables 10, 11, 12, 13, 14, 15, 16, and 17)*

World Review

World phosphate rock production decreased again in 1993 and was 20%

less than ouput in the peak year 1989. The decline in rock production was a consequence of lower phosphate fertilizer consumption worldwide. Morocco's phosphate rock exports were down by 8% compared to the level of 1992. However, Morocco's lower level of phosphate rock exports was probably due more to its built-up capacity for conversion of phosphate rock into other chemical products, rather than only a low international demand for raw materials. Preliminary estimated world phosphate fertilizer consumption showed a decline of about 6% in 1993 compared to that of the previous year. This was principally caused by reduced consumption in China and the former U.S.S.R. In Western Europe, during 1991, 1992, and 1993, phosphate rock imports decreased as a reflection of the closure or idling of various phosphoric acid plants with an annual capacity of more than 1.3 million tons P_2O_5. The acid plants were closed or idled for environmental and/or economic reasons. Closures of phosphoric acid plants during the previous 2 years had their final impact felt on phosphate rock production and trade in 1993.

Israel.—Fertilizers and Chemicals, a subsidiary of Israel Chemicals Ltd., formed a joint venture with Turkey's Trans Turk. The partners intended to build a plant in southern Turkey to produce liquid fertilizers. Fertilizers and Chemicals expected to have sales of more than $5 million in 1993.

Pakistan.—Fauji Fertilizer Co. (FFC), Pakistan, and Jordan Phosphate Mines Co. (JPMC), Jordan, have signed a memorandum of agreement to build a 200,000-ton-per-year phosphoric acid plant in Jordan and an ammonia, urea, and DAP facility at Port Qasim, Pakistan, with a capacity of 450,000 tons per year of DAP. The project cost was estimated at about $400 million. FFC was to own 65% of the phosphoric plant in Jordan and 75% of the facility in Pakistan, with the remaining 35% and 25%, respectively, to be owned by JPMC. The project cost was estimated at about $400 millon; plants in both countries were expected to start production by 1996.

Russia.—Phosphate concentrate production capacity of Production Association Apatit (P.O. Apatit) decreased by about 20% owing to the closure of the company's apatite-nepheline beneficiation plant No. 1, in January 1993. P.O. Apatit is Russia's largest producer of high-quality phosphate rock concentrates.

The U.S. Bureau of Mines estimates of world phosphate rock reserves and the reserve base are shown in table 19. Included are reserves and reserve base estimates with costs of less than $40 and $100 per ton, respectively. *(See tables 18, 19, and 20.)*

Current Research

The U.S. Bureau of Mines, research center in Tuscaloosa, AL, conducted research in an attempt to prevent loss of coarse phosphate in a flotation circuit. The results of this study to reexamine the conditioning of coarse Florida phosphate has determined that the mixing intensity of the conditioner affects the P_2O_5 rougher concentrate grade and recovery. The study also showed that removal of the residual clay or fine particles from the coarse flotation feed material resulted in a lower reagent consumption that could offset the added cost of scrubbing and/or elutriation. Optimizing the conditioning time, mixing intensity, and other conditioning parameters resulted in a rough phosphate concentrate grading 30% P_2O_5 with a total recovery of 95%.[6]

OUTLOOK

World production and consumption has declined steadily since 1989, primarily as a result of the sociopolitical restructuring of the economies of Eastern Europe and the former U.S.S.R. In addition, Western European imports were affected by the closure of a number of phosphoric acid plants the previous year that continued affecting the demand for phosphate rock. North American consumption of phosphate fertilizers has followed a downward trend in recent years as farmers learned to apply fertilizers following recommended procedures to optimize crop yield.

Significant dislocations worldwide have contributed to the decline in phosphate production, consumption, and trade. Despite all the negatives mentioned, the balance between supply and demand shifted in favor of the fertilizer producers during the last quarter of 1993. China resumed its levels of acquisition after almost a year of backcuts, and India, the second largest importer, increased fertilizer imports during the last part of 1993. The importance of having these two countries back into the international market cannot be ignored; these countries are recipients of about one-half the U.S. phosphate exports.

Based on the market recovery for phosphate fertilizer products that occurred during the last quarter of 1993, the outlook for domestic phosphate-based fertilizers within the next 2 to 3 years can be seen as optimistic. Farmers from the Midwestern States will need fertilizer to replace nutrients washed out by the worst flood in 100 years that took place in 1993. A modest increase in phosphate rock trade for 1994 is forecast. However, in the long term, phosphate rock trade will probably continue to decline. The continuing growth in world population will require increased use of fertilizer for food production. The long-term growth in phosphate-based fertilizers production should average between 1.5% to 2.0% annually beginning in 1996.

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TABLE 1
SALIENT PHOSPHATE ROCK STATISTICS

(Thousand metric tons and thousand dollars unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Mine production (crude ore)	170,268	151,277	154,485	154,936	106,790
Marketable production	49,817	46,343	48,096	46,965	35,494
P_2O_5 content	15,116	14,172	14,510	14,063	10,816
Value[1]	$1,084,022	$1,075,093	$1,109,094	$1,058,393	$758,983
Average per metric ton[2]	$21.76	$23.20	$23.06	$22.53	$21.38
Sold or used by producers[3]	49,280	49,754	44,707	45,113	40,051
P_2O_5 content	14,935	15,098	13,467	13,529	11,940
Value[1]	$1,072,454	$1,154,422	$1,030,913	$1,016,271	$856,414
Average per metric ton[2] [4]	$21.76	$23.20	$23.06	$22.53	$21.38
Exports[5]	7,842	6,238	5,082	3,723	3,198
P_2O_5 content	2,522	2,019	1,643	1,200	1,018
Value[1]	$227,272	$191,233	$162,624	$120,216	$91,175
Average per metric ton[2]	$28.98	$30.66	$32.00	$32.29	$28.51
Imports for consumption	705	451	552	1,530	[6]534
C.i.f. value	$29,878	$21,905	$28,001	$56,159	$32,279
Average per metric ton[7]	$42.44	$48.57	$50.73	$36.71	$60.45
Consumption[8]	42,143	43,967	40,177	42,920	[e]38,287
Stocks, Dec. 31: Producers	11,027	8,912	10,168	12,612	9,215
World: Production	[r]165,788	[r]161,554	[r]149,494	[r]146,004	[e]131,941

[e] Estimated. [r] Revised.

[1] The total value is based on a weighted value.

[2] Computer-calculated average value based on the weighted sold or used values.

[3] Includes domestic sales and exports.

[4] Weighted average of sold or used values.

[5] Exports reported to the U.S. Bureau of Mines by companies.

[6] Some phosphate rock import tonnage and value were supressed by the Bureau of the Census.

[7] Average unit value obtained from unrounded data.

[8] Expressed as sold or used plus imports minus exports. Includes an estimated 900,000 tons of phosphate rock imported from Morocco not reported by the Bureau of the Census.

TABLE 2
PRODUCTION OF PHOSPHATE ROCK IN THE UNITED STATES, BY REGION

(Thousand metric tons and thousand dollars)

Region	Mine production		Marketable production			Ending stocks
			Beneficiated			
	Rock	P_2O_5 content	Rock	P_2O_5 content	Value[1]	
1992	154,936	20,485	46,965	14,063	1,058,393	12,612
1993:						
January-June:						
Florida and North Carolina	56,433	7,964	15,857	4,775	347,110	8,900
Idaho, Montana, Utah	3,721	969	2,204	900	40,620	1,374
Total	60,154	8,933	18,061	5,675	387,730	10,274
July-December:						
Florida and North Carolina	42,073	8,323	14,440	4,305	316,092	7,668
Idaho, Montana, Utah	4,563	1,119	2,993	836	55,161	1,547
Total	46,636	9,442	17,433	5,141	371,253	9,215
Grand total	106,790	18,375	35,494	10,816	758,983	XX

XX Not applicable.

[1] Computer-calculated value based on the weighted sold or used value.

TABLE 3
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GRADE AND REGION

(Thousand metric tons and thousand dollars)

Grade (percent BPL[1] content)	Florida and North Carolina			Idaho, Montana, Utah			Total		
	Rock	P_2O_5 content	Value[2]	Rock	P_2O_5 content	Value[2]	Rock	P_2O_5 content	Value[2]
January-June 1992	20,330	6,151	477,230	2,762	783	49,968	23,092	6,934	527,198
July-December 1992	18,749	5,676	434,204	3,272	918	54,869	22,021	[3]6,595	489,073
January-June 1993:									
74 or more[4]	—	—	—	—	—	—	—	—	—
72 to less than 74	745	249	21,629	—	—	—	745	249	21,629
70 to less than 72	671	217	21,088	430	141	16,110	1,101	358	37,198
66 to less than 70	9,935	3,034	197,992	466	145	8,879	10,401	3,179	206,871
60 to less than 66	5,663	1,627	137,619	624	174	6,346	6,287	1,801	143,965
Below 60	—	—	—	1,381	353	18,362	1,381	353	18,362
Total	17,014	5,127	378,328	2,901	813	49,697	19,915	5,940	428,025
July-December 1993:									
74 or more[4]	—	—	—	—	—	—	—	—	—
72 to less than 74	832	277	22,609	414	139	15,516	1,246	416	38,125
70 to less than 72	215	72	5,882	—	—	—	215	72	5,882
66 to less than 70	10,506	3,218	207,276	402	127	7,521	10,908	3,345	214,797
60 to less than 66	4,855	1,404	115,885	638	179	6,582	5,493	1,583	122,467
Below 60	752	195	18,069	1,522	389	29,049	2,274	584	47,118
Total	17,160	5,166	369,721	2,976	834	58,668	20,136	6,000	428,389

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

[2] F.o.b. mine.

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

[4] No reported sold or used for 1993.

TABLE 4
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE

(Thousand metric tons)

Use	1992 total		1993					
			January-June		July-December		Total	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
Domestic:[1]								
Wet-process phosphoric acid	37,790	11,349	16,136	4,843	16,242	4,881	32,378	9,724
Normal superphosphate	23	8	11	3	8	3	19	6
Triple superphosphate	501	164	167	56	26	8	193	64
Deflourinated rock	—	—	42	14	43	14	85	28
Direct applications	(2)	(2)	24	7	4	1	28	8
Elemental phosphorus	3,076	808	2,033	537	2,117	555	4,150	1,092
Total	41,390	12,329	18,413	5,460	18,440	5,462	36,853	10,922
Exports[3]	3,723	1,200	1,502	480	1,696	538	3,198	1,018
Grand total	45,113	13,529	19,915	5,940	20,136	6,000	40,051	11,940

[1] Includes rock converted to products and exported.

[2] Less than 1/2 unit.

[3] Exports reported to the U.S. Bureau of Mines by companies.

TABLE 5
PHOSPHATE ROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE AND REGION

(Thousand metric tons)

Use	Florida and North Carolina		Idaho, Montana, Utah		Total	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1992	39,079	11,828	6,034	1,701	45,113	13,529
1993:						
January-June:						
Domestic:[1]						
Agricultural	15,300	4,576	836	267	16,136	4,843
Industrial	244	80	2,033	537	2,277	617
Subtotal	15,544	4,656	2,869	804	18,413	5,460
Exports[2]	1,471	471	31	9	1,502	480
Total	17,015	5,127	2,900	813	19,915	5,940
July-December:						
Domestic:[1]						
Agricultural	15,426	4,615	816	266	16,242	4,881
Industrial	81	26	2,117	555	2,198	581
Subtotal	15,507	4,641	2,933	821	18,440	5,462
Exports[2]	1,652	525	44	13	1,696	538
Total	17,159	5,166	2,977	834	20,136	6,000
Grand total	34,174	10,293	5,877	1,647	40,051	11,940

[1] Includes rock converted to products and exported.

[2] Exports reported to the U.S. Bureau of Mines by companies.

TABLE 6
MARKETABLE PHOSPHATE ROCK YEAREND STOCKS[1]

(Million metric tons)

Year	Quantity
1984	11.9
1985	15.5
1986	13.3
1987	10.9
1988	9.3
1989	11.0
1990	8.9
1991	10.2
1992	12.6
1993	9.2

[1] Includes inventory adjustments.

TABLE 7
PRICE OR VALUE OF FLORIDA AND NORTH CAROLINA PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade	1992			1993		
(percent BPL[1] content)	Domestic	Export	Average	Domestic	Export	Average
74 or more	—	—	—	—	—	—
72 to less than 74	29.57	34.13	32.13	26.93	29.20	28.04
70 to less than 72	25.03	30.14	29.28	20.31	31.57	30.43
66 to less than 70	20.55	30.60	21.00	19.33	25.80	19.83
60 to less than 66	25.56	—	25.56	24.11	26.45	24.11
Less than 60	—	—	—	24.03	—	24.03
Weighted average	22.47	31.69	23.32	21.26	28.11	21.89

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P_2O_5.

TABLE 8
PRICE OR VALUE OF IDAHO, MONTANA, AND UTAH PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade	1992			1993		
(percent BPL[1] content)	Domestic	Export	Average	Domestic	Export	Average
70 to less than 72	36.82	—	36.82	37.48	—	37.48
66 to less than 70	18.49	50.76	22.02	18.90	—	18.90
60 to less than 66	14.60	—	14.60	8.04	45.23	10.24
Less than 60	9.33	—	9.33	16.32	—	16.32
Weighted average	16.72	50.76	17.38	18.09	45.23	18.43

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate)=0.458% P_2O_5.

TABLE 9
PRICE OR VALUE OF U.S. PHOSPHATE ROCK, BY GRADE

(Dollars per metric ton, f.o.b. mine)

Grade (percent BPL[1] content)	1992			1993		
	Domestic	Export	Average	Domestic	Export	Average
74 or more	—	—	—	—	—	—
72 to less than 74	29.57	34.13	32.13	30.51	29.20	30.00
70 to less than 72	34.11	30.14	31.99	34.51	31.57	32.73
66 to less than 70	20.46	32.57	21.04	19.31	25.80	19.79
60 to less than 66	23.77	—	23.77	22.48	45.02	22.62
Less than 60	9.33	—	9.33	17.91	—	17.91
Weighted average	21.65	32.29	22.53	20.76	28.51	21.38

[1] 1.0% BPL (bone phosphate of lime or tricalcium phosphate) = 0.458% P_2O_5.

TABLE 10
U.S. EXPORTS OF GROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 2510.20.0000)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Canada	128		93	
France	122		(1)	
India	21	NA	—	NA
Mexico	2		1	
Other	15		13	
Total	288	NA	107	NA

NA Not available.
[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 11

U.S. EXPORTS OF UNGROUND PHOSPHATE ROCK, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 2510.10.0000)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Australia	118		188	
Belgium	(1)		206	
Brazil	4		20	
Canada	153		170	
France	236		14	
Germany	312		194	
India	450		272	
Italy	24	NA	—	NA
Japan	603		554	
Korea, Republic of	1,147		1,053	
Mexico	5		2	
Netherlands	346		315	
New Zealand	161		204	
Romania	32		31	
Other	98		241	
Total	3,689	NA	3,464	NA

NA Not available.

[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 12

U.S. EXPORTS OF SUPERPHOSPHATES, MORE THAN 40% P_2O_5, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 3103.10.0020)

Country	1992		1992	
	Quantity	Value	Quantity	Value
Argentina	27	NA	14	NA
Australia	227		228	
Bangladesh	108		16	
Brazil	186		99	
Canada	11		53	
Chile	175		148	
Colombia	10		13	
Costa Rica	2		2	
Dominican Republic	10		—	
Equador	15		—	
Indonesia	182		—	
Japan	52		50	
Mexico	4		—	
Peru	4		14	
South Africa, Republic of	6		—	
Spain	4		—	
United Kingdom	25		—	
Uruguay	29		4	
Venezuela	18		—	
Other	19		121	
Total	1,114	NA	762	NA

NA Not available.

Source: Bureau of the Census.

TABLE 13

U.S. EXPORTS OF DIAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 3105.30.0000)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Albania	10		—	
Argentina	191		190	
Australia	286		436	
Bangladesh	17		—	
Belgium	35		—	
Brazil	41		77	
Canada	175		175	
Chile	69		108	
China	3,582		2,109	
Colombia	98		135	
Costa Rica	7		10	
Cote d' Ivoire	34		—	
Dominican Republic	49		33	
Ecuador	44		38	
El Salvador	16		—	
France	61		34	
Germany	94		91	
Guatemala	21		5	
Honduras	15		—	
India	1,187		1,189	
Iran	281	NA	32	NA
Ireland	16		37	
Italy	26		—	
Japan	431		512	
Jordan	27		—	
Kenya	31		62	
Korea, Republic of	54		—	
Mexico	58		247	
Netherlands	30		—	
New Zealand	55		159	
Pakistan	713		732	
Panama	17		—	
Peru	14		24	
Philippines	33		—	
Spain	42		11	
Taiwan	55		—	
Thailand	111		87	
Turkey	74		131	
United Kingdom	25		—	
Uruguay	66		40	
Venezuela	45		10	
Other	36		652	
Total	8,272	NA	7,366	NA

NA Not available.

Source: Bureau of the Census.

TABLE 14
U.S. EXPORTS OF MONOAMMONIUM PHOSPHATES, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 3105.40.0000)

Country	1992 Quantity	1992 Value	1993 Quantity	1993 Value
Argentina	5		2	
Australia	216		188	
Brazil	8		132	
Canada	298		395	
Chile	33		34	
China	5		2	
Colombia	40		91	
Costa Rica	26		20	
Dominican Republic	1		([1])	
Ecuador	—	NA	5	NA
Guatemala	37		22	
Japan	157		111	
Mexico	22		38	
New Zealand	—		20	
Peru	([1])		([1])	
Saudi Arabia	—		10	
Thailand	17		([1])	
Venezuela	([1])		([1])	
Other	24		23	
Total	889	NA	1,093	NA

NA Not available.
[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 15
U.S. EXPORTS OF PHOSPHORIC ACID, LESS THAN 65% P_2O_5, BY COUNTRY

(Thousand metric tons and thousand dollars)
(HTS No. 2809.20.0010)

Country	1992 Quantity	1992 Value	1993 Quantity	1993 Value
Australia	60		46	
Canada	6		13	
Colombia	8		6	
India	279	NA	138	NA
Indonesia	69		61	
Japan	—		([1])	
Venezuela	56		37	
Other	124		197	
Total	602	NA	498	NA

NA Not available.
[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 16
U.S. EXPORTS OF ELEMENTAL PHOSPHORUS, BY COUNTRY

(HTS No. 2804.70.0000)

Country	1992 Quantity (metric tons)	1992 Value[1] (thousands)	1993 Quantity (metric tons)	1993 Value[1] (thousands)
Brazil	507	$1,060	748	$1,500
Canada	1,726	2,571	1,489	2,509
Japan	9,334	16,988	9,378	17,632
Korea, Republic of	134	596	24	101
Mexico	5,314	8,329	6,358	9,695
Netherlands	21	137	23	60
Taiwan	38	48	—	—
Other	806	3,055	333	691
Total	17,880	32,784	18,353	32,188

[1] All values f.a.s.

Source: Bureau of the Census.

TABLE 17
U.S. IMPORTS FOR CONSUMPTION OF PHOSPHATE ROCK AND PHOSPHATIC MATERIALS

(Thousand metric tons and thousand dollars)

Phosphatic materials	HTS No.[1]	1992 Quantity	1992 Value[2]	1993 Quantity	1993 Value[2]
Natural calcium[3] phosphates unground	2510.10.0000	1,528	55,986	532	32,028
Natural calcium[3] phosphates ground	2510.20.0000	2	173	2	251
Dicalcium phosphate	2835.25.0000	2	2,746	3	3,783
Phosphorus	2804.70.0000	4	10,330	1	7,257
Normal superphosphate	3103.10.0010	([4])	71	([4])	5
Triple superphosphate	3103.10.0020	([4])	5	([4])	8
Diammonium phosphate	3105.30.0000	22	4,907	38	7,096
Fertilizer containing nitrates and phosphates	3105.51.0000	1	150	56	5,604
Phosphoric acid	2809.20.0010	1	214	([4])	12

[1] Harmonized tariff schedule of the United States.

[2] Declared c.i.f values.

[3] Excludes reported imports from Canada and Israel.

[4] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 18

WORLD PHOSPHATE ROCK ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993, RATED CAPACITY[1]

(Million metric tons per year)

Country	Capacity
North America:	
Mexico	1.0
United States	50.0
Total	51.0
South America	10.0
Europe:	
Russia	18.0
Other	1.0
Total	19.0
Africa:	
Algeria	2.3
Morocco[2]	32.0
Senegal	2.0
South Africa, Republic of	4.5
Togo	3.2
Tunisia	8.0
Other	1.2
Total	53.2
Asia:	
China	25.0
Israel	4.0
Jordan	8.0
Kazakhstan	8.0
Korea, North	1.0
Vietnam	1.0
Other	1.0
Total	48.0
Oceania:	
Australia	1.0
Nauru	2.0
Total	3.0
World total	184.2

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

[2] Includes former Western Sahara.

TABLE 19

WORLD PHOSPHATE ROCK RESERVES 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	1,200	4,440
Total	97	1,260	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
Russia	8	—	1,000
Turkey	1	30	30
Total	10	30	1,100
Africa:			
Algeria	1	240	240
Egypt	5	—	760
Morocco[3]	11	5,900	21,440
Senegal	2	—	160
South Africa, Republic of	1	2,530	2,530
Togo	12	—	60
Tunisia	11	—	270
Total	43	8,670	25,460
Asia:			
China	6	210	210
Christmas Island	1	10	10
Israel	4	—	180
Jordan	3	90	480
Kazakhstan	3	—	100
Syria	2	190	190
Other	6	30	330
Total	25	530	1,500
Oceania:			
Australia	5	90	590
Nauru	1	5	5
Total	6	95	595
World total	195	11,225	34,045

[1] Phosphate rock reserves at a cost less than $40 per ton f.o.b. mine. Costs include capital, operating taxes, royalties (if applicable), miscellaneous costs and a 15% rate of return on investment. Costs and resources are as of Jan. 1993, f.o.b. mine.

[2] Reserve base at a cost less than $100 per ton. Costs are as defined in footnote 1.

[3] Includes former Western Sahara.

TABLE 20

PHOSPHATE ROCK, BASIC SLAG, AND GUANO: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 content				
	1989	1990	1991	1992	1993[e]	1989	1990	1991	1992	1993[e]
Phosphate rock:										
Albania[e]	25	10	9	2	2	3	1	1	(3)	(3)
Algeria	1,124	1,128	1,090	1,136	1,136	[e]371	[e]333	[e]322	[r][e]340	340
Australia	8	16	[e]4	[e]4	5	1	4	1	1	1
Brazil	3,655	2,968	3,280	[r]2,825	3,000	[r]1,279	[r]1,039	[r]1,148	[r]989	1,050
Burkina Faso[e]	3	3	3	3	3	1	1	1	1	1
Chile	14	14	13	[r]17	14	[e]1	[e]1	[e]1	[e]1	1
China[e]	20,000	21,550	22,000	23,000	24,000	6,000	6,400	6,500	6,800	7,000
Colombia	31	[r]31	32	32	32	[e]8	[e]8	[e]8	[e]8	8
Egypt	1,347	1,143	1,652	[r]2,000	2,000	[e]337	[e]286	[e]413	[r][e]500	500
Finland	580	546	472	[r]555	600	214	201	[e]170	[r]201	215
India	704	674	563	[e]600	635	235	[e]220	[e]195	[e]200	210
Indonesia	11	2	6	[e]8	7	4	1	2	3	2
Iraq[e] [4]	1,140	900	400	900	1,000	342	270	120	270	300
Israel[4]	3,922	3,516	[e]3,370	3,595	3,590	[e]1,231	[e]1,104	[e]1,070	[e]1,125	1,120
Jordan	6,900	6,082	4,433	4,296	4,200	[e]2,277	[e]2,007	[e]1,458	[r][e]1,409	1,300
Kazakhstan[e]	—	—	—	[r]12,000	10,000	—	—	—	[r]3,000	2,500
Korea, North[e]	500	500	[r]500	[r]500	510	160	160	[r]160	[r]160	163
Mali[e]	10	10	[r]—	[r]—	—	2	2	[r]—	[r]—	—
Mexico[5]	655	623	596	[r]452	350	197	[e]174	[e]180	[r][e]135	105
Morocco[6]	18,067	21,396	17,900	[r]19,145	[7]18,305	[e]5,781	[e]6,906	[e]5,700	[r][e]6,178	5,919
Nauru	1,181	926	530	747	600	[e]455	[e]355	[e]200	[e]285	228
Netherlands Antilles[e]	15	15	15	15	10	5	5	5	5	4
Pakistan	[e]40	[e]42	19	20	20	[e]13	[e]13	6	[e]6	6
Peru	15	47	18	[r][e]18	18	[r][e]5	[r][e]16	[e]6	[e]6	6
Philippines	4	3	21	[e]20	20	[e]2	[e]1	[e]5	[e]5	5
Russia[e]	—	—	—	[r]11,500	10,400	—	—	—	[r]4,336	3,928
Senegal[8]	2,273	2,147	1,741	[r]2,284	2,200	823	777	[e]630	[e]830	790
South Africa, Republic of	2,963	3,165	3,050	3,051	3,100	1,111	1,190	[e]1,150	[e]1,150	1,200
Sri Lanka	24	33	20	[r]26	25	[e]8	[e]11	[e]6	[e]6	8
Sweden	71	[r]7	—	—	—	26	[r]3	—	—	—
Syria	2,256	1,633	1,359	1,266	1,275	[e]690	[e]511	[e]425	[e]395	400
Tanzania	5	25	22	22	22	[e]1	[e]8	[e]7	[e]7	7
Thailand	7	10	6	[r]8	8	2	[e]3	2	2	2
Togo	3,355	2,314	2,965	[r]2,100	2,100	[e]1,270	[e]840	[e]1,076	[r][e]760	760
Tunisia	6,610	6,258	[r]6,352	6,400	6,400	[e]1,963	[e]1,858	[r][e]1,880	[e]1,900	1,900
Turkey	85	87	[r]4	[r]65	65	26	27	[r]1	[r]20	20
Uganda	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
U.S.S.R.[e] [9]	37,500	36,800	28,400	—	—	12,200	11,800	9,250	—	—
United States	49,817	46,343	48,096	46,965	[7]35,494	15,116	14,172	14,501	14,063	[7]10,816
Venezuela	237	165	162	[r]10	100	57	34	[e]34	[r]3	33
Vietnam[e]	500	[7]274	[r]274	275	250	175	96	96	95	90
Zimbabwe, concentrate	134	148	117	[r]142	145	47	52	41	42	45
Total	[r]165,788	[r]161,554	[r]149,494	[r]146,004	[r]131,641	[r]52,439	[r]50,890	[r]46,771	[r]45,237	40,983
Basic (Thomas converter) slag:										
Argentina[e]	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Egypt[e]	8	8	8	8	8	2	2	2	2	2

See footnotes at end of table.

TABLE 20—Continued

PHOSPHATE ROCK, BASIC SLAG, AND GUANO: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Commodity and country[2]	Gross weight					P_2O_5 content				
	1989	1990	1991	1992	1993[e]	1989	1990	1991	1992	1993[e]
Basic (Thomas converter) slag:										
France	701	488	538	[r]356	350	126	88	97	90	90
Germany	122	128	[r]142	[r]120	100	18	19	[r]21	18	15
Luxembourg	672	603	[r]536	[r]519	520	[r]121	109	[r][e]95	[r][e]93	93
Total	1,503	1,227	[r]1,224	[r]1,003	978	[r]267	218	[r]215	[r]203	200
Guano:										
Chile	3	[r]1	1	[r](3)	—	[e](3)	[e](3)	[e](3)	[e](3)	—
Philippines	48	1	[e]12	[e]10	10	16	[e](3)	[e]4	[e]3	3
Total	51	[r]2	13	[r]10	10	16	(3)	4	3	3

[e] Estimated. [r] Revised.

[1] Table includes data available through May 13, 1994. Data for major phosphate rock-producing countries derived in part from the International Fertilizer Industry Association; other figures are from official country sources where available.

[2] In addition to the countries listed, Belgium may have produced small quantities of phosphate rock and Namibia may have produced small quantities of guano, but output is not officially reported, and available information is inadequate for formulation of reliable estimates of output levels.

[3] Less than 1/2 unit.

[4] Beneficiated.

[5] Includes only output used to manufacture fertilizers.

[6] Production from Western Sahara area is included.

[7] Reported figure.

[8] Does not include aluminum phosphate production, gross weight estimated as follows in thousand metric tons: 1989—140; 1990—127; 1991—92; 1992—75 (revised); and 1993—75.

[9] Dissolved in Dec. 1991.

PLATINUM-GROUP METALS

By J. Roger Loebenstein

Mr. Loebenstein, a physical scientist with 19 years of industry and U.S. Bureau of Mines experience, has been the commodity specialist for platinum-group metals for 13 years. Domestic survey data were prepared by Evangeline Hemphill, statistical assistant; and international data tables were prepared by Harold Willis, international data coordinator.

Ore containing the platinum-group metals (PGM) was mined, concentrated, and smelted in Montana, and the resultant PGM matte was exported to Belgium for refining and separation of the individual PGM. In addition, PGM were recovered as byproducts of copper refining by two companies in Texas and Utah. Domestic mine production of PGM was valued at $47 million in 1993.

Secondary metal was refined by about 20 firms, mostly on the east and west coasts. About 4,800 kilograms (kg) of PGM was refined from scrap on a nontoll basis. The quantity of toll-refined secondary was 13 times larger, amounting to about 61,000 kg.

PGM were sold by at least 90 processors and dealers, largely in the northeast, and were used primarily in the automotive, electrical/electronic, dental/medical, chemical, jewelry, and petroleum refining industries. The automotive, chemical, and petroleum-refining industries used PGM mainly as catalysts. The other industries used them in a variety of ways that took advantage of their chemical inertness and refractory properties.

Dealer prices for iridium, rhodium, and ruthenium continued to decline in 1993, while prices for palladium and platinum increased somewhat. The annual average price for rhodium, $1,066 per troy ounce, was the lowest since 1989.

PGM were mined in at least 10 countries in 1993; production was dominated by the Republic of South Africa, which accounted for 60% of the world total, and Russia, which accounted for 30%. Platinum and palladium amounted to 49% and 42%, respectively, of all PGM mined, and the other four metals—iridium, osmium, rhodium, and ruthenium—together amounted to 9%.

Identified world PGM resources at yearend 1993 were estimated jointly by the U.S. Geological Survey and U.S. Bureau of Mines (USBM) at 100 million kg. The reserve base was estimated by the USBM at 66 million kg and reserves at 56 million kg. Of the reserve base and the reserves, the Republic of South Africa had nearly 90% of each; Russia had 9 and 11%, respectively; and the United States had 1% and 0.4%, respectively.

DOMESTIC DATA COVERAGE

Domestic production data for PGM are developed by the USBM from a voluntary survey of U.S. refiners. Of the 13 refiners to which a survey request was sent, 8 responded. These respondents represent 62% of the total refined metal production shown in tables 1 and 2. Production for nonrespondents was estimated using prior-year levels adjusted for general industry trends. *(See tables 1 and 2.)*

ANNUAL REVIEW

Strategic Considerations

Although some platinum and palladium were produced at the only PGM mine in the United States, the Stillwater Mine, the great majority of PGM consumed in the United States was imported.

Inventories of platinum, palladium, and iridium in the National Defense Stockpile remained unchanged in 1993, as shown in table 1. No purchases of rhodium or ruthenium were made, even though there are unmet stockpile goals for these two metals.

Consumption and Uses

Reported sales of PGM by refiners is shown in table 3. For comparison, the calculated apparent consumption of the individual PGM also is shown. *(See table 3.)*

Automotive demand for platinum, palladium, and rhodium was estimated on the basis of 10.4 million automobiles and light trucks produced in 1993, the quantities and proportions of the three metals differing from model to model. While the trend toward palladium-only autocatalysts—reportedly suitable only for smaller vehicles—continued, most autocatalysts still contained all three metals or a combination of platinum and rhodium.

Federal standards require that medium-duty trucks, beginning with model year 1994, be fitted with catalysts. International Catalyst Technology Inc., a joint subsidiary of Degussa (Germany) and Nippon Shokubai (Japan), started producion of diesel catalysts for the North American market in Calvert City, KY, at a rate of 3 million catalyst units per year. Engelhard Corp., in Huntsville, AL, and Johnson Matthey PLC, in Wayne, PA, also produced diesel catalysts. *(See table 4.)*

Markets and Prices

There was some tightness in the world palladium market because of greater demand by the automotive and electronics industries. The average annual dealer price for palladium rose $33, to $120 per troy ounce. In contrast, average monthly dealer prices for rhodium declined substantially, dropping below $1,000 per ounce for 7 months of the year.[1] The average annual dealer price was $1,066, thus remaining more than $1,000 per ounce for the eighth consecutive year. The world supply of rhodium exceeded demand significantly for the second consecutive year despite a 16% increase in world autocatalyst demand.[2]

Foreign Trade

U.S. imports of palladium rose 29% in 1993. U.S. exports of palladium rose 48%, spurred by higher demand for palladium for use in automobile catalysts in Europe and for dental and electrical uses in Japan. *(See tables 5 and 6.)*

World Review

North American Palladium Ltd. (formerly Madeline Mines) started up its open pit PGM mine, 81 kilometers north of Thunder Bay, Ontario, Canada. At full production in 1994, the mine was expected to yield 3,100 kg of palladium and 230 kg of platinum annually.[3]

In the Republic of South Africa, Rustenburg Platinum Mines Ltd., in response to weak platinum demand, closed its Boschfontein shaft, a move that reduced its platinum production by about 8,000 kg. The mine reportedly was a high-cost producer. Also, Rustenburg brought the open pit Potgietersrust Mine on-stream. The mine reportedly is one of the lowest cost producers in the industry. Initial annual production was projected at 5,300 kg of platinum, 5,100 kg of palladium, and 400 kg of rhodium, along with subsidiary copper, gold, and nickel. *(See table 7.)*

Current Research

A new alloy of palladium, ruthenium, and zirconium having extraordinary wear characteristics was developed at the Paffenbarger Research Center, National Institute of Standards and Technology, in Gaithersburg, MD.[4] The patent for the new alloy is held by the American Dental Association Health Foundation, sponsor of the research. The alloy has no known toxic reactions with human tissue and is strong enough to be used surgically for tooth, hip, and knee implants. It also could be used as an industrial coating for high-performance bearings and mechanical joints.

OUTLOOK

Future demand for PGM is expected to continue to grow worldwide, given the strong demand for a cleaner environment. Catalytic converters for controlling emissions from gasoline-powered automobiles are currently used in Australia, Canada, Japan, Mexico, the Republic of Korea, Taiwan, the United States, and several Western European nations. Brazil, Hong Kong, Indonesia, Malaysia, Singapore, and Thailand are expected to start using catalytic converters in the very near future. The potential market for the catalytic converter is huge—there are 500 million motor vehicles worldwide. The use of palladium is growing because the wider use of cleaner, lead-free fuels permits its use as a substitute for more expensive platinum. However, platinum will probably continue to remain the dominant metal in catalytic converters for some time in the future. The advantage in price that palladium has over platinum is somewhat negated by the necessity of using as much as three times more palladium than platinum to achieve the desired reduction in emissions.

The world market for diesel catalysts, now $30 million to $40 million per year, is expected to double by 1998.

In the United States, California has for years had the most stringent automobile emission regulations, setting the tone for Federal standards. California will require that 2% of new vehicles sold in the State in 1998 be "zero-emission" vehicles. The percentage is scheduled to increase to 5% in 2001, and to 10% in 2003. Electric vehicles are being studied as a way to meet the zero-emissions requirement.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publication

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Other Sources

American Metal Market (daily paper).

Cowley, A. Platinum 1994. Publ. by Johnson Matthey PLC, London, England. 52 pp.; available from Donley Communications, New York, NY; Telephone: (212) 751-6126.

Metals Week.

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[1] U.S. Bureau of Mines. Platinum-Group Metals in the Fourth Quarter 1993, 7 pp.

[2] Cowley, A. Platinum 1994. Johnson Matthey PLC, London, England, p. 47.

[3] Skillings' Mining Review. North American Palladium Now Starting up Its Lac Des Iles Mine After Lengthy Delay. Sept. 11, 1993, pp. 4-6.

[4] American Society of Metals (ASM) News. New Dental/Medical Alloy Shows Unexpected Wear Potential. Oct. 1993, p. 5.

TABLE 1
SALIENT PLATINUM-GROUP METALS[1] STATISTICS

(Kilograms)

		1989	1990	1991	1992	1993
United States:						
Mine production:[2]						
Platinum		1,430	1,810	1,730	1,840	1,800
Palladium		4,850	5,930	6,050	6,470	6,500
Value[3]	thousands	$45,764	$48,911	$37,558	$39,157	$46,699
Refinery production:						
Primary refined		339	64	216	W	W
Secondary:						
Nontoll-refined		3,933	5,819	4,806	[r]5,327	4,837
Toll-refined		46,253	65,429	67,543	[r]58,982	60,955
Total refined metal		50,525	71,312	[4]72,564	[r]64,309	65,792
Stocks, yearend:						
Industry (refined)		32,543	30,324	24,313	26,946	20,199
National Defense Stockpile:						
Platinum		14,079	14,079	14,079	14,079	14,079
Palladium		39,334	39,334	39,334	39,334	39,334
Iridium		920	920	920	920	920
Exports:						
Refined[5]		23,082	20,148	27,401	[r]31,060	43,798
Total		38,301	55,044	39,624	[r]57,830	78,521
Imports for consumption:[6]						
Refined[5]		111,107	120,631	121,741	[r]129,419	148,790
Total		113,278	125,354	125,661	132,006	153,165
Consumption (reported sales to industry)		78,483	77,487	62,597	66,801	60,272
Consumption, apparent[7]		101,209	117,043	111,798	109,469	123,273
Net import reliance[8] as a percent of apparent consumption		90	88	90	87	91
Price, dealer, average, per ounce:						
Platinum		$507	$467	$371	$356	$370
Palladium		$144	$114	$87	$87	$120
Iridium		$303	$307	$283	$158	$47
Osmium		$549	$416	$400	$400	$400
Rhodium		$1,300	$3,565	$3,739	$2,365	$1,066
Ruthenium		$62	$61	$55	$29	$13
World: Mine production		281,629	291,015	[e,r]288,343	[e,r]281,438	[e]250,718

[e] Estimated. [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] Estimates for the Stillwater Mine are from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

[3] Value based on dealer prices.

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

[5] Excludes ores and scrap.

[6] Quantities for general imports and imports for consumption are identical.

[7] Includes mine production plus nontoll-refined production plus refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

[8] Refined imports for consumption minus refined exports plus or minus changes in Government and industry stocks.

TABLE 2
PLATINUM-GROUP METALS REFINED IN THE UNITED STATES

(Kilograms)

	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[1]
PRIMARY METAL							
Nontoll-refined:							
1989	47	289	2	—	—	2	339
1990	2	62	—	—	—	—	64
1991	11	205	—	—	—	—	216
1992	W	W	—	—	—	—	W
1993	W	W	—	—	—	—	W
SECONDARY METAL							
Nontoll-refined:							
1989	1,134	2,664	6	—	94	35	3,933
1990	1,928	3,672	7	—	178	34	5,819
1991	2,200	2,297	81	—	215	13	4,806
1992	[r]2,133	[r]2,903	(2)	—	(3)	(2)	[r]5,327
1993	2,521	2,184	(2)	—	(3)	(2)	4,837
Toll-refined:							
1989	24,058	20,037	219	1	1,565	373	46,253
1990	38,475	23,297	130	—	3,094	433	65,429
1991	39,394	24,045	128	4	3,080	891	67,543
1992	[r]27,001	[r]27,547	(2)	(2)	(3)	[r]1,325	[r]58,982
1993	30,553	26,053	(2)	(2)	(3)	1,109	60,955
1992 TOTALS[1]							
Total primary	W	W	—	—	—	—	W
Total secondary	[r]29,134	[r]30,449	(2)	(2)	[r]3,218	[r]1,325	[r]64,309
Total refined metal	[r]29,134	[r]30,449	(2)	(2)	[r]3,218	[r]1,325	[r]64,309
1993 TOTALS[1]							
Total primary	W	W	—	—	—	—	W
Total secondary	33,074	28,237	(2)	(2)	3,167	1,109	65,792
Total refined metal	33,074	28,237	(2)	(2)	3,167	1,109	65,792

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

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

[2] Withheld to avoid disclosing company proprietary data; included in "Total."

[3] Withheld to avoid disclosing company proprietary data; included in "Total" and "Total refined metal."

TABLE 3

PLATINUM-GROUP METALS[1] SOLD TO CONSUMING INDUSTRIES IN THE UNITED STATES

(Kilograms)

Year and industry	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total[2]
1989:							
Reported	33,698	39,273	400	57	3,019	2,037	78,483
Apparent consumption[3]	47,035	45,299	604	30	6,112	2,129	101,209
1990:							
Reported	36,055	35,116	448	40	4,187	1,641	77,487
Apparent consumption[3]	49,875	51,464	649	56	12,314	2,685	117,043
1991:							
Reported	31,112	25,747	359	30	3,778	1,571	62,597
Apparent consumption[3]	44,385	57,521	600	44	6,964	2,285	111,798
1992:							
Automotive[4]	20,503	2,930	—	—	2,930	—	26,363
Chemical	1,716	1,916	44	—	157	181	4,015
Dental and medical	635	5,085	111	40	1	11	5,883
Electrical	2,865	13,318	258	—	73	2,344	18,858
Glass	360	126	—	—	15	8	509
Jewelry and decorative	905	798	25	—	196	27	1,951
Petroleum	1,036	750	—	—	—	42	1,828
Miscellaneous	3,225	3,600	5	[r]1	558	4	7,394
Total[2]	31,245	28,523	444	41	3,930	2,617	66,801
Apparent consumption[3]	45,606	54,485	207	-19	6,873	2,317	109,469
1993:							
Automotive[4]	19,446	5,001	—	—	5,123	—	29,570
Chemical	(5)	(5)	(5)	—	(5)	W	(5)
Dental and medical	(5)	5,147	(5)	W	(5)	W	5,978
Electrical	(5)	9,454	(5)	—	(5)	W	11,962
Glass	(5)	(5)	(5)	—	(5)		(5)
Jewelry and decorative	1,179	914	(5)	—	160	W	2,338
Petroleum	(5)	(5)	(5)	—	(5)	W	(5)
Miscellaneous	2,675	880	W	—	578	W	4,133
Total	29,801	23,837	528	W	6,106	W	60,272
Apparent consumption[3]	47,023	64,815	955	219	(5)	(5)	123,273

[r] Revised. W Witheld to avoid disclosing company proprietary data.

[1] Comprises primary and nontoll-refined secondary metals.

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

[3] Defined as mine production plus nontoll production of secondary metal plus refined imports minus refined exports plus beginning stocks minus ending stocks. Export data for iridium, osmium, and ruthenium are not available separately; in this calculation, the collective export figure was assigned to ruthenium.

[4] 1989-93 platinum, palladium, and rhodium sales to the automotive industry are estimated based on U.S. light truck sales and U.S. automobile production.

[5] Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 4
REFINER, IMPORTER, AND DEALER STOCKS OF REFINED PLATINUM-GROUP METALS[1] IN THE UNITED STATES, DECEMBER 31

(Kilograms)

Year	Platinum	Palladium	Iridium	Osmium	Rhodium	Ruthenium	Total
1989	14,791	15,182	522	36	1,096	916	32,543
1990	13,421	14,425	483	55	1,089	851	30,324
1991	10,349	12,263	483	46	318	854	24,313
1992	14,187	10,641	W	122	364	W	26,946
1993	10,263	8,324	W	42	134	W	20,199

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

[1] Includes metal in depositories of the New York Mercantile Exchange (NYMEX); on Dec. 31, 1993; this comprised 3,524 kilograms of platinum and 1,148 kilograms of palladium.

TABLE 5
U.S. EXPORTS OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

Year and country	Platinum (kilograms)	Palladium (kilograms)	Rhodium (kilograms)	Iridium, osmium, ruthenium (kilograms)	Ores and concentrates (kilograms)	Waste and scrap (kilograms)	Total[1] Quantity (kilograms)	Total[1] Value (thousands)
1992	12,103	17,701	[r]836	[r]420	[r]488	26,279	[r]57,830	$382,016
1993:								
Australia	79	99	—	—	—	1	179	1,017
Belgium	2,066	5,744	—	—	—	11,999	19,808	60,888
Brazil	3	3	—	—	—	3	10	92
Canada	569	1,260	14	18	—	4,144	6,005	27,243
China	—	—	22	—	—	16	38	1,109
France	227	304	2	1	32	298	864	7,996
Germany	625	296	—	62	—	1,788	2,770	13,687
Hong Kong	131	20	20	8	—	14	193	2,400
Italy	51	677	—	—	4	804	1,536	9,038
Japan	5,555	4,907	313	424	—	3,204	14,403	130,861
Korea, Republic of	888	217	1	3	5	—	1,114	10,925
Netherlands	44	2,776	319	—	47	6	3,191	19,606
Russia	—	—	—	23	—	—	23	231
Singapore	7	898	—	7	—	—	912	2,736
Sweden	59	104	—	—	—	369	532	2,388
Switzerland	3,213	4,352	—	66	—	1	7,632	68,006
Taiwan	8	1,944	—	2	6	—	1,960	6,091
United Kingdom	1,948	2,063	16	26	—	11,974	16,026	66,711
Other	673	578	60	3	4	7	1,325	10,028
Total	16,146	26,242	767	643	98	34,628	78,521	441,053

[r] Revised.

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

Source: Bureau of the Census.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF PLATINUM-GROUP METALS, BY YEAR AND COUNTRY

Year and country	Platinum (kilograms)	Palladium (kilograms)	Rhodium (kilograms)	Ruthenium (kilograms)	Iridium (kilograms)	Osmium (kilograms)	Waste and scrap (kilograms)	Ores (kilograms)	Total	
									Quantity (kilograms)	Value (thousands)
1992	[1]57,573	61,093	7,753	2,736	207	57	2,587	—	[1]132,006	$1,483,680
1993:										
Australia	577	—	—	—	—	—	308	—	885	9,641
Belgium	3,054	11,096	246	—	—	—	—	—	14,396	88,798
Canada	631	2,242	—	7	2	—	278	41	3,201	20,510
Columbia	2,335	(2)	—	—	—	—	—	—	2,335	19,186
France	(2)	(2)	23	—	—	—	585	—	608	2,884
Germany	1,726	3,424	170	374	109	1	(2)	1	5,805	40,919
Hong Kong	(2)	—	—	—	—	—	369	—	369	2,562
Italy	551	109	36	—	—	—	74	—	770	9,084
Japan	583	2,813	34	—	—	—	28	—	3,458	19,325
Mexico	14	20	3	—	—	—	1,109	—	1,146	12,276
Netherlands	(2)	63	199	—	—	—	12	—	274	9,003
Norway	440	627	43	—	—	—	11	—	1,121	7,952
Russia	4,428	21,367	2,033	16	(2)	—	4	—	27,848	205,175
South Africa, Republic of	31,836	22,906	3,784	3,591	675	126	—	—	62,918	629,500
Switzerland	3,781	1,080	377	84	17	—	—	—	5,339	64,445
Taiwan	(2)	509	—	—	—	—	212	—	721	5,570
United Kingdom	6,693	12,139	228	416	93	3	1,172	—	20,744	154,280
Other	547	480	29	—	—	—	171	—	1,227	9,785
Total	[3]57,196	78,875	7,205	4,488	896	130	4,333	42	[3]153,165	1,310,895

[1] Of this amount, 2,544 kilograms was in the form of platinum coins.

[2] Less than 1/2 unit.

[3] Of this amount, 967 kilograms was in the form of platinum coins.

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

TABLE 7
PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Australia, metal content, from domestic nickel ore:[e] [3]					
Platinum	100	100	100	100	100
Palladium	400	400	400	400	400
Canada:[4]					
Platinum[e]	4,467	5,044	4,683	[r]4,800	5,500
Palladium[e]	4,676	5,269	6,439	[r]5,800	6,900
Other[e]	1,246	1,396	586	[r]1,307	1,407
Total	10,389	11,709	11,708	[r]11,907	[5]13,807
Colombia: Placer platinum	973	1,316	1,603	[r]1,956	2,000
Ethiopia: Placer platinum[e] [6]	2	2	1	1	1
Finland:[e]					
Platinum	60	60	60	60	60
Palladium	100	100	100	100	100
Japan, metal recovered from nickel-copper ores:[7]					
Platinum	1,031	1,425	988	[r]629	660
Palladium	821	1,047	1,053	[r]986	1,200
Russia: Placer platinum and platinum-group metals recovered from nickel-copper ores:[e] [8]					
Platinum	—	—	—	28,000	20,000
Palladium	—	—	—	[r]70,000	50,000
Other	—	—	—	[r]6,000	4,000
Serbia and Montenegro:[9]					
Platinum	—	—	—	[e]10	10
Palladium	—	—	—	[r] [e]60	50
South Africa, Republic of: Platinum-group metals from platinum ore:[4] [10]					
Platinum[e]	82,884	87,813	88,861	[r]94,891	92,000
Palladium[e]	35,800	38,300	38,000	[r]41,000	41,000
Other[e]	15,000	15,800	16,000	17,000	17,000
Total	133,684	141,913	142,861	[r]152,891	150,000
U.S.S.R.: Placer platinum and platinum-group metals recovered from nickel-copper ores:[e] [8] [11]					
Platinum	32,000	31,000	30,000	—	—
Palladium	85,000	84,000	82,000	—	—
Other	10,500	10,000	9,500	—	—
United States: Platinum-group metals from palladium ores:[e] [12]					
Platinum	1,430	1,810	1,730	1,840	1,800
Palladium	4,850	5,930	6,050	6,470	6,500
Yugoslavia:[9] [13]					
Platinum	23	21	[r] [e]22	—	—
Palladium	199	130	[e]120	—	—
Zimbabwe:					
Platinum	25	21	19	[r]9	10
Palladium	43	31	30	[r]19	20
Grand total[14]	281,629	291,015	[r]288,343	[r]281,438	250,718

See footnotes at end of table.

TABLE 7—Continued

PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1]

(Kilograms)

Country[2]	1989	1990	1991	1992	1993[e]
Grand total[14]—continued:					
Of which:					
Platinum	122,994	128,611	[r]128,065	[r]132,296	122,141
Palladium	131,889	135,207	134,192	[r]124,835	106,170
Other	26,746	27,196	26,086	[r]24,307	22,407

[e]Estimated. [r]Revised.

[1] Table includes data available through May 25, 1994. Platinum-group metal production by Germany (Western states), Norway, and the United Kingdom is not included in this table because the production is derived wholly from imported metallurgical products and to include it would result in double counting.

[2] In addition to the countries listed, China, Indonesia, Papua New Guinea, and the Philippines are believed to produce platinum-group metals, and several other countries may also do so, but output is not reported quantitatively, and there is no reliable basis for the formulation of estimates of output levels. However, a part of this output not specifically reported by country is presumably included in this table credited to Japan. (See footnote 7).

[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 7).

[4] Unless otherwise indicated, data show estimated proportions of platinum, palladium, and other platinum-group metals within the reported total.

[5] Reported preliminary estimate.

[6] Data are for years ending July 7 of the years listed.

[7] 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.

[8] All production in the U.S.S.R. from 1989-91 came from Russia.

[9] All production in Yugoslavia from 1989-91 came from Serbia and Montenegro.

[10] Includes osmiridium produced in gold mines.

[11] Dissolved in Dec. 1991.

[12] Estimates for the Stillwater Mine, from published sources. A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.

[13] Dissolved in Apr. 1992.

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

POTASH

By James P. Searls

Mr. Searls, a physical scientist and economist, has been a commodity specialist for 14 years. Domestic survey data were prepared by Kelly Dorney, statistical assistant; and international data were prepared by Theodore Spittal, international data coordinator.

Potash is the third of the three essential nutrients for plant growth, fixed nitrogen, phosphorus, and potassium. There are no substitutes for these elements in lifeforms on this Earth. As fertilizers they are essential to the intensive agriculture system, which has allowed more people to live on the production of more food from less crop area.

U.S. potash production in terms of potassium oxide (K_2O) equivalent decreased about 12% compared with that of 1992 because of the permanent closure of a Carlsbad, NM, muriate of potash mine. Apparent consumption increased about 2% in spite of the summer floods because of relatively greater autumn applications of potash. Prices increased less than 2% owing to larger amounts of sulfate of potash (SOP) and sulfate of potash magnesia being sold relative to muriate of potash sales and the much higher unit prices for SOP and sulfate of potash magnesia. Yearend producers' stocks increased about 8% in terms of tons, K_2O.

DOMESTIC DATA COVERAGE

The U.S. Bureau of Mines developed potash domestic data from voluntary semiannual surveys of U.S. operations. Of the 12 survey requests sent to operations in the first half of the year, 10 responded, and data concerning the 11th was provided by another U.S. Department of the Interior agency. In the second half of the year, the 11th company was not in production. The 12th operation was estimated in both the first and second half of the year. Responses to the U.S. Bureau of Mines surveys and data from another agency provided about 97% of total production shown in table 3.

ANNUAL REVIEW

Issues

A muriate of potash operation closed permanently in April, and a receiver occupied the premises. The receiver sold movable equipment, but not plant or real estate, by auction in December. The holder of the bond for reclamation and abandonment refused to perform under the bond at the end of the year.

The Carlsbad potash industry considered an antidumping action against the former U.S.S.R. but filed a petition to the President under Section 406(d) of the Trade Act of 1974 for consultations with Belarus, Russia, and Ukraine. The Russian Foreign Economic Relations Ministry agreed to the concept of consultations, but consultations were not held concerning potash in 1993.

The suspension of the antidumping investigation against the Canadian potash producers by the U.S. Department of Commerce, International Trade Agency, was continued for another year.

Several civil antitrust lawsuits were filled in California, Illinois, Minnesota, and New York in April. The cases were consolidated into one case in the Federal District Court in St. Paul, MN, where all information from a former employee for Potash Corp. of Saskatchewan (PCS) was considered tainting and disqualifying; all lawyers having direct or indirect contact with the former General Counsel were disqualified.

The U.S. Department of Justice, Anti-Trust Division, convened a grand jury in Cleveland, OH, to hear evidence concerning allegations of antitrust behavior by U.S. producers. Subpoenas were issued for company records concerning possible criminal activity.

Production

Domestic potash production, in terms of K_2O content, declined about 12% to 1.5 million metric tons[1] in 1993 from that in 1992. *(See tables 1 and 2.)* Of the total production for the year, 66% was standard, coarse, and granular muriate of potash (MOP), also known as potassium chloride (KCl), and 17% was SOP, also known as potassium sulfate. The remaining 17% of production included manure salts, soluble and chemical grades of muriate of potash, and sulfate of potash magnesia, also known as potassium magnesium sulfate. In muriate of potash, "standard," "coarse," and "granular" refer to their particle sizes and are known as the three muriates, a term that ignores the soluble and chemical grades. "Standard" and "soluble" grades of muriate of potash and sulfate of potash also have industrial end uses. "Manure salts" formerly referred to high-grade "run-of-mine" ore and was applied to a few crops; 25% K_2O sylvinite ore is approximately 40% KCl, which can be used on sugar beets. Currently, it refers to a mixture of white KCl and sodium chloride (NaCl or table salt) for industrial uses.

The New Mexico potash producers accounted for 81% of the total marketable potash salts production. The production of crude salts (ore) in New Mexico was 13.0 million tons, excluding Horizon Potash Corp.'s crude ore production, with an average K_2O content of 12.5%, a 2% decrease in ore grade from that of 1992. Four producers operated five mines at the end of 1993. *(See table 3.)* Horizon shut down permanently on April 23d, the day the petition for consultation with the potash producers of Belarus, Russia, and Ukraine was filed with the Office of the U.S. Trade Representative. The company cited the low price of potash in the southern United States and Latin America for its demise. About 340 employees were laid off. Other producers were Eddy Potash Inc., owned by Trans-Resources Inc.; IMC Fertilizers Inc. (IMCF); Mississippi Potash, Inc.; New Mexico Potash Corp., owned by Trans-Resources Inc.; and Western Ag-Minerals Co., owned by Rayrock Resources of Toronto, Canada. Mississippi Chemical Corp.'s potash mine became Mississippi Potash, Inc., a separate subsidiary on July 1. Mississippi Potash announced plans in August to (1) increase production by operating at full capacity rather than 10 days on and 4 days off, and (2) install a compactor bought from the closed potash refinery to increase granular MOP capacity. Mississippi Potash has more than 100 years of reserves and plans to serve some of the closed mine's former customers. *(See table 4.)*

All the New Mexico potash producers mined underground bedded ore zones and all except Western Ag-Minerals mined sylvinite ore (the mixture of sylvite and halite) from which muriate of potash originates and beneficiated the ore to 95%-pure (60% K_2O) muriate of potash. Several forms of beneficiation were used; the flotation of sylvite (potassium chloride) from halite (sodium chloride) was used at Eddy Potash and Mississippi Potash. The IMCF plant used both heavy-media separation and flotation. New Mexico Potash used hydrocyclones to wash away some of the 6% clay in the ore, leached the sylvite crystals, separated more clay in hydrocyclones and thickeners, then produced white muriate of potash in crystallizers. Western Ag-Minerals mined langbeinite ore and beneficiated the ore by dissolving the halite with water to liberate sulfate of potash magnesia (potassium magnesium sulfate). IMCF mined langbeinite ore that was beneficiated by heavy-media separation and flotation to produce sulfate of potash magnesia. With both langbeinite and sylvite products, IMCF reacted fractions of each potash product to produce sulfate of potash. Some muriate of potash from New Mexico was sold to a domestic potassium nitrate manufacturer who produced about 50,000 tons.

In Utah, Moab Salt Inc. produced muriate of potash for Texasgulf Inc., owned by Elf Aquitaine Inc., from an underground bedded sylvinite deposit by two-well solution mining and solar evaporation. The sylvinite salts from the solar ponds were beneficiated by flotation to separate sylvite from halite. Great Salt Lake Minerals Corp. (GSLMC), of Harris Chemical Group, produced sulfate of potash from the brines of the North Arm of the Great Salt Lake by solar evaporation and a proprietary process of fractional crystallization. GSLMC purchases muriate of potash from other sources for conversion to sulfate of potash owing to an excess of sulfate ions in the lake brine concentrate, but these purchases of muriate of potash were not factored into 1993 numbers owing to scheduling errors. The Reilly-Wendover operation of Reilly Industries produced muriate of potash and manure salts from near-surface brines at the west end of the Bonneville Lake.

In California, the muriate and sulfate of potash (and other products) operation at Searles Lake, owned by North American Chemical Corp. of Harris Chemical Group, continued to produce by solar evaporation and selective crystallization from the underground brines of the lake bed. This is the oldest (since 1915) inorganic potash production site in the United States.

In Michigan, Kalium Chemical Ltd. continued pilot plant efforts to develop the technology to extract and concentrate muriate of potash from a deep ore body.

Greensand, also known as glauconite, a natural silicate of aluminum, iron, magnesium, and potassium, was produced by Inversand Co., a subsidiary of Hungerford and Terry Inc., near Clayton, NJ. Production and sales information are withheld to avoid disclosing company proprietary data. Processed greensand was sold as a filter media for the removal of iron, manganese, and hydrogen sulfide from drinking water supply systems. Classified raw greensand was resold by Zook and Ranck Inc. as a soil conditioner and as a slowly released potash, with a K_2O equivalent between 5% and 10%, to the organic farmers of North America.

Consumption and Uses

According to the Potash & Phosphate Institute, shipments of agricultural potash from Canadian and United States producers increased by about 1% from 1992 to 1993. Shipments of nonagricultural potash increased 9% for a total (agricultural plus nonagricultural) increase of 2% from 1992 to 1993. The major States receiving agricultural potash from Canadian and United States producers, in decreasing order, were Illinois, Iowa, Ohio, Indiana, Minnesota, Missouri, and Wisconsin. *(See tables 5 and 6.)* These seven States received 53% of the total. Domestic producers accounted for 3% of agricultural shipments to Illinois, 4% of the agricultural shipments to Iowa, 7% of the agricultural shipments to Ohio, 5% of the agricultural shipments to Indiana, 1% of the agricultural shipments to Minnesota, 59% of the agricultural shipments to Missouri, and 1% of the agricultural shipments to Wisconsin. The major receiving States of domestically produced agricultural potash, in decreasing order, were Texas, Missouri, California, Kansas, Florida, Arkansas, and Louisiana, and these States received 63% of the total. The major States receiving domestically produced agricultural sulfates of potash (sulfate of potash and sulfate of potash magnesia) were, in decreasing order, Florida, California, Georgia, Kentucky, Ohio, and Texas. These six States accounted for 59% of the total. These figures do not account for the imports from the rest of the world. The potash import tonnage from the rest of the world is counted only at the port of entry and is not tracked to the State in which the potash is applied to the field.

The major States for shipments of nonagricultural potash from Canadian and United States producers, in decreasing order, were Alabama, Ohio, Delaware, Wisconsin, and Mississippi. These five States accounted for 75% of the total. Domestic producers supplied less than 1% of the first four States and 100% of Mississippi.

Stocks

Yearend producers' stocks increased 8% compared with those of 1992. Yearend stocks represented 20% of annual production or about 11 weeks of average production.

Prices

The average annual price, $193.06 per ton f.o.b. mine, of U.S. potash sales of all types and grades was about 2% greater than that of 1992. *(See table 7.)* The average price was $187.88 for the first half of the year and $200.91 for the second half of the year. The average annual price of the three grades of muriate was $127.84, down 6% from that of 1992. For the full calendar year standard grade averaged $130.56 per ton; coarse grade, $124.94 per ton; and granular grade, $126.95 per ton. The average annual price for all grades of sulfate of potash averaged $329.59 per ton, essentially unchanged.

Foreign Trade

Total potash exports from the United States as reported by the Bureau of the Census decreased 37% relative to those of 1992. *(See tables 8 and 9.)* Muriate of potash fell 49% and sulfate of potash fell 28%. Only sulfate of potash magnesia exports increased, about 14%. By half year, muriate of potash exports (in competition with the exports from the former U.S.S.R. states and others) to all countries decreased from 242,000 tons in the first half of 1992 to 184,000 tons in the second half of 1992, 121,000 tons in the first half of 1993, and 96,000 tons in the second half of 1993. Exports of muriate of potash to Latin America, where U.S. potash producers historically had transportation cost advantages, fell from 196,000 tons in the first half of 1992 to 148,000 tons in the second half of 1992, 100,000 tons in the first half of 1993, and finally 72,000 in the second half of 1993. Exports of muriate to Brazil declined from 106,000 tons in the first half of 1992 to 81,000 tons in the second half of 1992, 33,000 tons in the first half of 1993, and 29,000 tons in the second half of 1993. For 1993, 42% of all potash exports was muriate of potash shipments to Latin America while 17% of all potash exports was sulfate of potash shipments to the countries in and around the Pacific Ocean.

Potash imports for consumption into the United States as reported by the Bureau of the Census increased slightly relative to those of 1992. *(See tables 10 and 11.)* Imports of muriate of potash increased by less than 3% while sulfate of potash increased by nearly 29%. Potassium nitrate imports fell by 28%. Imports of muriate of potash from Canada increased to 3.84 million tons. Muriate of potash from Canada was about 90% of total potash imports and about 72% of total U.S. consumption of potash. Imports from the former U.S.S.R. (Russia, Belarus, and from those two countries passing through Latvia) rose by about 4% to 205,000 tons. These imports provided less than 5% of potash imports and less than 4% of total U.S. consumption of potash. Imports of muriate from Israel rose 94% to 142,000 tons.

World Review

World potash production was estimated to have declined about 13% from that of 1992. *(See table 12.)* Production has declined about 11 million tons in the past 5 years, a drop of 34.5% from the production level of 1988. World price, as exemplified by the per ton price of standard muriate of potash, f.o.b. Vancouver, Canada, was about $167 per ton ($100 per ton product) in January and February, jumping to about $182 per ton in March, and declining to about $177 per ton in December.[2] This price would have been lower had Canpotex Ltd. attempted to compete in the South American market where pricing was much lower.

Argentina.—Potasio Rio Colorado SA of Minera Tea has reported an ore grade of 27% to 28% K_2O. Minera Tea has written of a 150,000-ton-per-year K_2O muriate of potash for 25 years, which calculates to about a 5-million-ton reserve using solution mining technology. FMC Lithium International is investigating the Salar del Hombre Muerto for lithium production; potash may be a byproduct of the operation.

Belarus.—The potash producer in Belarus produced only 1.95 million tons from a capacity of 5.6 million tons in 1993 as it struggled with gas supply dislocations, reduced domestic consumption, and fluctuations in potash exports owing to several factors, such as loss of rail cars at new national boundaries, inability to coordinate train shipment arrivals with vessel arrivals, and transportation price increases. Domestic consumption has been suppressed partially because approximately one-quarter of the arable crop land was rendered unusable by fallout from the Chernobyl nuclear station accident in 1988. Potash was exported through the Latvian port of Ventspils. Belarus potash passed through Ventspils more easily than Russian potash. The Belarus potash producers announced their intent to jointly construct an exporting dock in Gdansk, Poland, with Gdansk port officials. Rail freight tariffs increased by 50% in October, but it is not clear how much this affected sales. Belarus sold through the export group AgroChemExport, a former state operation, through the year but the three large potash producers, including Beloruskalii, planned to form their own sales organization in 1994.

Bolivia.—FMC Lithium International has ceased consideration of the Salar de Uyuni for lithium production and the possible byproduct potash.

Brazil.—The potash mine in Sergipe Province was leased from Petrobrás S.A., the Brazilian national petroleum company, through its subsidiary Petrobrás Mineraçào S.A. (Petromisa) by Companhia Vale do Rio Doce, a state-owned mining company in January 1992. The operational branch is named Unidade Operacional do Rio Doce. The new operator planned to increase production, to a 180,000-ton-per-year rate, then up to a 300,000-ton-per-year rate. Reserves are estimated to be 12 million tons, and the ore grade was placed at 17.4% K_2O.

Canada.—From an annual capacity of 12 million tons per year, Canadian potash companies produced 6.85 million tons in response to sales of only 7 million tons and efforts to reduce relatively large end-of-year stocks. Mines at Cory and Lanigan operated at about 30% capacity, and the sum of all the Canadian potash mine temporary closures was 142 mineweeks.[3] The Canadian average unit value of muriate of potash sales was C$79 per ton of product (C$129.50 per ton K_2O), a decrease of C$6 per ton of product from that of 1992. Operations at Saskatchewan mines produced about 85% of Canada's total potash production while operations at New Brunswick mines produced the remaining 15%. The Potash Corp. of Saskatchewan (PCS), with mines in Saskatchewan and New Brunswick, operated at 40% capacity for the year to control product inventories.

Rio Algom Ltd. sold its Potash Co. of America mines to PCS in September for C$160 million plus C$30 million of working capital. The sale included the solution mine at Patience Lake in Saskatchewan, the underground Penobsquis Mine near Sussex, New Brunswick, and the warehouse and dock in St. John, New Brunswick. The PCS news release[4] mentioned that Patience Lake "...produced 300,281 tons with 89 employees" in 1992 while the New Brunswick mine's capacity was placed at 716,683 tons and produced 671,324 tons of product in 1992 with 350 employees. Production from the Patience Lake Mine continued to be exported through the Canpotex while production from the Sussex Mine continued to be exported independently. Kalium Chemical announced a 5-year, C$45 million conversion of capacity from agricultural sales to nonagricultural grades of potash. The Province of Saskatchewan sold its last shares of PCS stock in December, ending the Province's 17 years of potash involvement, just after PCS acquired more than 50% of Provincial potash capacity. Since the autumn of 1986, the Province has not been in active management and has sold off shares. Formed as a crown corporation in 1976 with the aim of acquiring one-half of the Provincial potash capacity, the firm lost C$103 million (operating loss was put at C$47 million) on sales of 3,765,000 tons of product (or about C$27.45 lost per ton) in 1986 and was quickly privatized. Big Quill Resources, the Saskatchewan potassium sulfate (SOP) producer on Big Quill Lake, announced expansion plans, from 2,000 tons per year to about 10,000 tons per year, for an investment of C$550,000. It produced SOP from MOP and Big Quill Lake water, which is rich in sulfate ions, using ion exchange technology. Entreprise Minière et Chimique reported that Potacan Mining Co.'s Clover Hill Mine in New Brunswick reached profitability in 1992, earning C$9.2 million.

In April, there were several civil antitrust suits filed against the Canadian (and most of the United States) potash producers. The suits were filed in New York and Minnesota on behalf of several small fertilizer retailers. It was consolidated into one suit, including a later California suit, in U.S. District Court in St. Paul, MN. In December, any information from a former employee of PCS who was general counsel for some period of time was disqualified by the Federal judge for violating ethical obligations, and any lawyer who received information from that lawyer was declared tainted. The remaining lawyers had the option to refile an amended complaint. In November, both the Canadian Director of Investigation and Research, under the Competition Act, and the U.S. Justice Department's Anti-Trust Division commenced investigations of their respective potash industries.

Chile.—Minera Yolanda Ltda. received $9 million ($7 million in loans and $2 million in equity financing) from the Inter-American Investment Corp. for development of surface deposits of nitrates and iodine. The property is known as the Taltal Project, and Kap Resources Ltd. of Vancouver, British Columbia, Canada, continued to develop the property. Potassium nitrate, sodium nitrate, and iodine were the projected coproducts. Sociedad Quimica y Minera S.A. (Soquimich) purchased Molibdenos y Metales' 11.25% portion of the Minsal project, giving Soquimich 75% ownership of the property.

China.—Israel and China reported studies of a sulfate of potash project in southern China. China was considering participating in a 90,000-ton-per-year potassium nitrate expansion plant at Mishor Rotem in Israel. The agreement between Israel and China concerning the Qinghai project for 480,000 tons of MOP was finalized in early October.

Eritrea.—Newly separated from Ethiopia after 30 years of civil war, Eritrea has asked any mining company for help with its economy by exploiting what few minerals it has, including potash resources in the Dallol region.

European Community.—The European Commission reopened the investigation of the prices of Russian MOP after being informed by Western European potash producers that Russian potash was suspected of being sold at prices lower than the 1992 minimum prices. The European Commission also reviewed the combination of West German and former East German potash companies. The Commission acknowledged, late in the year, the German market dominance by the combination but considered that the former East German companies could not compete very well alone or as owned by someone else. The West German and former East German potash mining companies were allowed to combine but told to discontinue cooperation with Entreprise Minière et Chimique, the French potash producer, in European sales and in exports through Kali-Export.

France.—Entreprise Minière et Chimique (EMC) reported losses of F500 million in 1992 due to former U.S.S.R. dumping, a 30% decrease in French potash consumption due to the Common Agricultural Policy, and a price drop in France. The company will continue to need subsidies from the state to provide retirement funds for the employees and operating funds until the last Alsatian mine closes in 2004. After that, the company intended to continue mining potash in New Brunswick and Manitoba, Canada. The Government of France started a divestiture program of 21 holdings, including Société Nationale Elf Aquitaine, which owns the U.S. firm Texasgulf Chemical Co., which owns a small potash mine in Utah.

Germany.—The European Commission on Monopolies allowed Kali & Salz and Mitteldeutsche Kali to form a single company, but the single company will have to compete with French potash throughout Europe. The Commission noted that German potash capacity has dropped to about 56% of the preunification total. The unification will cost DM1.5 billion, paid through Treuhandanstalt to the new company. Kali und Salz will have to withdraw from Kali Export. Only in the Potash Co. of Canada (Potacan) joint venture can Kali and Salz and EMC continue to cooperate, but potash from that mine must be marketed separately and competitively in Europe.

India.—In June, the Ministry of Agriculture announced a program for reduced subsidies for imported muriate of potash. The subsidy will be Rs1,000 per ton of MOP, reducing prices from the Rs4,600 to 4,900 range down to Rs3,600 to 3,900 range.

Israel.—Israel was considering building a potassium nitrate plant in southern China along with a potassium sulfate plant. Israel formed a joint venture with Alkim Alkali Kimya of Turkey to build a potassium sulfate plant in Turkey.

Jordan.—Arab Potash Co. Ltd. (APC) reported that potash was very important to the economy of Jordan. Potash exports accounted for 15% of total Jordan exports, and sales (all exports) were 3.3% of the Jordanian gross domestic product. APC announced plans in May to commence development of the bromine, magnesium, and sodium chloride resources of the Dead Sea. APC also has commenced studies for 75,000 tons per year of product of SOP in Safi or Aqaba and mentioned future plans for a potassium hydroxide, potassium carbonate, and potassium nitrate plant.

Russia.—The Russian agricultural economy was in turmoil as that economy continued to convert from planned production to independent production with no money and diminished state-allocated inputs. The producers of fertilizers, including potash, changed, temporarily, to exports to maintain production and cash-flow for the schools and hospitals of the mining towns. The potash production managers had to change managerial styles as they dealt with their changing cost structures and markets. Uralkalii (formerly Berezniki) and Sylvinit (formerly Solikamsk) combined produced 2.6 million tons from a capacity of 7.7 million tons.

Russian fertilizer consumption continued to decline as farmers did not receive free market prices for their production, therefore receiving little money for investment in fertilization. Russian potash shipments to Western Europe were restrained by a European Commission dumping duty. Potash exporters had to turn toward the rest of the world, especially Asia, to expand their market. India and China decreased imports in late 1992, and Russian potash exporters could only ship toward South America and Pacific Basin countries. A small but significant amount found its way into the Mississippi River Basin to add to U.S. potash producers' problems.

Some of Russia's potash exports passed through a Latvian port. Rail freight tariffs increased by 50% in October, but it is not clear how much this affected sales. Uralkali and Sylivinit sold through the export group AgroChemExport, a former state operation, throughout the year, but the three large potash producers, including Beloruskalii, planned to form their own sales organization in 1994.

Spain.—The workers of Potasas del Llobregat struck in February over plans to release 347 of the 850 miners employed. The mine is now part of Teneo, still part of Instituto Nacional de Industria (INI), the large state holding company. The Teneo group is the profitable portion of INI, and the release of 347 workers was part of the "profitablility" plan.

Turkey.—Alkim Alkali Kimya was investigating a joint project with the Dead Sea Works Ltd. of Israel. The joint venture was constructing a pilot plant to investigate the solvent extraction of SOP. For the present this would be a pilot plant effort in Turkey. If successful, the companies were considering a 75,000-ton-per-year plant.

United Kingdom.—Minorco SA of Luxembourg announced in September an asset swap with Anglo-American Corp. that would transfer ownership of Cleveland Potash Ltd. to Minorco.

OUTLOOK

The world potash industry was in a situation of overcapacity in 1993 and seemed likely to remain so for at least a decade. The United States will lose more capacity (another mine) before the year 2000, but also has a workable solution mine in central Michigan seeking a solution to an unspecified problem(s). It seems likely to start up before the year 2000 because it is extremely close to the world's largest potash-consuming area and will use a mining technology that is relatively low cost. Some cautious development in Thailand may come on-stream around the turn of the century or shortly thereafter as a Canadian developer takes an in-depth look at the Udon Thani (silvinite) concession. The ASEAN Potash Mining Co. Ltd. (carnallite) concession in Thailand has problems with the disposition of magnesium chloride brine. The Government of China signed a joint venture with Israel to further develop the closed, nonmarine Qaidam Basin that contains Lake Qarhan; production on a large scale is still problematic. The Colorado River potash property in Argentina is apparently a small but high-quality resource in an undeveloped area. It will probably be viable when the region has more infrastructure.

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[1] All tonnages are reported in metric tons, K_2O equivalent, unless otherwise noted.

[2] The British Sulphur Corp. (London). Price Trends, Phosphorus & Potassium. No. 189, Jan.-Feb. 1994, p. 3.

[3] Personal communications with Michel Prud'homme, Canadian Dep. of Natural Resources.

[4] News Release. Potash Corp. of Saskatchewan Inc. Purchases Potash Co. of America Mines From Rio Algom. Sept. 6, 1993.

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TABLE 1

SALIENT POTASH[1] STATISTICS

(Thousand metric tons and thousand dollars, unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Production		3,132	3,360	3,446	3,341	3,067
K_2O equivalent		1,595	1,713	1,749	1,705	1,506
Sales by producers		3,008	3,391	3,327	3,467	3,031
K_2O equivalent		1,536	1,716	1,709	1,766	1,484
Value[2]		$271,500	$303,300	$304,500	$334,406	$286,001
Average value per ton of product	dollars	$90.28	$89.46	$91.52	$96.45	$94.36
Average value per ton of K_2O equivalent	do.	$176.74	$176.80	$178.20	$189.36	$192.72
Exports[3]		945	1,016	1,256	1,330	935
K_2O equivalent		446	470	624	663	415
Value[4]		NA	$136,100	NA	NA	NA
Imports for consumption[3] [5]		[6]5,618	6,952	6,862	[r]7,013	7,204
K_2O equivalent		[6]3,410	4,164	4,158	[r]4,248	4,363
Customs value		$501,300	$545,700	$549,600	[r]$580,435	$577,874
Consumption, apparent[7]		[6]7,680	9,327	8,933	[r]9,150	9,300
K_2O equivalent		[6]4,500	5,410	5,243	[r]5,351	5,432
Yearend producers' stocks, K_2O equivalent		307	303	343	283	305
World: Production, marketable K_2O equivalent		[r]29,276	[r]27,493	[r]26,136	[r]24,044	[e]20,864

[e] Estimated. [r] Revised. NA Not available.

[1] Includes muriate and sulfate of potash, potassium magnesium sulfate, and some parent salts. Excludes other chemical compounds containing potassium.

[2] F.o.b. mine.

[3] Excludes potassium chemicals and mixed fertilizers.

[4] F.a.s. U.S. port.

[5] Includes nitrate of potash.

[6] Imports probably underreported.

[7] Calculated from sales plus imports minus exports.

TABLE 2
PRODUCTION, SALES, AND INVENTORY OF U.S. PRODUCED POTASH, BY TYPE AND GRADE

(Thousand metric tons and thousand dollars)

Type and grade	Production				Sold or used						Stocks, end of 6-month period			
	Gross weight		K_2O equivalent		Gross weight		K_2O equivalent		Value[e] [1]		Gross weight		K_2O equivalent	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
January-June:														
Muriate of potash, 60% K_2O minimum:														
Standard	340	274	[r]207	168	351	267	214	163	[r]28,414	21,059	97	99	59	60
Coarse	92	62	57	38	123	98	75	60	[r]9,671	7,255	33	9	20	5
Granular	642	525	391	319	722	621	439	377	[r]59,063	46,826	132	79	80	48
Chemical	9	7	5	4	9	7	5	4	W	W	1	2	1	1
Potassium sulfate	246	282	125	143	305	286	154	145	[r]50,293	47,642	56	63	29	32
Other potassium salts[2]	398	419	106	114	497	506	129	137	W	W	143	148	31	37
Total[3]	1,728	1,569	891	787	2,007	1,786	1,016	887	[r]192,199	166,642	462	399	220	183
July-December:														
Muriate of potash, 60% K_2O minimum:														
Standard	324	272	198	167	320	227	195	139	26,700	18,384	98	144	60	88
Coarse	101	89	62	54	90	84	54	51	[r]7,426	6,774	45	14	28	8
Granular	533	410	323	249	492	313	299	191	[r]41,507	25,313	175	175	106	106
Chemical	7	6	4	4	7	7	4	4	W	W	1	1	1	1
Potassium sulfate	232	213	118	108	221	196	113	100	[r]37,591	33,136	68	80	34	40
Other potassium salts[2]	416	508	109	137	331	418	85	113	W	W	228	238	55	62
Total[3]	1,613	1,498	814	719	1,460	1,246	750	597	142,206	119,358	616	652	283	305
Grand total[3]	3,341	3,067	1,705	1,506	3,467	3,031	1,766	1,484	334,406	286,001	XX	XX	XX	XX

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." XX Not applicable.

[1] F.o.b. mine.

[2] Includes soluble muriate, manure salts, and potassium magnesium sulfate.

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

TABLE 3
PRODUCTION AND SALES OF POTASH IN NEW MEXICO

(Thousand metric tons and thousand dollars)

Period	Crude salts[1] (mine production)		Marketable potassium salts				
			Production		Sold or used		
	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Gross weight	K_2O equivalent	Value[e] [2]
1992:							
January-June	8,247	1,095	1,439	731	1,658	826	145,578
July-December	7,792	949	1,345	663	1,212	610	111,042
Total[3]	16,039	2,044	2,783	1,395	2,869	1,436	256,620
1993:							
January-June	6,323	794	1,292	637	1,488	725	125,753
July-December	6,640	822	1,254	581	1,010	465	90,105
Total[3]	12,963	1,616	2,546	1,218	2,497	1,190	215,858

[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)

	1989	1990	1991	1992	1993
Production	166	219	230	243	251
Sales by producers	147	221	211	267	245
Value[2]	$47,355	$70,226	$67,432	$87,884	$80,778
Exports[3]	78	124	104	158	114
Value[4]	NA	$43,300	NA	NA	NA
Imports[3]	32	26	29	35	45
Value[5]	$11,700	$11,000	$11,800	$13,600	$17,300
Consumption, apparent[6]	101	123	136	[r]144	176
Yearend producers' stocks	42	39	58	34	40

[r]Revised. NA Not available.

[1]Excluding potassium magnesium sulfate.

[2]F.o.b. mine.

[3]Bureau of the Census.

[4]F.a.s. U.S. port.

[5]C.i.f. to U.S. port.

[6]Calculated from sales plus imports minus exports.

TABLE 5

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1992	1993	1992	1993
Alabama	86,341	92,549	169,071	161,919
Alaska	2,141	1,266	416	1,375
Arizona	3,649	2,814	782	1,093
Arkansas	62,225	54,791	602	850
California	85,358	89,505	7,333	8,441
Colorado	12,818	14,984	3,387	2,306
Connecticut	2,398	1,711	458	552
Delaware	20,779	17,666	47,968	53,351
Florida	169,878	147,210	1,545	2,014
Georgia	140,501	158,717	1,940	1,902
Hawaii	7,495	7,031	23	47
Idaho	29,381	38,798	223	411
Illinois	549,257	568,478	6,874	7,418
Indiana	310,805	317,234	3,269	3,632
Iowa	441,900	416,940	3,503	6,434
Kansas	47,723	48,121	4,166	5,680
Kentucky	127,890	124,814	674	759
Louisiana	125,756	143,579	2,461	2,834
Maine	6,734	5,890	705	670
Maryland	28,591	18,353	238	979
Massachusetts	10,776	3,729	290	413
Michigan	180,550	181,748	7,101	7,266
Minnesota	278,284	271,415	2,851	5,633
Mississippi	73,678	64,284	46,653	49,355
Missouri	253,652	237,382	3,035	4,918
Montana	13,374	15,849	68	86
Nebraska	32,772	37,635	1,310	2,315

See footnote at end of table.

TABLE 5—Continued

SALES OF NORTH AMERICAN POTASH, BY STATE OF DESTINATION

(Metric tons of K_2O equivalent)

State	Agricultural potash		Nonagricultural potash	
	1992	1993	1992	1993
Nevada	221	142	107	64
New Hampshire	452	708	243	221
New Jersey	4,289	5,278	823	670
New Mexico	7,437	3,328	12,465	18,296
New York	57,810	61,746	654	705
North Carolina	108,351	90,028	961	1,015
North Dakota	26,102	29,775	12	28
Ohio	348,282	383,063	66,048	73,707
Oklahoma	21,956	25,367	1,754	2,089
Oregon	34,724	34,473	1,373	1,278
Pennsylvania	58,048	52,293	2,517	3,124
Rhode Island	1,055	953	24	728
South Carolina	69,049	58,113	64	61
South Dakota	16,372	13,642	151	238
Tennessee	104,648	128,591	355	402
Texas	141,909	169,872	23,584	20,136
Utah	22,391	19,996	8,867	8,616
Vermont	8,262	6,254	833	138
Virginia	73,734	87,835	221	293
Washington	40,591	41,873	3,468	3,012
West Virginia	29,622	4,099	937	992
Wisconsin	206,267	227,250	33,427	50,757
Wyoming	2,531	3,154	1,299	1,792
Total[1]	4,488,808	4,530,326	477,132	521,016

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

Source: Potash & Phosphate Institute.

TABLE 6

SALES OF NORTH AMERICAN MURIATE OF POTASH TO U.S. CUSTOMERS, BY GRADE

(Thousand metric tons of K_2O equivalent)

Grade	1989	1990	1991	1992	1993
Agricultural:					
Standard	310	263	251	271	262
Coarse	2,036	1,882	1,862	1,988	1,984
Granular	1,658	1,658	1,482	1,651	1,692
Soluble	342	334	349	383	395
Total	4,346	4,137	3,944	4,293	4,333
Nonagricultural:					
Soluble	116	131	85	107	415
Other	305	314	387	365	106
Total[1]	421	445	473	472	521
Grand total[1]	4,767	4,582	4,417	4,765	4,853

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

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	1991		1992		1993	
	January-June	July-December	January-June	July-December	January-June	July-December
Muriate, 60% K_2O minimum:						
Standard	[r]126.22	[r]127.11	[r]132.77	137.05	128.88	132.61
Coarse	[r]143.17	129.17	[r]128.71	136.38	121.04	132.08
Granular	[r]135.62	[r]129.97	134.64	138.99	124.08	132.62
All muriate[2]	[r]133.18	[r]128.95	133.48	138.04	125.08	132.54
Sulfate, 50% K_2O minimum	315.67	324.32	325.87	334.03	327.76	332.24

[r] Revised.

[1] Average prices, f.o.b. mine, based on sales.

[2] Excluding soluble and chemical muriates.

TABLE 8
U.S. EXPORTS OF POTASH, BY TYPE

	Approximate average K_2O content (percent)	Quantity (metric tons)	
		Product	K_2O equivalent
1992:			
Potassium chloride, all grades	61	[r]708,474	[r]432,169
Potassium sulfate	51	[r]309,812	[r]158,004
Potassium magnesium sulfate	22	[r]292,630	[r]64,378
Potassium nitrate	45	[r]18,597	[r]8,368
Total	XX	[r]1,329,513	[r]662,919
1993:			
Potassium chloride, all grades	61	361,193	220,328
Potassium sulfate	51	223,180	113,822
Potassium magnesium sulfate	22	332,855	73,228
Potassium nitrate	45	17,782	8,002
Total	XX	935,010	415,380

[r] Revised. XX Not applicable.

Source: Bureau of the Census.

TABLE 9
U.S. EXPORTS OF POTASH, BY COUNTRY

(Metric tons of product)

Country	Potassium chloride		Potassium sulfates, all grades[1]		Potassium nitrate		Total[2]	
	1992	1993	1992	1993	1992	1993	1992	1993
Argentina	5,884	85	4,589	2,556	—	—	[r]10,473	2,641
Australia	[r]16,399	2,732	8,525	7,985	—	—	[r]24,924	10,717
Bangladesh	—	—	—	1,513	—	—	—	1,513
Belize	1,813	1,169	276	—	—	—	2,089	1,169
Bolivia	4,375	120	—	—	—	—	4,375	120
Brazil	[r]311,983	102,965	750	2,552	—	—	[r]312,733	105,517
Canada	8,515	4,327	[r]87,849	109,012	4,914	4,404	[r]101,278	117,743
Chile	[r]32,464	32,773	[r]16,426	25,917	—	—	48,890	58,690
China	—	—	[r]161,417	111,659	—	—	[r]161,417	111,659
Colombia	1	1,999	4,551	7,289	1	—	4,553	9,288
Costa Rica	[r]53,806	28,014	[r]38,166	26,588	—	—	[r]91,972	54,602
Cote d'Ivoire	—	—	4,200	—	—	—	4,200	—
Dominican Republic	[r]27,005	9,759	7,184	2,733	18	19	[r]34,207	12,511
Ecuador	[r]22,533	13,837	4,490	3,500	—	—	[r]27,023	17,337
Fiji	3,447	—	—	—	—	—	3,447	—
France	[r]44,579	—	—	—	6	—	[r]44,585	—
Guatemala	9,748	—	5	2,105	—	—	9,753	2,105
Honduras	5,951	2,999	2,174	16,438	—	—	8,125	19,437
Indonesia	3	—	[r]11,567	84	—	—	11,570	84
Italy	6,091	21,549	16,000	—	—	1	[r]22,091	21,550
Jamaica	3,249	2,800	—	—	12	—	3,261	2,800
Japan	[r]16,384	28,077	[r]127,951	115,160	9,098	9,041	[r]153,433	152,278
Korea, Republic of	6,117	6,435	646	8,030	2	2	6,765	14,467
Malaysia	—	—	—	25,219	—	—	—	25,219
Mexico	[r]63,436	50,830	[r]50,127	59,642	4,434	4,294	[r]117,997	114,766
Nicaragua	1,500	—	1,500	—	—	—	3,000	—
Panama	[r]14,282	4,183	2,905	996	—	—	[r]17,187	5,179
Peru	7,047	5,638	4,000	4,727	—	—	[r]11,047	10,365
Philippines	14,990	6	[r]14,499	1	—	—	[r]29,489	7
Saudi Arabia	—	—	1	3,300	—	1	1	3,301
South Africa, Republic of	—	—	[r]11,021	—	2	—	[r]11,023	—
Spain	1,000	—	—	19	—	—	1,000	19
Sweden	538	1,460	—	22	—	—	538	1,482
Thailand	—	10,286	5,000	10,383	—	—	5,000	20,669
Trinidad and Tobago	2,431	2,386	—	—	—	—	2,431	2,386
United Kingdom	[r]15,513	6	11	—	—	—	[r]15,524	6
Uruguay	7,266	—	—	—	—	—	7,266	—
Venezuela	5	25,914	[r]15,267	2,917	—	—	[r]15,272	28,831
Zimbabwe	—	—	—	5,050	—	—	—	5,050
Other	[r]119	844	[r]1,345	638	[r]110	20	[r]1,574	1,502
Total[2]	[r]708,474	361,193	[r]602,442	556,035	[r]18,597	17,782	[r]1,329,513	935,010

[r] Revised.

[1] Includes potassium magnesium sulfate.

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

Source: Bureau of the Census.

TABLE 10
U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY TYPE

	Approximate average K_2O content (percent)	Quantity (metric tons)		Value (thousands)	
		Product	K_2O equivalent[e]	Customs	C.i.f.
1992:					
Potassium chloride	61	[r]6,869,502	[r]4,190,396	[r]$551,808	[r]$648,996
Potassium sulfate	51	[r]67,746	[r]34,550	[r]11,779	[r]13,617
Potassium nitrate	45	[r]39,067	[r]17,580	[r]11,267	[r]12,575
Potassium sodium nitrate mixtures	14	[r]36,914	[r]5,168	[r]5,581	[r]6,197
Total	XX	[r]7,013,229	[r]4,247,695	[r]580,435	[r]681,385
1993:					
Potassium chloride	61	7,050,036	4,300,522	548,639	649,061
Potassium sulfate	51	87,308	44,527	15,437	17,343
Potassium nitrate	45	28,140	12,663	7,827	8,752
Potassium sodium nitrate mixtures	14	38,907	5,447	5,971	6,573
Total	XX	7,204,391	4,363,159	577,874	681,729

[e] Estimated. [r] Revised. XX Not applicable.

Source: Bureau of the Census, as adjusted by the U.S. Bureau of Mines.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF POTASH, BY COUNTRY

Country	Metric tons of product										Total value (thousands)			
	Potassium chloride		Potassium sulfate		Potassium nitrate		Potassium sodium nitrate		Total[1]		Customs		C.i.f.	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Belarus	59,159	197,535	—	—	—	—	—	—	59,159	197,535	$5,064	$16,331	$5,756	$18,596
Belgium	2,000	3,000	7,751	15,787	21	—	—	—	9,772	18,787	1,625	2,919	1,915	3,462
Canada	[r]6,345,120	6,401,456	1,064	2,768	4	14	8,556	12,266	[r]6,354,744	6,416,504	[r]508,245	497,123	[r]600,047	589,641
Chile	—	—	—	—	13,882	13,822	28,155	26,587	42,037	40,409	7,788	7,764	8,663	8,627
Denmark	—	—	—	—	264	1,224	—	—	264	1,224	97	458	117	557
Dominican Republic	—	—	49	—	—	169	—	—	49	169	11	61	13	67
France	1,500	—	1,977	—	—	—	2	—	3,479	—	543	—	658	—
Germany	72,120	64,398	56,902	67,139	5	247	—	—	129,027	131,784	14,991	15,849	17,633	18,229
Israel	120,006	232,359	—	—	24,697	12,554	—	—	144,703	244,913	19,881	25,738	21,888	28,575
Japan	68	6	3	407	11	25	198	56	280	494	191	309	226	347
Jordan	—	7,298	—	—	—	—	—	—	—	7,298	—	647	—	788
Latvia	62,158	34,539	—	—	—	—	—	—	62,158	34,539	4,619	2,300	5,264	2,820
Netherlands	127	28	—	1,200	25	—	—	—	152	1,228	36	262	45	264
Poland	—	—	—	—	106	36	—	—	106	36	56	19	68	24
Russia	184,938	109,077	—	—	50	43	—	—	184,988	109,120	15,215	7,911	16,286	9,510
Sweden	818	21	—	—	—	—	—	—	818	21	68	20	77	22
Ukraine	21,200	—	—	—	—	—	—	—	21,200	—	1,887	—	2,596	—
United Kingdom	288	319	—	7	—	—	—	—	288	326	115	156	133	193
Other	(2)	—	(2)	—	[r]1	6	(2)	—	1	6	2	6	2	6
Total[1]	[r]6,869,502	7,050,036	[r]67,746	87,308	[r]39,067	28,140	[r]36,914	38,907	[r]7,013,229	7,204,391	[r]580,435	577,874	[r]681,385	681,729

[r] Revised.

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

[2] Revised to zero.

Source: Bureau of the Census.

TABLE 12
MARKETABLE POTASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons of K_2O equivalent)

Country	1989	1990	1991	1992	1993[e]
Belarus	—	—	—	[r]3,311	[2]1,947
Brazil	97	66	101	[r]85	[2]173
Canada	[r]7,333	[r]6,989	[r]7,406	[r]7,270	[2]6,841
Chile[e]	[r]45	[r]50	[r]55	[r]55	55
China[e]	[r]42	[r]29	[r]32	[r]21	25
France	1,195	1,292	1,129	[r]1,141	1,000
Germany:					
Eastern states	[r]3,200	2,653	—	—	—
Western states	[r]2,188	[r]2,307	—	—	—
Total	[r]5,388	[r]4,960	[r]3,855	[r]3,473	3,250
Israel	1,273	1,311	1,320	[r][e]1,320	1,300
Italy	112	[r]68	31	[r]86	80
Jordan	792	841	[r]818	[r]808	800
Russia	—	—	—	[r]3,454	[2]2,597
Spain	741	[r]686	[r]585	[r]594	600
Ukraine	—	—	—	[r]197	160
U.S.S.R.[3]	10,200	9,000	[e]8,560	—	—
United Kingdom	462	488	[r]495	[r]524	[2]530
United States	1,595	1,713	1,749	1,705	[2]1,506
Total[4]	[r]29,276	[r]27,493	[r]26,136	[r]24,044	20,864

[e] Estimated. [r] Revised.

[1] Table includes data available through May 4, 1994.

[2] Reported figure.

[3] Dissolved in Dec. 1991.

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

RARE EARTHS
THE LANTHANIDES, YTTRIUM, AND SCANDIUM

By James B. Hedrick

Mr. Hedrick is a physical scientist in the Branch of Industrial Minerals. He has been the commodity specialist for rare earths since 1981. Domestic survey data were prepared by Ms. Debra A. Nolan, management analyst, Kelly A. Dorney, management analyst, and Eraina C. Dixon, supervisory statistical assistant. The international data tables were prepared by Mr. Harold Willis, international data analyst.

The rare earths are a relatively abundant group of elements that range in crustal abundance from cerium, the 25th most abundant element of the common elements at 60 parts per million, to lutetium, the 61st most abundant element at 0.5 part per million. The rare earths were discovered in 1787 by Swedish Army Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine near the village of Ytterby, Sweden. With similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated from ytterbite by Finnish chemist Johann Gadolin. The rare earths are iron gray to silvery lustrous metals; typically soft, malleable, and ductile; and usually reactive, especially at elevated temperatures or when finely divided. Melting points range from 798°C for cerium, which at atmospheric pressure is denser as a liquid than as a solid, to 1,663°C for lutetium. The rare earths' unique properties are used in a wide variety of applications.

Domestic mine production of rare earths decreased in 1993. The domestic economy continued to recover slowly during the year and inflation rose a modest 2.5%. Estimated domestic apparent consumption decreased 21%; however, earnings by the major domestic processor reportedly increased amid a slight decline in sales. *(See table 1.)* Demand increased for rare earths used in petroleum fluid cracking catalysts, automotive catalytic converters, permanent magnets, and television and lighting phosphors. Demand decreased for rare earths in automotive UV glass applications.

The domestic use of scandium in 1993 remained small. Commercial demand remained extremely small, with most metal and compounds sold for research and analytical standards. Minor amounts were used in specialty lighting and semiconductors.

DOMESTIC DATA COVERAGE

Domestic mine production data for rare earths are developed by the U.S. Bureau of Mines (USBM) from the voluntary survey, "Rare Earths, Thorium, and Scandium." The two mines to which a survey form was sent responded, representing 100% of known mine production. Mine production data are withheld to avoid disclosing company proprietary data.

BACKGROUND

Definitions, Grades, and Specifications

The rare earths are defined by the USBM as a group of 17 elements composed of scandium, yttrium, and the lanthanides. Rare earths are classified chemically as members of the IIIB subgroup of the periodic table.[1]

Scandium, atomic number 21, is the lightest rare earth. It is the 31st most abundant element in the Earth's crust with an average crustal abundance of 22 parts per million. Although its occurrence in crustal rocks is greater than lead, mercury, and the precious metals, scandium occurs widely dispersed in the lithosphere and has no affinity to combine with the common ore-forming anions. It is a member of the first transition series of elements.

Yttrium, atomic number 39, is chemically similar to the lanthanides and commonly occurs in the same minerals. The average concentration of yttrium in the Earth's crust is 33 parts per million, the second most abundant rare earth in the Earth's crust. Yttrium is a member of the Second Transition Series.

The lanthanides comprise a group of 15 elements with atomic numbers 57 through 71, and include: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. The lanthanides are part of the Third Transition Series. Cerium, the most abundant of the group at 60 parts per million, is more abundant than copper and lead. Thulium, the least abundant of the lanthanides at 0.48 part per million, occurs in the Earth's crust in higher concentrations than bismuth, indium, selenium, and silver.

Based largely on trivalent ionic radii, the rare-earth elements are broadly classified into two groups: the light rare-earth elements (LREE) or cerium subgroup, composed of the first seven lanthanides (atomic numbers 57 through 63) and the heavy rare-earth elements (HREE) or yttrium subgroup, composed of the remaining lanthanides and yttrium (atomic numbers 64 through 71 and 39). Yttrium is classed with the heavy subgroup because of its occurrence, ionic radius, and other similar properties.

Bastnasite can theoretically contain 74.81% rare-earth oxide (REO).[2] Flotation concentrates of bastnasite average 60% REO, which can be upgraded to 70% REO by acid leaching and to 85% REO by a combination of acid leaching and calcining.

Monazite can theoretically contain 69.73% REO. Monazite concentrate usually is sold at 55% minimum REO contained plus thorium, with product grading from 55% to 65% REO. Thorium contents are variable, but typically occur in the range of 4% to 10% equivalent thorium oxide.

Xenotime can theoretically contain 61.40% yttrium oxide. However, xenotime concentrates from Southeast Asia and Australia typically contain 25% to 30% yttrium oxide. Xenotime commonly is upgraded by acid leaching to produce an yttrium concentrate grading 60% yttrium oxide and the balance comprised primarily of other rare earths.

Various metallic rare-earth products are produced. The term "mischmetal" is used to denote a mixture of rare-earth elements in metallic form. It generally has the same ratio of rare-earth elements as that found in the ore and is typically 98% to 99% pure. Recently, a high-purity "battery-grade" mischmetal was produced to supply the market for rechargeable rare-earth-nickel hydride batteries.

Ferrocerium is a pyrophoric alloy of mischmetal and iron. A typical ferrocerium alloy contains 74% mischmetal, 23% iron, 2% copper, and 1% magnesium.

Rare-earth silicide is an alloy typically containing about one-third mischmetal, one-third iron, and one-third silicon. The rare-earth content of a silicide may be as high as 50%.

The rare-earth content of master alloys range from tenths of a percent in nodularizing alloys for ductile iron to tens of a percent in inoculants for gray cast iron. Alloys containing nearly 100% rare-earth metals, such as mischmetal, are additives to certain steels.

The purity of separated rare-earth elements, produced primarily by solvent extraction or ion exchange, usually grade 96% or higher in purity. High- purity rare-earth compounds and metals are produced up to 99.99999% purity. Rare-earth products grading higher than 99.9% purity are often produced to specification. As a result of the wide range of products in which rare earths are consumed, many grades of rare-earth concentrates, compounds, alloys, and metals are produced.

Products for Trade and Industry

A wide variety of products is available for trade and industry, including concentrates, individual and mixed compounds, and pure and alloyed metals. Bastnasite concentrate produced in the United States is available in three grades, an unleached concentrate grading 60% REO, an acid-leached concentrate containing 70% REO, and a calcined concentrate upgraded to 85% REO. A mixed bastnasite-monazite concentrate (predominantly bastnasite) from China is produced in three grades, a 30% minimum REO, a 60% minimum REO, and a 71% minimum REO.

Mixed compounds derived from bastnasite include rare-earth chloride, rare-earth nitrate, lanthanum-rare-earth carbonate, lanthanum carbonate, cerium carbonate, cerium nitrate, cerium fluoride, neodymium carbonate, neodymium fluoride, praseodymium fluoride, cerium-rare-earth hydrate, and rare-earth hydrate.

Monazite is marketed as a concentrate containing 55% to 60% minimum REO plus contained thorium. Mixed compounds produced from monazite include cerium chloride, ceric ammonium nitrate, ceric sulfate, cerium carbonate, cerium hydroxide, cerium nitrate, cerium octoate, rare-earth carbonate, lanthanum carbonate, lanthanum-neodymium carbonate, lanthanum-neodymium nitrate, neodymium carbonate, neodymium nitrate, praseodymium oxalate, rare-earth octoate, and yttrium nitrate.

Xenotime concentrate with a minimum 25% yttrium oxide content is a source of yttrium. It typically is upgraded chemically to a 60% yttrium oxide product known as yttrium concentrate, the balance of the concentrate being mostly other rare earths. The primary product derived from yttrium concentrate is high-purity yttrium oxide.

Rare-earth ion adsorption ore, produced in southern China, is the principal source of yttrium. The ores vary by locality, but two principal concentrates, an yttrium concentrate and an europium concentrate, are produced. The yttrium concentrate is enriched in the heavy rare earths and has greater than 60% yttrium oxide. Although the europium concentrate grades from 0.5% to nearly 1% europium oxide and 12% yttrium oxide, it is predominantly enriched in lanthanum oxide, 33% to 43%.

Individual rare-earth oxides and other compounds, except promethium, are produced from bastnasite, monazite, xenotime, and ion adsorption ore. Purities from 96% up to 99.9999% are available for most oxides. Compounds for almost all of the rare earths are available as oxides, acetates, carbonates, chlorides, fluorides, nitrates, oxalates, and sulfates.

High-purity rare-earth metals are marketed in the form of sponge, lump, ingot, crystal, rod, wire, chips, powder, sheet, foil, plate, sputtering plates, and custom cast and machined shapes. Alloys such as mischmetal, rare-earth silicide, ferrocerium, and other rare-earth alloys are available in a variety of ingot shapes and sizes.

Rare-earth magnet alloys are produced to individual requirements. Magnet alloys are marketed in ingot form, crushed ribbon, or may be purchased as mixed oxides for powder metallurgical processes. Magnets are available in finished and semifinished shapes, bonded and unbonded, and magnetized and unmagnetized.

Scandium is marketed primarily as a high-purity oxide. Oxide purities from 98% to 99.9999% have been produced in the United States. In addition to the oxide, scandium compounds are available as the acetate, acetylacetonate, bromide, carbonate, chloride, fluoride, hydride, iodide, nitrate, oxalate, and sulfate. Scandium metal is produced in ingot, powder, lump, and foil form.

Industry Structure

Few rare-earth companies are fully integrated. Rare earths are typically mined and processed by different companies. In the United States, Molycorp, Inc. is the only fully integrated producer from its mine, mill, and refinery at Mountain Pass, CA. The other principal producer, RGC (USA) Minerals Inc., operated a mine and wet and dry concentrating plants at Green Cove Springs, FL. Except for Molycorp, all other domestic refiners have operated independently.

Rare-earth ore is beneficiated by mine producers into concentrates that are sold directly to processors or, to a lesser extent, are sold to brokers for resale.

Rare-earth concentrates undergo extensive processing to produce mixed or separated compounds. The major processes used in separating rare earths are precipitation, solvent extraction (SX), and ion exchange (IX). Processors sell refined rare-earth products directly to consumers or brokers.

The scandium industry, for the most part, is separate and distinct from the lanthanide and yttrium industry. Its high-price and very limited demand have made scandium one of the smallest commodity markets in the world. Its limited demand has supported only intermittent mine production in the United States. As with lanthanides, the scandium industry is rarely fully integrated. Byproduct mine production in 1993 is reported only from China and the former Soviet Union. Minor amounts of scandium have been separated from lanthanide and yttrium ores, most scandium is produced as a byproduct from other ores. In the United States, scandium has been recovered as a byproduct during processing of uranium at a copper mine, from tailings from a mined-out fluorite mine, and from tungsten byproduct from a molybdenum operation. Tailings and concentrates from these sites were shipped to processors for production of high-purity scandium oxide and other compounds. Most scandium is sold in oxide form. A small group of companies produce scandium metal, primarily for lighting and research purposes.

Geology-Resources

Rare-earth minerals occur in a variety of geologic environments. Concentrations exist in igneous, sedimentary, and metamorphic rocks. Rare earths are mined primarily from igneous and sedimentary deposits. The geologic age of the deposits range from Recent to Precambrian.

The rare earths are constituents in more than 100 minerals, but only a few are recovered for commercial production. Bastnasite, monazite, xenotime, and rare-earth-bearing clay are the major sources of the world's rare-earth supply. Other sources are loparite, uraniferous phosphorites, synchisite, and byproduct solutions from processing uranium.

Bastnasite.—Bastnasite, a rare-earth fluocarbonate mineral, is found in vein deposits, contact metamorphic zones, pegmatites, and carbonatites. It is typically enriched in the LREE (Bastnasite-Ce); however, a rare HREE variety (Bastnasite-Y) is known from Kazakhstan. Bastnasite forms in the trigonal crystal system and ranges in color from yellow to reddish-brown. It has the following mineralogical properties: transparent to translucent; vitreous to greasy luster; density of 4.78 to 5.2 grams per cubic centimeter; and a hardness of 4 to 4½ on the Mohs scale.[3] It forms as an igneous or hydrothermal mineral and occurs as an accessory mineral in several large deposits. Deposits containing bastnasite as a high-grade accessory mineral are at Mountain Pass, CA, United States; Bayan Obo, Nei Monggol Autonomous Region, China; Wigu Hill, Tanzania; and Karonge, Burundi.[4] Bastnasite and other independent rare-earth minerals commonly form by hydrothermal processes, although its occurrence at Mountain Pass, CA, is considered primary igneous. Concentration of the rare earths can occur as a result of coprecipitation with calcium carbonate or by precipitation in the presence of fluorine. While the Mountain Pass bastnasite is believed to have formed by the coprecipitation process, the Bayan Obo's bastnasite is hydrothermal in origin and formed by alteration of dolomite in the presence of large amounts of fluorine.[5] Most of the world's rare earths resources are recovered from bastnasite.

Monazite.—Monazite, a rare-earth phosphate, is one of the most abundant rare-earth minerals. It occurs as an accessory mineral in granitic and metamorphic rocks, pegmatites, vein deposits, as a detrital mineral in placer deposits, and as a hydrothermal and supergene mineral in carbonatites. It is classified as a LREE and is usually enriched in cerium (Monazite-Ce). Rarer monazite varieties are a lanthanum-rich monazite (Monazite-La) and a neodymium-rich monazite (Monazite-Nd) described from Italy and from Marmara, Greece.[6] Monazite, which forms as a monoclinic mineral, is found in a wide range of colors, including honey yellow, greenish brown, reddish brown, yellowish brown, brown, pink, yellow, grayish white, dark grey, and black. It has the following mineralogical properties: transparent to subtranslucent; resinous, waxy, vitreous, or subadamantine luster; density of 4.6 to 5.4 grams per cubic centimeter; and a hardness of 5 to 5½ on the Mohs scale.[7] Monazite forms primarily as an accessory mineral in igneous and metamorphic rocks, including granites, gneisses, aplites, and pegmatites, and occasionally as a vein mineral (VanRhynsdorp, Republic of South Africa).

Economic placers develop where monazite has been weathered from its original host rock and concentrated by wind and water. Placer monazite is mined as a byproduct of titanium and zirconium minerals or tin minerals. Significant placer deposits are in

Australia, Brazil, Malaysia, Thailand, and the United States.[8]

Monazite of hydrothermal and supergene origin in carbonatites also represents a large rare-earth resource. Deposits of this type occur at Araxá, Minas Gerais, Brazil; Catalao I, Goiás, Brazil; Bayan Obo, Nei Monggol Autonomous Region, China; and Mount Weld, Western Australia, Australia.[9] Although China's Bayan Obo deposit is known primarily as the world's largest bastnasite deposit, it contains substantial tonnages of monazite. Formed by hydrothermal alteration of dolomite, the Bayan Obo monazite occurs in veins and stockworks in the footwall rocks.[10] One of the richest grade deposits in the world, the Mount Weld carbonatite grades 15 million metric tons at 11.2% REO, including a 1.3-million-metric-ton zone at 23.6% REO.[11] Enriched by supergene solutions, the deposit's primary ore minerals are secondary monazite and cheralite, along with lesser amounts of monazite, rhabdophane, cerianite, florencite, and churchite.

Technology

Exploration.—Commercial exploration for rare-earth minerals (primarily thorium) began in the 1880's, for the purpose of locating thorium and cerium for incandescent gas mantles. After electric lighting came into general use about 1912, demand for gas mantles fell. Subsequently, most rare-earth deposits have been located during the search for other minerals and metals, especially gold, ilmenite, rutile, uranium, and zircon.

Exploration methods to locate rare earths include surface and air reconnaissance with magnetometric, electromagnetic, and radiometric equipment. Other techniques include satellite imagery, aerial photography, and remote sensing. The application of geologic principles to develop depositional models is also used. After identifying a match for a depositional model or an indicator from one of the other methods, a ground survey of the region is conducted. A typical ground survey would include geologic mapping; rock, soil, and gas sampling; geophysical testing; surface radiometric surveying; and geochemical testing of the water, rocks, and plants.

Following visual identification of a rare-earth mineral, a systematic subsurface drilling and sampling program is conducted to determine ore grades. Individual rare-earth contents are analyzed by various assay methods, including X-ray fluorescence, instrumental neutron activation analysis, spark source mass spectrometry, and inductively coupled plasma and direct current plasma-atomic emission spectrometry.

Because rare-earth minerals are often associated with the radioactive elements uranium and thorium, many rare-earth deposits were discovered during exploration for these elements. Prospectors searching for radioactive minerals in California discovered bastnasite, which eventually led to the discovery of the Mountain Pass deposit.

Most monazite mineral sands deposits were discovered by exploring alluvial deposits using radiometric and magnetometric equipment. Discovery of buried alluvial deposits are typically located by depositional modeling.

Mining and Beneficiation.—Bastnasite is mined domestically as a primary product from a hard-rock carbonatite. The carbonatite is mined via bench-cut, open pit methods. Ore is drilled and blasted, loaded into trucks by rubber-tired loaders, and hauled to the mill. At the mill the ore is crushed, screened, and processed by flotation to produce a bastnasite concentrate.

In China, bastnasite and lesser amounts of associated monazite, also are mined from a hard-rock deposit. The ore is recovered as a byproduct of iron ore mining by open pit methods. After primary crushing at the mine site, the ore is transported by rail 135 kilometers southeast to the mill because of the scarcity of water at the mine site. A bastnasite concentrate and a mixed bastnasite-monazite concentrate are produced as flotation byproducts during processing for the iron ore.

Heavy-mineral sands are the source of most monazite and xenotime mined in the world. Most of these minerals are recovered by surface placer methods from unconsolidated sands. Almost all mining of these sands is done by floating cutterhead or bucket wheel dredges that concentrate the heavy minerals ("heavies") onboard and discharge the unwanted tailings back into previously mined areas. An onboard wet mill separates the "heavies" (specific gravity greater than 2.9) from the lighter weight fraction through a series of wet-gravity equipment that includes screens, hydrocyclones, spirals, and cones.

Consolidated and partially consolidated sand deposits that are too difficult to mine by dredging are mined by dry methods. Ore is stripped by typical earth-moving equipment such as dozers, scrapers, shovels, and loaders. Sand recovered by these techniques is crushed and screened and then processed by wet mill methods as describe above.

Wet mill product, a mixed heavy-mineral concentrate, is sent to a dry mill to separate the individual heavy minerals and produce a concentrate. Dry mill processing includes a combination of scrubbing, drying, screening, electrostatic, electromagnetic, magnetic, and gravity processes. Monazite, in contrast to ilmenite, rutile, and several other heavy minerals, is nonconductive and can be separated, with zircon, by electrostatic methods. Monazite, which is moderately susceptible to induced magnetism and may be slightly higher in specific gravity, can be separated from zircon by electromagnets or by additional gravity methods. Xenotime, which has a specific gravity and magnetic properties similar to monazite, usually is separated from monazite by precise gravity methods. Certain deposits also require an acid-leach treatment and calcining to eliminate iron oxide or other grain coatings.

Economic Factors

Prices.—Time-price relationships for bastnasite and monazite concentrates, based on 1993 constant dollars, were calculated based on U.S. Government implicit price deflators for gross domestic product. The 1993 price for bastnasite concentrate in real dollars remained unchanged from that of the previous year. Adjusting for inflation, bastnasite's price in terms of 1993 constant dollars decreased $0.07 per kilogram of REO from the previous year, the result of a $0.025 decrease in purchasing power per dollar. The 1993 price for monazite decreased $0.02 per kilogram of REO from last year's level. Adjusting for inflation, monazite's price in terms of 1993 constant dollars decreased $0.03 per kilogram of REO, the result of a $0.025 decrease in purchasing power per dollar. *(See figures 1 and 2.)*

Concentrates of bastnasite and monazite have traditionally been low priced. Significant value is added when the concentrates are separated into the individual REO's or other compounds. Mischmetal prices also have been historically low, with kilogram prices remaining in the $7 to $13 range over the past 21 years. Individual high-purity metals have commanded the highest prices of the rare-earth products. Metal prices typically run from two to six times the separated REO price.

Initially available in 1954, bastnasite concentrate was priced at $3.31 per kilogram. By the early 1960's, the development of the first major commercial applications for the rare earths caused its price to drop to less than $0.50. Bastnasite prices have increased progressively since that time, doubling in price between 1974 and 1980 as a result of the domestic energy crisis.

Monazite's price series is more complex than bastnasite's. As a byproduct, the supply and price of monazite is partially dependent on production and demand of the primary minerals. As a result of Australia's dominant position as a monazite producer, fluctuations in monazite's domestic price also are based on United States-Australian foreign exchange rates. Monazite's historical price trend displays an overall increase in price through 1985. In the 1950's, its price was $0.33 to $0.40 per kilogram of REO, decreasing to $0.22 to $0.33 per kilogram in the early 1960's. By the mid-1960's, monazite's price began to increase steadily, with a major increase appearing in 1985, the result of a weak Australian economy and increased competition for monazite supplies. Balanced supply and demand was seen in monazite's price through 1990. In 1991, however, a decline in monazite prices signaled an oversupply, the result of the availability of low-cost separated rare earths from China, a downturn in the U.S. economy, and the decision by a major domestic consumer to switch from monazite to a thorium-free rare-earth feed material. As a result of further decreases in demand, monazite's price continued to decline in 1992 and 1993, as a major foreign consumer switched to alternative feed material.

Costs.—U.S. mine and mill operating costs to produce concentrates of bastnasite and monazite differ substantially. The cost to mine bastnasite is greater than that for monazite. Bastnasite, as a primary product, incurs all costs of production, whereas monazite, as a byproduct, accounts for only a fraction of the production costs. The cost to recover monazite is based almost entirely on the expenses made to recover the primary minerals. Mine production costs for bastnasite are also higher than monazite because of the type of deposit. Costs to mine a hard-rock deposit (bastnasite) are significantly higher than mining a placer deposit (monazite).

Because both domestic mines have been in production for several years, mining costs are related mostly to direct costs, which include labor, mining equipment (trucks, drills, loaders, dredges, pumps, etc.), supplies (explosives, drill bits, etc.), and utilities (fuel, natural gas, water, and electricity). Capital expenditures for plant expansions and other major capital improvements represent the balance of significant costs. These costs commonly are added to long-term debt, but occur intermittently and are based typically on an increase in market demand.

Costs to comply with environmental regulations continue to increase. These costs are mostly indirect operating costs which include waste treatment and disposal, water purification, systems monitoring, reclamation, administration, and legal and technical personnel.

Tariffs.—U.S. tariff rates, specific to the rare earths, including scandium and yttrium, are unchanged for 1993 and 1994, except for certain special tariff revisions for Canada and Mexico. The regular tariff rates reflect results from the 1979 Tokyo Round of Multilateral Trade Negotiations under which the tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1, 1987. Revisions to rare-earth tariffs for Canada and Mexico were the result of Presidential Proclamation 6641, implementing the North American Free Trade Agreement, effective January 1, 1994. Except for certain staged reductions for Canada and Mexico, tariff rates are expected to remain at present rates until the Uruguay Round of Multilateral Trade Negotiation are completed. The Uruguay Round of negotiations is expected to be completed in 1994 with new staged rate schedules taking effect in 1995. U.S. tariff rates for rare earths are listed in the Harmonized Tariff Schedule of the United States (1993), publication 2567, and the Harmonized Tariff Schedule of the United States (1994), supplement 1, publication 2690, as compiled by the U.S. International Trade Commission.

Depletion Provisions.—Depletion is defined as the exhaustion of mineral or oil and gas reserves by mining or drilling of wells and the resulting production from these mines or wells.[12] Depletion allowance is a tax deduction that may be taken against income provided by the U.S. Internal Revenue Code to compensate mining companies in the United States for decreasing capital brought about by production. The allowance is based on gross income.

There are two ways of figuring depletion allowance: cost depletion and percentage depletion.[13] Cost depletion is calculated by dividing the adjusted basis of the mineral property by the total number of recoverable units. Percentage depletion is figured by taking a percentage, specified for certain minerals (elements), of the gross income from the mineral property during the tax year. The depletion deduction may not be more than 50% of the taxable income from the property figured without the deduction.

The depletion allowance for monazite is 22% on the thorium content and 14% on the rare-earth content when mined from domestic deposits and 14% on the thorium content and 14% on the rare-earth content from foreign deposits.[14] Bastnasite's depletion allowance is 14% on the rare-earth content on both domestic and foreign production.

Operating Factors

Toxicity.—Rare-earth toxicity may be broadly classified into two groups—nonradioactive and radioactive. The relative risk is greater from nonradioactive rare earths because there are few naturally occurring radioactive isotopes. As a group, they are classified as slightly toxic.

Nonradioactive.—Toxicity of rare earths is dependent on the chemical form, its route of administration, and the individual rare earth.[15] Only limited data are available for humans, with most research acquired from experiments on small vertebrates. Overall, the rare earths are considered only slightly toxic.[16] Orally administered lanthanides are poorly absorbed by the gastrointestinal tract and have very low toxicity. Administered at levels as high as 1 to 10 grams of lanthanide oxides and lanthanide sulfates per kilogram (kg) of body weight, the compounds were not lethal to small vertebrates.[17]

Lanthanides administered by routes other than orally are absorbed at greater rates and are thus more toxic. Intravenous injection is the most toxic method. Pharmacologic responses to intravenous-administered lanthanides were calcification, hypotension, and hypoglycemia. Intravenous injection of salts of neodymium in humans caused increased blood coagulation times with toxic manifestations.[18] Intravenous injections of lanthanum chloride solutions in humans produced abdominal cramps, chills, fever, hemoglobinemia, hemoglobinuria, and muscle pain.[19] Intravenous injections of rare-earth nitrates (Ce, Pr, Nd, Sm, and Er) in rats were highly toxic compared to other routes of administration with a general decrease in toxicity with increasing atomic weight. The LREE salts were noted to be 7 to 11 times more toxic to female rats than male rats while the HREE erbium salt was only 1.5 times more toxic.[20] The production of skin and lung granulomas (in rats and mice) after exposure to oxides, fluorides, chlorides, and metals by prolonged breathing, intradermal or intraperitoneal injection, or subcutaneous implantation requires extensive protection to prevent exposure through cuts and abrasions of the skin or through inhalation. Symptoms of toxicity observed (in mice and rats) included anorexia, writhing, ataxia (loss of voluntary muscle control), diarrhea, dyspnea (labored respiration), walking on the toes with arched back, and sedation.

Humans exposed to airborne lanthanides reported itching, insensitivity to heat, and a sharpening of the senses of taste and smell.[21] Chronic exposure to lanthanide dust can lead to *rare-earth pneumoconiosis*.[22] This condition has been noted in those exposed to lanthanide oxide-bearing fumes from carbon arc lamps.

Intratracheal injections of 50 milligrams (mg) of a mixed lanthanide oxide into rats were 100% lethal within 24 hours, the result of pulmonary edema.[23] However, a similar injection of 200 mg/kg of the rare-earth ore monazite into mice produced no ill effects.[24] Extreme care also must be taken when exposed to finely divided rare-earth metals and metallic powders to avoid burns from rapid and possibly instantaneous oxidation, especially if inhaled. Certain finely divided rare-earth metals, alloys, and metal powders also may present the additional hazard of oxidizing rapidly enough to explode.

Radioactive.—Toxicity from rare earths also may occur from radioactive lanthanides. Only neodymium, samarium, gadolinium, and lutetium have naturally occurring radioactive isotopes.

The risk of toxicity from these natural isotopes is believed to be very low due to their extremely long half-lives and low radioactivity levels. Neodymium's one radioactive isotope, Nd^{144}, represents 23.85% of the naturally occurring material and is an alpha emitter. Samarium has three alpha emitting isotopes: Sm^{147}, Sm^{148}, and Sm^{149}, which represent 14.97%, 11.24%, and 13.83% of the naturally occurring material, respectively. Gadolinium's sole alpha emitting isotope is Gd^{152}, with an abundance of only 0.2% in naturally occuring gadolinium. Lutetium also has one radioactive isotope, Lu^{176}, with an abundance of 2.59% in naturally occuring lutetium. Lutetium is the only natural lanthanide isotope that decays by negative beta emission.

Manufactured rare-earth isotopes were produced primarily for use in nuclear medicine. The relative health risks for these materials varied depending on the application and dosage.

It should be noted that the rare earths often exist in ore and concentrates in association with other elements that have vastly different properties, including varying toxicities and possibly radioactive emissions. Care should be taken to assess the health factors associated with each substance present.

Employment.—Rare-earth mine and mill employment statistics, based on the domestic quarterly average number of employees on-site, are shown in figure 3. For the second consecutive year, rare-earth mining employment in the United States dropped, falling 4.8% from the previous year's level. The 1993 decrease was the result of several plant closings initiated by Molycorp, in 1992 and the closing of Nord Ilmenite Corp's Jackson, NJ, operation at yearend 1992. Data were furnished by the U.S. Department of Labor and compiled by the USBM.

(See figure 3.)

Productivity Trends.—The 11-year trend for U.S. rare-earth mine productivity, based on capacity utilization for bastnasite concentrate and monazite concentrate, are shown in figures 4 and 5.

Bastnasite production decreased in 1993, changing its previous 11-year productivity trend from a slight increase to a slight decrease. *(See figure 4.)*

The 11-year trend for domestic monazite capacity utilization continued to decline. The decline is primarily a function of continued decreased demand for monazite and continued depressed demand for the primary products. *(See figure 5.)*

ANNUAL REVIEW

Legislation and Government Programs

The calendar year 1993 included the U.S. Government fiscal years for 1993 and 1994. Public Law 102-484, the National Defense Authorization Act for Fiscal Year 1993, covered the year 1993 through September 30, and continued specific previous authorizations for disposal of stocks in the National Defense Stockpile (NDS) classified as excess to goal. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, was enacted on November 30, and covered the last month of 1993. Stocks of rare earths in sodium sulfate were all classified as excess to goal at yearend 1993 and were inventoried at 457 tons. Rare earths in the NDS, which were not authorized for disposal during fiscal year 1993, received authorization for disposal in fiscal year 1994 under Public Law 103-160.

Issues

In response to environmental regulations under the Resource Conservation and Recovery Act, Molycorp is reportedly taking corrective actions at its Mountain Pass plant to comply with the law. Compliance with the regulations was not expected to have an adverse material effect on the company's operations or financial situation.[25]

Sales of rare earths by Molycorp in 1993 were slightly lower than in 1992, however, earnings reportedly increased as a result of cost-reduction measures. Molycorp's Mountain Pass, CA, mine and plant and its operations at White Plains, NY, received ISO 9002 certification by meeting or exceeding the standards for the international quality rating.

Molycorp's mine, plant, and operations continued to be for sale throughout 1993. No potential purchasers were announced during the year. The company was expected to continue to remain for sale in 1994.

Production

Two domestic mines produced rare earths in 1993. The United States was the world's second largest producer of rare earths in 1993. Producers were Molycorp, a wholly owned subsidiary of Unocal Corp., and RGC (USA). Bastnasite was mined by open pit methods by Molycorp at Mountain Pass, CA. Molycorp's mine was the leading producer of rare earths in the United States and second in the rest of the world. Mine production decreased from the previous year's level of 20,699 tons REO to 17,754 tons REO in 1993.

Monazite was produced as a byproduct of titanium and zirconium minerals production by RGC (USA). RGC (USA) operated a placer dredging operation at Green Cove Springs, FL. Production increased 6% from last year's level, primarily the result of increased demand for the primary products.

Refined lanthanides were produced by three companies. Molycorp produced refined compounds from bastnasite at its separation plant at Mountain Pass, CA. Rhône-Poulenc Basic Chemicals Co. produced lanthanide compounds from rare-earth intermediate compounds at its facility at Freeport, TX, and Davison Specialty Chemical Co. refined rare earths from rare-earth chloride at its operations in Chattanooga, TN.

Three scandium processors operated in 1993. High-purity products were available in various grades with scandium oxide produced up to 99.999% purity.

Sausville Chemical refined scandium concentrates at its facilities in Garfield, NJ, to produce scandium oxide, fluoride, nitrate, chloride, and acetate. Boulder Scientific Co. processed scandium at its Mead, CO, operations. Scandium concentrates were derived from a variety of ores. Boulder's main ore source was thortveitite-bearing tailings from the mined-out Crystal Mountain fluorite mine near Darby, MT. Scandium was also processed by APL Engineered Materials in Urbana, IL. APL produced both compounds and metal.

Reactive Metals and Alloys Corp. (REMACOR) was the principal domestic producer of mischmetal. Production of mischmetal, rare-earth silicide, and other rare-earth alloys decreased 25% in 1993, primarily the result of decreased demand in the other rare-earth alloy group. Production of high-purity metals also decreased as a result of plant closures by Molycorp.

Principal domestic producers of neodymium-iron-boron magnet alloys were the Delco Remy Div. of General Motors, Anderson, IN; Molycorp, York, PA; Neomet Corp., West Pittsburg, PA; and Rhône-Poulenc, Phoenix, AZ. Leading U.S. producers of rare-earth magnets were the Delco Remy Div. of General Motors, Anderson, IN; Hitachi Magnetics, Edmore, MI; Crucible Materials, Elizabethtown, KY; and IG Technologies, Valparaiso, IN.

Consumption and Uses

Domestic reported consumption of rare earths decreased 14% in 1993 compared with that of 1992. The producers of mischmetal, rare-earth silicide, and other rare-earth alloys consumed essentially the same amount of rare earths in 1993 than they did in 1992, despite a 25% decrease in domestic shipments. Consumption of mixed rare-earth compounds showed a 90% gain as demand increased for petroleum fluid cracking catalysts and automotive catalytic converters. Domestic shipments of mixed compounds, however, increased only 7% as adequate supplies of materials were produced. Shipments of high-purity rare-earth metals from domestic processors decreased 27% during the year amid a major decrease in production; the result of plant closures in 1992.

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, 47%; metallurgical uses as iron and steel additives and as alloys, 24%; glass polishing compounds, glass additives, and ceramics, 18%; permanent magnets, 10%; lighting, phosphors, mantles, research, and miscellaneous, 2%.

Rare earths are used in hundreds of applications, ranging from 19th century traditional applications to modern high-technology uses. The applications encompass a wide range of products from mixed rare-earth compounds and alloys to ultrahigh-purity individual metals and compounds. Quantities vary by application and range from tonnage quantities to milligrams. Following are the uses, in order of increasing atomic number, of rare earths, including the metals, oxides, and both inorganic and organic compounds.

Scandium.—Metal halide lamps to improve color appearance and produce high output, lasers crystals (GSGG), high-strength aluminum alloys, anode tubes in X-ray spectrometers, semiconductors, tracer material, collimators in neutron lenses.

Yttrium.—High-temperature superconductor (YBaCuO), incandescent lamp mantle, phosphor for cathode-ray tubes (reddish orange), trichromatic fluorescent lighting phosphors (reddish orange), metal halide lamp phosphor (reddish orange), high-temperature sensing phosphor, oxygen sensor ceramic, laser crystal (YAG, YLF), gemstone simulants (CZ and YAG), microwave ferrites (YIG), cast iron alloys, magnesium castings, superalloys, dispersion strengthened nickel and titanium alloys, aromatization of n-hexane, prostheses, stabilizer for silicon nitride and zirconia ceramics, microwave filter, and semiconductors, acetylene lights, deoxidizer for vanadium and other nonferrous metals, solid oxide fuel cell electrolyte and anode, refractory crucibles and coatings, high-temperature furnace electrodes.

Lanthanum.—Petroleum fluid cracking catalyst, glass additive to increase refractive index and decrease dispersion (eyeglasses, cameras, binoculars, rifle scopes, and telescope lenses), nickel hydride rechargeable batteries, hydrogen storage alloys, optical glass, solid oxide fuel cell cathode and interconnect, trichromatic fluorescent lighting phosphor (green), X-ray intensifying screen phosphor (violet, blue, yellow-green, and blue green), low-temperature sensing phosphor, phosphor lamp coating, laser glass, calcium lighting, lighting electrode, tungsten welding electrode, cast iron alloys, steel alloys, superalloys, aromatization of n-hexane, fluoride determination, conductive ceramic heating elements (chromites), dielectric ceramic capacitors (titanates), electrooptical ceramics, oxidative dimerization of methane to ethylene, antiseptic, electronic thermoemissive cathode (boride), insulation, reducing agent to convert nitrogen oxides to nitrogen, low-temperature superconductor, cryogenic refrigerant using hydrogen ($LaNi_5$), semiconductors (LaAs, LaSb, LaP).

Cerium.—Glass, metal, and gemstone polishing, radiation shielding glass, glass colorization and decolorization, discolorization stabilizer, photochromic glass opacifier, ceramic pigment, ceramic glaze, enamel opacifier, carbon arc lighting, incandescent lamp mantle, trichromatic fluorescent lighting phosphor (yellow green), pyrophoric alloys including lighter flints, cast iron alloys, steel alloys, aluminum alloys, magnesium alloys, superalloys, automotive catalytic converter monolith, heat stabilizer in alumina catalyst, fluid cracking catalyst, hydrolysis of phosphoric acid esters, oxidation of naphthalene, polymerization catalyst for olefins, corrosion inhibitor, getter in azide manufacture, getter in vacuum tubes, developing agent for aniline black, heavy metal soaps for lubricating greases and flatting agents, waterproofing and mildewproofing, dying and printing textiles, ceramic capacitors, semiconductors, cathodes, desulfurizing catalysts, high-strength glass, catalyst for ammonia production, illuminant in photography, radiation dosimeter, diluent in plutonium nuclear fuels, fluorinating agent, oxidant for organic compounds, antiknock fuel additive, oxidizer in self-cleaning ovens, and pharmaceutical for sea sickness and morning sickness.

Praseodymium.—Ceramic pigment (yellow), glass colorization (light green), refractory ceramic heating element, laser crystal, aluminum alloys, magnesium alloys, permanent magnets, oxidative dimerization of methane to ethylene, cryogenic refrigeration ($PrNi_5$).

Neodymium.—Permanent magnets (NdFeB), glass colorization (violet), glass decolorization, dopant in laser crystals and glass, ceramic capacitors, ceramic glaze (pinkish violet), magnesium alloys, welder's protective glass, carbon arc lighting electrodes, catalyst for polymerization of olefins, fiber-optic temperature sensor.

Promethium.—Fluorescent lighting starter, coatings for self-luminous watch dials, beta particle source for thickness gauges, miniature atomic batteries, semiconductor battery, X-ray source (Pm-147), tungsten cermet for space power system.

Samarium.—Permanent magnets (SmCo), dopant in laser crystals, neutron absorber, nuclear reactor control rod, catalyst in dehydrogenation of ethyl alcohol, catalyst in oxidative dimerization of methane to ethylene, infrared absorbing glass.

Europium.—Cathode-ray tube phosphor (reddish orange), trichromatic fluorescent phosphor (reddish orange and blue), X-ray intensifying screen phosphor (violet), metal halide lamp phosphor (reddish orange), high- and low-temperature sensing phosphors, nuclear reactor neutron absorber, nuclear reactor control rods, ceramic sensor, organic shift reagent in nuclear magnetic spectroscopy, dopant in laser crystals, tagging agent in postage stamp glue.

Gadolinium.—Trichromatic fluorescent lighting phosphor (yellow green), X-ray intensifying screen phosphor (yellow green), nuclear reactor control rods, nuclear reprocessing, neutron absorbing paint, high refractive index glass, synthetic garnet for computer memory (GGG), scavenger for oxygen in titanium production, dielectric ceramics, laser crystal, cryogenic refrigeration, pharmaceutical isotope in scanning devices to detect osteoporosis (Gd-153), magneto-optical recording,

Terbium.—Trichromatic fluorescent lighting phosphor (yellow green), X-ray intensifying screen phosphors (yellow green, violet, and blue), magnetostrictive alloys for transducers (TbFeNi), dopant in laser crystals.

Dysprosium.—Permanent magnet addition (NdFeB), nuclear reactor control rods, semiconductors (DyAs, DySb, DyP), measurement of neutron flux, atomic weight determination, high-temperature sensing phosphor.

Holmium.—Dopant in laser crystal, getter in vacuum tubes, refractories.

Erbium.—Fiber-optic amplifier, glass colorizing of crystal and glassware (light pink), additive for colorization and nonreflective coating for sunglasses, infrared-absorbing glass, colorization of simulant gemstones, lasers, burnable poison in nuclear reactor, chemical catalyst for n-hexane, permanent magnet additive.

Thulium.—X-ray source (Tm-170), dopant in laser crystal, ferrites.

Ytterbium.—Portable X-ray source for blood irradiation, dielectric ceramics, carbon rods for industrial lighting, dopant in synthetic garnet, dopant in laser crystal, additive in special glass.

Lutetium.—High-temperature sensing phosphor, nuclear technology.

Stocks

U.S. Government stocks of rare earths in the NDS remained at 457 tons throughout 1993. Rare-earth stocks held in the stockpile were contained in sodium sulfate and were inventoried on a contained-REO basis. NDS stocks of rare earths were not available for sale in 1993 until the 30th of November, when Pubic Law 103-160 went into effect.

Prices

Prices for rare earths generally were unchanged in 1993. Published prices were stable for most rare earth oxides and compounds, but remained nominal and subject to change without notice. Competitive pricing policies remained in effect with prices for most rare-earth products quoted on a daily basis.

The price range of Australian monazite (minimum 55% rare-earth oxide including thoria, f.o.b./f.i.d.),[26] as quoted in Australian dollars (A$),[27] remained unchanged at A$300 to A$350 per ton at yearend 1993. Changes in the United States-Australia foreign exchange rate in 1993, resulting from a slightly weaker Australian dollar, caused the corresponding U.S. dollar to be up $0.01 against the Australian dollar at yearend. The U.S. price range, converted from Australian dollars, decreased slightly from US$207 to US$241[28] per ton in 1992 to US$204 to US$238[29] per ton in 1993. Prices for monazite remained depressed as several major world processors switched to thorium-free rare-earth feed materials.

Prices quoted by Molycorp for unleached, leached, and calcined bastnasite in standard quantities, containing 60%, 70%, and 85% REO, were $2.87, $3.20, and $3.86 per kilogram ($1.30, $1.45, and $1.75 per pound) of contained REO, respectively, at yearend 1993. Bastnasite concentrate prices increased $0.10 for the 70% grade and $0.20 for the 85% grade, the first increases since 1990.

The price of cerium concentrate was quoted by Molycorp at $5.73 per kilogram ($2.60 per pound) of contained cerium oxide at yearend 1993, unchanged from the 1992 price. The yearend price of lanthanum concentrate was also unchanged from the 1992 level of $3.08 per kilogram ($1.40 per pound) of REO contained. Prices for cerium concentrate and lanthanum concentrate are quoted for 907-kilogram minimum (2,000-pound minimum), f.o.b. shipping point. Molycorp began quoting prices for cerium carbonate on a contained REO basis. The yearend 1993 price for cerium carbonate was $21.50 per kilogram ($9.75 per pound) of contained REO.

The nominal price for basic neodymium-iron-boron alloy, compiled by the USBM, was $25.35 per kilogram ($11.50 per pound) at yearend, f.o.b. shipping point, 1,000-pound minimum. Most alloy was sold with additions of cobalt (up to 15%) or dysprosium (up to 5%). The cost of the additions was based on market pricing; with cobalt at $52.91 per kilogram ($24.00 per pound) the cost would be about $0.53 for each percent addition per kilogram ($0.24 for each percent addition per pound).

The price for standard-grade mischmetal remained unchanged from the previous year at $12.68 per kilogram.

Molycorp quoted prices for lanthanide (rare earth) and yttrium oxides, net 30 days, f.o.b. Louviers, CO, Mountain Pass, CA, or York, PA, in effect at yearend 1993, as shown in table 2. *(See table 2.)*

Molycorp also quoted prices for lanthanide (rare earth) compounds, net 30 days, f.o.b. York, PA, Louviers, CO or

Mountain Pass, CA, in effect at yearend 1993, as shown in table 3. *(See table 3.)*

Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 1993, as shown in table 4. *(See table 4.)*

No published prices for scandium oxide in kilogram quantities were available. Yearend 1993 nominal prices for scandium oxide per kilogram were compiled by the USBM from information from several suppliers and processors. Prices remained unchanged from the previous year for most grades and were listed as follows: 99% purity, $1,500; 99.9% purity, $3,000; 99.99% purity, $5,000; and 99.999% purity, $8,000. The price for 99.999% purity decreased $2,000 per kilogram from the previous year.

Scandium metal prices, as listed by the Johnson Matthey Aesar Group, were as follows: 99.99% purity, lump, sublimed dendritic, ampouled under argon, $312.00 per gram; 99.9% purity, 250-micron powder, ampouled under argon, $559.00 per 2 grams; and 99.9% purity, lump, vacuum remelted, ampouled under argon, $405.00 per 2 grams; 99.9% purity, foil, 0.025 millimeters (mm) thick, ampouled under argon, 25 mm by 25 mm, $117.00 per item.[30]

Scandium compounds prices, as listed by Aldrich Chemical Co., were as follows, scandium acetate hydrate 99.9% purity, $33.10 per gram; scandium chloride hydrate $99.99% purity, $44.50 per gram; scandium nitrate hydrate 99.9% purity, $47.70; and scandium sulfate hydrate 99.9% purity, $53.20 per gram. Prices for standard solutions for calibrating analytical equipment were $17.30 per 100 milliliter of scandium atomic absorption standard solution and $272.20 per 100 milliliter of scandium ICP/DCP standard solution.[31]

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost of the oxide while higher purity distilled scandium metal was approximately five times the cost.[32]

Foreign Trade

Rare-earth imports showed mixed results in 1993. Imports declined in two major categories and increased in four categories. U.S. imports of ore and compounds are shown in tables 5 and 6. As in the previous 4 years, France dominated the import market, especially for rare-earth compounds. *(See tables 5 and 6).*

U.S. imports of monazite concentrate (thorium ores and concentrates) remained at zero for the third consecutive year as a result of a major domestic processor switching to a thorium-free rare-earth feed material in 1991. Imports of cerium compounds increased 57% from the 1992 level as cerium demand increased for use in automotive exhaust catalysts, UV-absorbing glass additives, and polishing compounds. Principal sources, by quantity, were China, France, and Japan. For the first time, China became the largest source of imported cerium compounds, displacing France.

Imports of individual rare-earth compounds, other than cerium compounds, also increased in 1993. The 20% gain was mainly for feed material for permanent magnet alloys. Principal sources of these imports were France, China, and Japan.

Imports of mixed rare-earth compounds, excluding cerium compounds and mixed chlorides, decreased 15% as demand fell for plant feed materials. France, China, and Japan were the major suppliers in order of decreasing volume. U.S. imports of rare-earth metals decreased 33% during the year. Principal sources for the metals, by quantity, were China and Brazil. Decreased demand for alloy imported from Austria was responsible for most of the decrease.

Imports of mixed rare-earth chlorides gained 49%, with India remaining the principal source. China's share of the market also increased substantially. Rare-earth chloride imports were mainly used as feed material for manufacturing fluid cracking catalysts with lesser amounts consumed in producing mischmetal.

Ferrocerium imports in 1993 increased about 12%, with most material originating from France, Brazil, Austria, and Belgium. The principal sources of U.S. imports, in terms of volume of equivalent REO contained, are displayed in figure 6. *(See figure 6.)*

U.S. exports of rare earths in 1993 were diverse. Exports of cerium compounds decreased 16% from 1992's level. Principal destinations were automobile catalyst plants and glass polishing operations in Canada, Japan, Singapore, and the Republic of Korea. Exports of rare-earth compounds, excluding cerium compounds, also declined, down 17% as a result of decreased demand from Japan and Canada.

Exports of ferrocerium and other pyrophoric alloys increased 76%. A large number of countries received shipments, with the largest quantities going to Japan, Hong Kong, and Canada. U.S. exports of rare-earth metals also increased, up 343%, with principal destinations of Germany, Canada, and the United Kingdom. Domestic exports of rare earths are shown in table 7. Based on limited available U.S. Bureau of the Census data, Japan, Canada, and Hong Kong were the leading export destinations of rare earths from the United States in 1993. This was a shift from 1992 when Brazil, Japan, and Taiwan were the leaders. Principal destinations of U.S. exports are displayed in figure 7. *(See table 7 and figure 7.)*

World Review

Industry Structure.—Bastnasite 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. Minor production also was reported from Madagascar. Significant quantities of rare earths were also recovered from monazite, a byproduct of heavy-mineral sands mined for titanium and zirconium minerals or tin minerals in Australia, Brazil, China, the former U.S.S.R., India, Indonesia, Malaysia, the Republic of South Africa, Sri Lanka, Taiwan, Thailand, and the United States.

Smaller amounts of rare earths, especially yttrium, were obtained from the mineral xenotime. Xenotime was recovered primarily as a byproduct of processing for tin minerals in Indonesia, Malaysia, and Thailand, but was also produced as a byproduct of processing titanium and zirconium minerals in Australia and China.

Most yttrium produced in the world is now derived from ion-adsorption ores in China. The ore was mined and processed as a primary product for yttrium and the other rare earths at several locations in southeastern China.

Mining in Russia, Kazahkstan, Kyrgyzstan, and Ukraine produced rare earths from loparite, synchisite-(Y), and uraniferous phosphorites. Minor production was also reported from pilot-plant processing eudialyte in Russia. *(See tables 8 and 9.)*

Scandium was recovered as a byproduct of processing ore for beryllium, iron, tin, and tungsten in China, and previously was produced as a byproduct of uranium processing in the United States. In the former U.S.S.R., scandium was recovered as a byproduct of uranium.

Reserves.—World reserves of rare earths were estimated by the Bureau of Mines at 100 million metric tons of contained REO. China has the largest share of world reserves with 43%. *(See figure 8.)*

OUTLOOK

Demand for rare earths continues to shift towards higher purity mixed and separated products with applications in a wider range of products. This trend of increased demand and diversification is expected to accelerate through the year 2000. Strong growth is forecast in the areas of permanent magnets, materials for auto catalytic converters, and rechargeable batteries.

World rare-earth reserves are sufficient to meet world demand well into the 21st century. Considering the likelihood that additional deposits of rare earths will continue to be located and assuming reasonable increases in energy, transportation, processing, and environmental costs, world resources are more than adequate to fulfill demand for the foreseeable future.

Domestic companies have shifted away from radioactive-bearing rare-earth ores. This trend has had a negative impact on monazite-producing mineral sands operations worldwide. Future long-term demand for monazite, however, is expected to increase due to its abundant supply and low cost byproduct recovery. The cost to monitor and dispose of radioactive waste products in the United States is expected to continue to increase, severely limiting domestic use of monazite and other thorium-bearing ores.

Domestic and foreign demand in 1994 is expected show strong growth as the domestic economy shows signs of strengthening. Competitive world markets are expected to endure in the future, with economic restructuring in Russia and the rest of the former U.S.S.R. greatly expanding market opportunities. Future growth, however, will be greatest wherever low-radioactivity, easily beneficiable deposits are found.

The distant outlook is for an increasingly competitive and diverse group of rare-earth suppliers. The economic base of the rare-earth industry is forecast to continue to grow and broaden. Emerging applications are expected to develop faster and demand higher-purity materials at faster rates in response to rapid technological changes and increasing global competitivness. Demand is forecast to continue to grow as improved knowledge of the rare earths continues to generate new commercial applications, a trend that is expected to continue.

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TABLE 1
SALIENT U.S. RARE-EARTH STATISTICS

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1989	1990	1991	1992	1993
Production of rare-earth concentrates	[1] 20,787	[1] 22,713	[2] 16,465	[2] 20,699	[2] 17,754
Exports:					
Cerium compounds	1,433	1,730	1,369	1,935	1,622
Rare-earth metals, scandium, and yttrium	425	241	[r] 71	[r] 44	194
Ores and concentrates	NA	NA	[3] 459	—	—
Rare-earth compounds, organic or inorganic	NA	1,460	1,793	1,306	1,088
Ferrocerium and pyrophoric alloys	74	83	[r] 2,100	[r] 2,431	4,268
Imports for consumption:[e]					
Monazite	426	440	—	—	—
Metals, alloys, oxides, compounds	6,125	4,489	6,114	[r] 5,333	6,673
Stocks, producers and processors, yearend	W	W	W	W	W
Consumption, apparent[e]	27,770	28,700	22,100	[r] 21,400	17,000
Prices, yearend, dollars per kilogram:					
Bastnasite concentrate, REO basis	2.76	2.87	2.87	2.87	2.87
Monazite concentrate, REO basis	1.19	1.19	.93	.41	.40
Mischmetal, metal basis	12.35	11.02	11.02	12.68	12.68
Employment, mine and mill[e] [4]	381	397	411	372	352
Net import reliance[e] [5] as a percent of apparent consumption	[r] 29	20	25	[r] 33	([6])

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

[1] Comprises only the rare earths derived from bastnasite, as reported in Unocal Corp. annual reports.

[2] Comprises only the rare earths derived from bastnasite as obtained from Molycorp, Inc., company representative.

[3] Source: The Journal of Commerce Trade Information Service.

[4] Employment at a rare-earth mine in California and at a mineral sands operation in Florida, and a mineral sands tailings operation in New Jersey. The latter mines produced monazite as a byproduct and employees were not assigned to specific commodities.

[5] Imports minus exports plus adjustments for Government and industry stock changes.

[6] Net exporter.

TABLE 2
MOLYCORP RARE-EARTH OXIDE PRICES

Product (oxide)	Percent[1] purity	Quantity (pounds)	Price per pound
Cerium (5310)	96.00	200.00	$7.50
Cerium (5350)	99.00	200.00	10.50
Dysprosium	96.00	50.00	60.00
Erbium	98.00	50.00	65.00
Europium	99.99	25.00	450.00
Gadolinium	99.99	55.00	55.00
Lanthanum	99.99	300.00	8.75
Neodymium (5400)	96.00	300.00	6.75
Neodymium (5410)	99.90	50.00	40.00
Praseodymium	96.00	300.00	16.80
Samarium	96.00	55.00	30.00
Terbium	99.90	44.10	375.00
Yttrium	99.99	50.00	52.50

[1] Purity expressed as percent of total REO.

TABLE 3
MOLYCORP RARE-EARTH COMPOUND PRICES

Product (compound)	Percent[1] purity	Quantity (pounds)	Price[2] per pound
Cerium carbonate	99.0	150	$5.75
Cerium fluoride	Tech. grade	250	3.50
Cerium nitrate	96.0	250	2.90
Lanthanum chloride	46.0	525	1.25
Lanthanum carbonate	99.9	175	5.90
Lanthanum-lanthanide carbonate	60.0	150	2.15
Lanthanum-lanthanide chloride	46.0	525	1.05
Lanthanum-lanthanide nitrate	39.0	250	1.75
Neodymium carbonate	96.0	300	4.50

[1] Purity expressed in terms of REO equivalent.
[2] Priced on contained REO basis.

TABLE 4
RHÔNE-POULENC RARE-EARTH OXIDE PRICES

Product (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	96.00	20	23.00
Cerium	99.50	20	$16.00
Dysprosium	95.00	20	95.00
Erbium	96.00	20	175.00
Europium	99.99	10	1,000.00
Gadolinium	99.99	50	118.00
Holmium	99.90	5	485.00
Lanthanum	99.99	25	45.00
Lutetium	99.99	2	5,500.00
Neodymium	95.00	20	17.90
Praseodymium	96.00	20	30.00
Samarium	96.00	25	85.00
Terbium	99.90	5	575.00
Thulium	99.90	5	2,750.00
Ytterbium	99.00	10	220.00
Yttrium	99.99	50	80.00

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF MONAZITE, BY COUNTRY

Country	1989		1990		1991[1]		1992[1]		1993[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	180	$117	—	—	—	—	—	—	—	—
Indonesia	594	413	800	$686	—	—	—	—	—	—
Total	774	530	800	686	—	—	—	—	—	—
REO content[e]	426	XX	440	XX	—	XX	—	XX	—	XX

[e] Estimated. XX Not applicable.

[1] No data reported by the Bureau of the Census for 1991-93.

Source: Bureau of the Census. REO content estimated by the U.S. Bureau of Mines.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds, including oxides, hydroxides, nitrate, sulfate chloride, oxalate: (2846.10.0000)						
Austria	1,400	$20,291	12,005	$136,703	24,586	$262,304
Belgium	—	—	—	—	7,900	58,950
Brazil	—	—	2,300	11,500	—	—
Canada	—	—	—	—	366	21,938
China	6,000	50,529	[r]128,621	[r]691,535	668,670	2,852,447
France	379,104	3,135,018	534,523	4,174,266	280,502	2,672,344
Germany	79,951	47,498	30	17,552	2,308	62,790
India	—	—	—	—	127,928	167,565
Japan	77,465	1,647,700	128,196	2,926,126	147,861	3,863,785
Netherlands	—	—	369	37,971	—	—
Russia[1]	—	—	24	4,100	2,306	7,666
Switzerland	—	—	—	—	2	5,380
Taiwan	—	—	—	—	1,039	10,000
U.S.S.R.[2]	2	2,532	1	2,200	—	—
United Kingdom	1,040	9,355	172	8,364	4,316	39,946
Total	544,962	4,912,923	[r]806,241	[r]8,010,317	1,267,784	10,025,115
Rare-earth compounds, including oxides, hydroxide, nitrate, and other compounds except chlorides: (2846.90.5000)						
Austria	—	—	—	—	845	14,617
Belgium	[r]13	[r]4,176	59,017	225,980	—	—
Brazil	—	—	—	—	9,000	38,111
Bulgaria	3,030	4,545	—	—	2,838	29,590
Canada	11,287	1,369,709	732	76,333	2,812	92,853
China	154,843	2,477,305	496,260	3,037,119	381,790	3,615,210
France	3,337,395	19,036,155	3,457,977	21,396,888	4,419,718	26,056,013
Germany	839	99,207	1,156	105,928	4,082	502,016
Hong Kong	5,115	166,067	34	24,912	—	—
Hungary	10,099	47,699	5,121	26,733	—	—
Ireland	—	—	—	—	375	41,978
Japan	132,902	6,922,345	94,373	8,842,106	144,640	8,199,437
Korea, Republic of	—	—	2,999	60,569	—	—
Netherlands	98	26,506	400	80,220	—	—
Norway	9,514	901,297	975	221,511	731	140,242
Russia[1]	—	—	799	20,916	3,956	362,268
South Africa, Republic of	[r]16,732	[r]628,392	—	—	—	—
Sweden	[r]26	[r]1,800	114	11,852	90	7,910
Taiwan	—	—	—	—	513	25,125
U.S.S.R.[2]	9,500	1,659,821	—	—	—	—
United Kingdom	1,715	721,596	12,862	441,114	4,601	268,435
Other	[r]55	[r]11,951	(3)	(3)	11	7,057
Total	3,693,163	34,078,571	[r]4,132,819	[r]34,572,181	4,976,002	39,400,862
Mixtures of rare-earth oxide except cerium oxide: (2846.90.2010)						
Austria	1,566	175,641	14,266	975,392	4,464	179,150
Belgium	—	—	—	—	9,000	26,131

See footnotes at the end of table.

TABLE 6—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Mixtures of rare-earth oxide except cerium oxide—Continued: (2846.90.2010)						
China	277,943	2,597,046	109,119	$1,663,993	59,966	$1,255,919
Estonia	—	—	4,000	12,088	9,040	26,695
France	44,734	4,452,935	70,782	6,031,045	71,073	4,808,138
Germany	6,506	1,011,363	7,550	1,259,266	6,901	837,255
Hong Kong	80,384	868,111	4,950	143,560	7,542	553,426
India	399,928	240,522	—	—	28,854	92,909
Japan	21,968	2,364,992	42,657	3,568,048	38,199	1,931,156
Norway	242	42,758	7	1,350	—	—
Taiwan	19,205	196,464	301	24,599	89	33,969
U.S.S.R.[2]	8,536	247,233	—	—	—	—
United Kingdom	31,265	941,229	41,339	1,173,735	14,325	802,297
Other	—	—	—	—	40	9,805
Total	892,277	13,138,294	294,971	14,853,076	249,493	10,556,850
Rare-earth metals, whether inter-mixed or alloyed: (2805.30.0000)						
Austria	1,400	32,000	[r]83,000	[r]418,647	—	—
Belgium	4,950	19,800	—	—	—	—
Brazil	30,866	208,963	18,072	125,973	20,412	142,385
Canada	—	—	—	—	179	6,716
China	131,480	1,480,056	[r]173,346	[r]1,337,730	160,929	1,546,305
Germany	34,500	181,579	7,760	90,523	51	6,572
Hong Kong	741	33,727	675	94,660	60	4,350
Japan	6,767	232,527	1,834	210,406	1,234	140,075
Norway	50	8,205	45	6,771	45	6,771
Russia[1]	—	—	—	—	3,282	113,195
Taiwan	—	—	100	7,250	5	1,800
U.S.S.R.[2]	2,400	57,086	150	75,000	—	—
United Kingdom	12,666	1,075,301	8,109	797,443	9,649	673,906
Other	—	—	[r]2	[r]3,000	20	1,700
Total	225,820	3,329,244	[r]293,093	[r]3,167,403	195,866	2,643,775
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)						
Austria	4,246	117,165	45	4,011	—	—
China	104,300	1,467,839	205,661	2,501,856	315,154	4,151,373
Estonia	—	—	1,000	9,288	—	—
France	—	—	2,022	94,709	1	8,000
Germany	1	4,000	51	4,721	327	62,042
Hong Kong	—	—	—	—	3,000	5,324
India	2,971,130	2,336,576	1,064,732	821,455	1,898,619	1,577,792
Japan	65,581	4,453,877	33,401	3,625,637	23,956	1,356,420
Malaysia	203,874	220,838	217,350	308,314	—	—
Norway	—	—	31	7,600	117	22,391
Russia[1]	—	—	—	—	7,205	61,243
Sweden	—	—	—	—	51,190	390,951
Taiwan	3,000	37,262	1,615	11,526	28	16,003
United Kingdom	25,110	252,121	57,494	302,787	56,203	427,259

See footnotes at the end of table.

TABLE 6—Continued

U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Mixtures of rare-earth chlorides, except cerium chloride—Continued: (2846.90.2050)						
Other	—	—	—	—	2	$8,801
Total	3,377,242	$8,889,678	1,583,402	$7,691,904	2,355,802	8,087,599
Ferrocerium and other purophoric alloys: (3606.90.3000)						
Austria	20,414	406,476	5,158	122,408	15,756	292,268
Belgium	3,400	64,023	17,109	331,266	14,058	223,030
Brazil	20,596	260,672	34,200	454,907	34,780	449,740
Canada	1,250	2,417	—	—	—	—
France	44,340	628,533	46,443	669,429	50,209	612,464
Germany	159	6,460	—	—	3,197	66,409
Hong Kong	500	5,099	—	—	—	—
Japan	2,250	46,905	2,720	34,780	50	3,700
Other	88	3,486	—	—	32	6,360
Total	92,997	1,424,071	105,630	1,612,790	118,082	1,653,971

[r] Revised.

[1] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[2] Dissolved in Dec. 1991; however, information is not available for individual countries, other than those listed in this table.

[3] Revised to zero.

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country		1991		1992		1993	
		Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cerium compounds:	(2846.10.0000)						
Argentina		2,400	$20,869	17,596	$63,751	2,620	$32,991
Australia		21,009	89,837	454	4,030	—	—
Austria		—	—	4,632	50,868	—	—
Belgium		2,523	16,960	4,738	35,821	17,851	87,805
Brazil		228,459	724,330	699,907	1,877,191	84,314	429,716
Canada		292,633	2,022,321	364,122	3,059,470	385,206	3,437,688
Chile		—	—	—	—	1,642	13,088
China		2,400	19,656	—	—	—	—
Colombia		882	4,200	—	—	3,840	21,043
Ecuador		—	—	720	3,427	—	—
Egypt		3,433	26,240	2,499	4,158	2,400	11,280
France		35,904	212,097	42,202	279,966	40,007	423,236
Germany		108,502	1,001,295	82,861	541,511	64,579	589,249
Greece		1,794	2,621	2,480	13,865	2,900	14,738
Hong Kong		106,868	655,274	93,715	534,379	86,090	617,903
India		—	—	—	—	5,181	66,367
Indonesia		700	54,710	1,920	3,455	960	5,338
Israel		3,347	21,159	3,850	26,644	2,879	19,826
Italy		12,000	74,277	15,424	98,187	18,953	171,451
Japan		231,140	1,037,752	146,363	663,341	236,972	2,465,838
Korea, Republic of		61,051	963,527	65,187	703,928	211,181	1,423,390
Kuwait		—	—	—	—	960	6,010
Malaysia		—	—	—	—	467	87,017
Mexico		30,628	74,835	24,860	150,790	19,520	197,015
Netherlands		794	7,052	8,288	53,729	3,814	47,478
Norway		[r]490	[r]2,780	500	2,921	—	—
Pakistan		—	—	—	—	480	2,842
Philippines		—	—	960	5,338	—	—
Portugal		5,760	27,603	13,500	61,560	—	—
Saudi Arabia		960	4,944	1,920	10,724	14,153	3,373
Singapore		39,520	159,591	178,121	791,412	228,845	834,406
Spain		25,440	145,467	15,360	94,504	7,173	37,692
Switzerland		—	—	72	14,361	500	14,263
Taiwan		118,741	518,094	92,629	546,995	141,043	541,997
Thailand		13,552	102,551	15,626	114,475	29,609	56,817
Trinidad and Tobago		3,672	51,437	5,365	68,600	—	—
United Kingdom		5,976	38,766	29,150	209,418	6,289	39,397
Venezuela		7,897	52,849	—	—	1,440	11,448
Other		[r]60	[r]61,454	—	—	74	6,300
Total		1,368,535	8,194,548	1,935,021	10,088,819	1,621,942	11,717,002
Rare-earth compounds:	(2846.90.0000)						
Antigua and Barbuda		—	—	—	—	295	2,687
Argentina		99	22,997	—	—	30	9,163
Australia		650	7,650	342	4,550	119	5,896
Austria		2,006	36,889	836	3,982	2,808	478,503
Bahamas, The		—	—	534	7,051	21,361	29,978

See footnote at the end of table.

TABLE 7—Continued

U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth compounds—Continued: (2846.90.0000)						
Barbados	—	—	1,858	$3,529	—	—
Belgium	43,893	$166,487	415	119,868	791	$230,870
Bolivia	2,155	2,938	—	—	—	—
Brazil	19,059	129,782	23,505	214,658	55,013	223,650
Canada	39,973	825,404	184,664	538,427	99,772	335,077
Chile	—	—	149,527	161,369	88,101	104,476
China	—	—	11,020	77,200	888	65,463
Colombia	—	—	—	—	936	9,593
Costa Rica	—	—	65	14,350	53	11,698
Denmark	87	12,000	43	5,200	—	—
Finland	r3,894	r152,056	16,581	584,053	34,840	818,877
France	418,723	576,858	222,720	308,960	241,486	420,238
Germany	93,284	2,424,107	37,641	2,125,749	54,951	2,066,439
Hong Kong	—	—	771	4,860	5,685	232,272
Hungary	550	136,940	—	—	1	4,425
India	316	13,730	277	7,900	31	7,225
Indonesia	3,018	4,339	—	—	—	—
Ireland	—	—	—	—	1,633	14,750
Israel	2,195	180,000	—	—	—	—
Italy	276	58,412	75	21,292	370	147,088
Japan	927,538	12,299,034	526,292	6,128,194	366,327	5,782,176
Korea, Republic of	63,766	1,764,122	2,804	231,686	14,819	646,115
Lebanon	—	—	8,988	42,783	—	—
Mexico	77,536	139,340	19,120	146,103	1,749	34,282
Netherlands	29,517	786,771	1,109	33,555	5,000	120,290
Netherlands Antilles	—	—	14,274	30,170	1,764	5,811
Oman	—	—	2,720	8,803	—	—
Portugal	30,995	34,926	—	—	—	—
Romania	—	—	—	—	356	14,406
Saudi Arabia	3,311	12,509	1,007	3,412	1,063	7,734
Singapore	124	200,708	83	140,855	9	17,023
Spain	2,318	33,200	20,510	61,162	—	—
Sweden	350	90,023	2,241	125,718	891	85,955
Switzerland	3,159	204,000	2,644	97,397	1,140	69,010
Taiwan	8,588	458,967	32,475	972,425	59,228	1,737,660
United Kingdom	14,623	170,877	21,322	545,748	26,055	379,448
Venezuela	1,089	9,401	—	—	—	—
Other	(1)	(1)	(1)	(1)	19	4,286
Total	1,793,092	20,954,467	1,306,463	12,771,009	1,087,584	14,122,564

See footnote at the end of table.

TABLE 7—Continued

U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Rare-earth metals, including scandium and yttrium: (2805.30.0000)						
Argentina	118	$5,740	—	—	6	$9,080
Bahamas, The	18,954	18,745	—	—	—	—
Canada	10,215	194,712	13,780	$205,997	39,341	283,298
China	—	—	—	—	14,000	58,305
Denmark	—	—	168	6,650	—	—
Finland	—	—	—	—	2,115	64,494
France	833	160,392	1,327	44,814	1,646	54,846
Germany	27	8,340	2,550	202,308	65,280	130,976
Hong Kong	—	—	470	4,037	—	—
Hungary	—	—	—	—	5,315	717,638
India	5	5,000	140	36,150	197	8,210
Japan	25,337	1,874,990	5,647	293,319	1,553	574,500
Korea, Republic of	—	—	7,934	38,970	478	55,503
Mexico	—	—	—	—	200	2,624
Netherlands	150	7,350	—	—	—	—
Singapore	—	—	212	5,926	3,150	125,000
South Africa, Republic of	400	12,323	—	—	—	—
Sweden	30	100,549	1,467	111,000	2,490	157,553
Taiwan	—	—	388	32,708	633	25,347
United Kingdom	1,966	288,068	2,344	109,616	25,002	124,277
Venezuela	1,000	6,650	—	—	—	—
Other	(1)	(1)	[r]25	[r]6,250	15	3,690
Total	59,035	2,682,859	36,452	1,097,745	161,421	2,395,341
Ferrocerium and other pyrophoric alloys: (3606.90.0000)						
Argentina	13,553	31,855	7,892	11,784	77,298	529,983
Aruba	5,443	45,207	—	—	1,323	5,904
Australia	124,567	262,556	120,862	292,453	96,930	249,465
Austria	—	—	719	2,518	653	2,586
Bahrain	—	—	28,182	36,368	42,464	59,799
Bangladesh	—	—	—	—	746	14,550
Barbados	55,737	64,048	56,027	65,593	44,054	48,251
Belgium	204	5,832	2,180	78,249	42,404	201,467
Bermuda	1,398	2,561	—	—	—	—
Brazil	2,200	14,071	186,466	70,916	41,835	80,195
Brunei	—	—	—	—	3,252	6,734
Canada	37,261	1,987,397	35,038	1,861,877	377,634	1,880,608
Chile	—	—	—	—	14,587	50,126
China	499	205,000	—	—	109,650	129,580
Colombia	3,481	8,283	4,160	10,330	—	—
Costa Rica	7,483	66,690	—	—	8,126	61,361
Cyprus	14,834	16,863	—	—	26,859	35,451
Denmark	5,377	84,920	3,451	77,378	62,077	114,439
Dominican Republic	[r]276	[r]14,661	42,846	111,124	47,080	163,608
Ecuador	42,400	138,512	—	—	1,154	4,175

See footnotes at the end of table.

TABLE 7—Continued

U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys-Continued: (3606.90.0000)						
El Salvador	12,955	$15,300	37,540	$47,331	—	—
France	18,555	343,857	10,789	212,528	99,302	$385,457
Gambia, The	—	—	—	—	112,890	1,577,876
Germany	243,520	1,533,980	222,508	1,014,354	283,564	825,520
Greece	47,717	120,052	81,509	51,073	123,544	94,241
Guatemala	74,755	19,766	156	8,300	137,451	166,203
Haiti	25,009	65,500	—	—	—	—
Honduras	—	—	58,874	69,530	35,677	124,125
Hong Kong	319,632	521,546	367,885	598,736	437,391	930,548
Iceland	—	—	—	—	19,291	499,399
Indonesia	3,838	24,050	10,160	36,930	9,041	32,621
Ireland	4,519	31,646	11,297	17,126	20,993	48,722
Israel	566	25,632	1,654	17,343	2,240	39,063
Italy	1,287	43,003	1,623	117,966	4,122	34,175
Jamaica	50,407	75,019	49,517	58,150	96,324	123,387
Japan	50,392	646,589	85,496	547,235	695,832	4,443,097
Jordan	29,046	16,012	43,002	49,613	31,510	17,660
Korea, Republic of	[r]7,987	[r]49,424	36,585	177,984	4,999	21,980
Kuwait	—	—	35,370	47,673	61,044	111,390
Lebanon	—	—	16,511	25,492	267	6,620
Malaysia	8,313	48,670	5,392	65,545	15,450	13,425
Malta	2,066	3,082	1,847	2,822	—	—
Marshall Islands	7,144	21,336	—	—	—	—
Martinique	—	—	2,177	2,612	—	—
Mexico	22,437	146,497	8,180	145,531	45,524	206,737
Netherlands	137,208	213,570	25,385	68,649	90,078	1,195,316
Netherlands Antilles	[r]9,118	[r]34,349	20,893	66,425	11,696	99,371
New Zealand	[r]22,915	[r]42,555	26,600	56,030	40,840	58,977
Nicaragua	—	—	2,163	10,000	—	—
Nigeria	—	—	13,922	25,574	—	—
Norway	627	66,912	—	—	286	8,760
Panama	—	—	4,023	24,917	17,957	141,389
Philippines	[r]1,926	[r]44,931	38,594	142,023	25,353	150,593
Poland	—	—	—	—	388	15,000
Qatar	13,971	16,237	—	—	144	7,332
Romania	—	—	—	—	31,328	132,000
Saudi Arabia	81,868	215,764	110,231	176,990	294,985	1,644,217
Singapore	214,026	294,713	167,748	445,949	358,131	1,282,449
Slovenia	—	—	2,903	15,520	—	—
South Africa, Republic of	16,395	80,323	819	26,815	1,326	61,378
Spain	6,042	248,211	5,335	88,688	12,861	47,046
Sweden	148	3,000	140	280,428	235	11,059
Switzerland	14,354	20,094	3,967	41,362	4,282	53,896
Taiwan	18,920	919,670	516,500	7,915,177	119,431	586,970
Thailand	468	14,097	3,733	11,000	30,068	91,945

See footnotes at the end of table.

TABLE 7—Continued
U.S. EXPORTS OF RARE-EARTHS, BY COUNTRY

Country	1991		1992		1993	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Ferrocerium and other pyrophoric alloys-Continued: (3606.90.0000)						
Trinidad and Tobago	—	—	9,357	$22,774	29,153	$42,602
Turkey	5,055	$8,424	265	5,200	105	14,100
United Arab Emirates	131,392	184,428	175,785	246,484	229,197	310,124
United Kingdom	166,491	195,298	32,127	218,456	255,488	923,008
Uruguay	—	—	—	—	634	14,560
Venezuela	13,531	27,656	834	9,850	16,856	36,455
Zimbabwe	—	—	104	5,082	—	—
Other	[r]304	[r]13,150	[r]19	[r]6,108	1,381	113,234
Total	[r]2,099,617	9,342,799	2,737,342	15,841,965	4,806,785	20,382,309

[r] Revised.

[1] Revised to zero.

Source: Bureau of the Census.

TABLE 8
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons, gross weight)

Country[2]	1989	1990	1991	1992	1993[e]
Australia[e]	13,000	11,000	[r]7,000	[r]7,000	10,000
Brazil	2,503	1,656	[r]1,308	[r]1,400	1,400
China	1,782	2,382	1,185	[e]1,800	1,800
India[e]	4,300	4,500	[r]4,000	[r]4,000	4,600
Malaysia	2,948	3,323	1,981	[r]777	320
South Africa, Republic of[e]	1,200	[3]1,317	1,300	1,300	1,300
Sri Lanka[e]	200	200	200	200	200
Thailand	631	377	[e]400	[r]89	100
United States	W	W	W	W	W
Zaire	175	124	[e]120	[r e]50	50
Total	26,739	24,879	[r]17,494	[r]16,616	19,770

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; excluded from "Total."

[1] Table includes data available through June 9, 1994.

[2] In addition to the countries listed, Indonesia, North Korea, Republic of Korea, Nigeria, and the former U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels.

[3] Reported figure.

TABLE 9
RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons of REO equivalent)

Country[2]	1989	1990	1991	1992	1993[e]
Australia[e]	7,150	6,050	3,850	3,850	5,500
Brazil	[r]1,377	[r]911	[r]719	[r][e]770	770
Canada[e]	100	—	—	—	—
China[e]	25,220	16,480	16,150	[r]21,340	22,100
India[e]	[r]2,400	[r]2,500	[r]2,200	[r]2,200	2,500
Malaysia	[r]1,621	1,828	[r]1,090	[r]427	[3]224
Madagascar:					
Bastnasite	[r]5	[r]5	[r]5	[r]5	5
Monazite	(4)	(4)	(4)	(4)	(4)
South Africa, Republic of[e]	660	[3]724	715	715	715
Sri Lanka[e]	110	110	110	110	110
Thailand	[r]382	[r]221	[r]235	[r][e]64	70
U.S.S.R.[e] [5]	8,500	8,500	8,500	8,000	7,000
United States[6]	20,787	22,713	16,465	20,699	17,800
Zaire[e]	96	68	[r]66	[r]28	28
Total	[r]68,408	[r]60,110	[r]50,105	[r]58,208	56,822

[e] Estimated. [r] Revised.

[1] Table includes data available through July 19, 1994.

[2] In addition to the countries listed, rare earth minerals are believed to be produced in Indonesia, North Korea, Mozambique, and Vietnam, but information is inadequate to formulate reliable estimates.

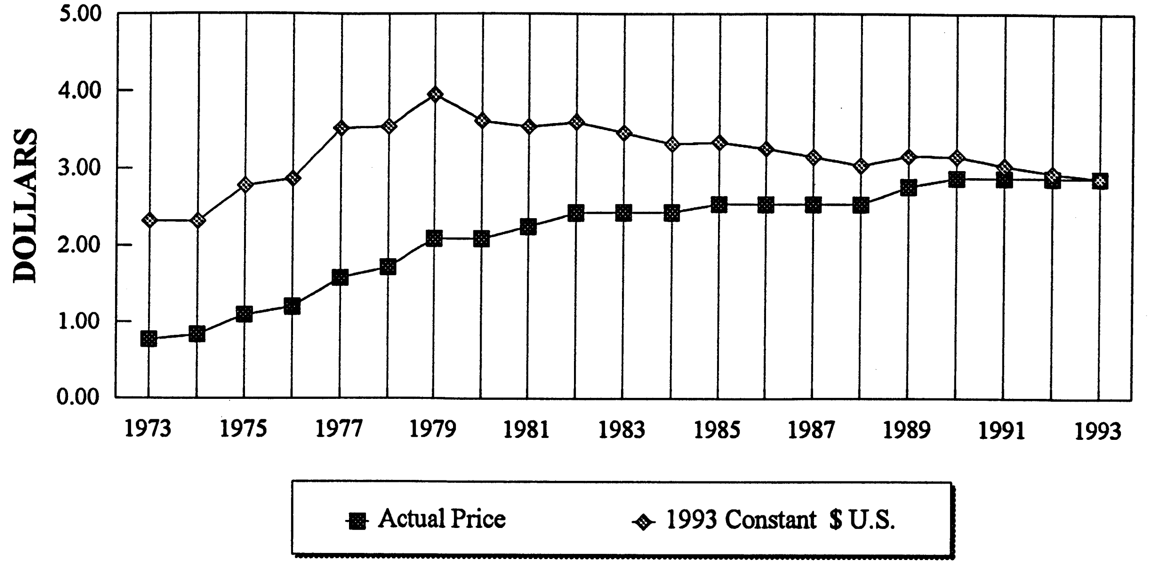
[3] Reported figure.

[4] Less than 1/2 unit.

[5] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

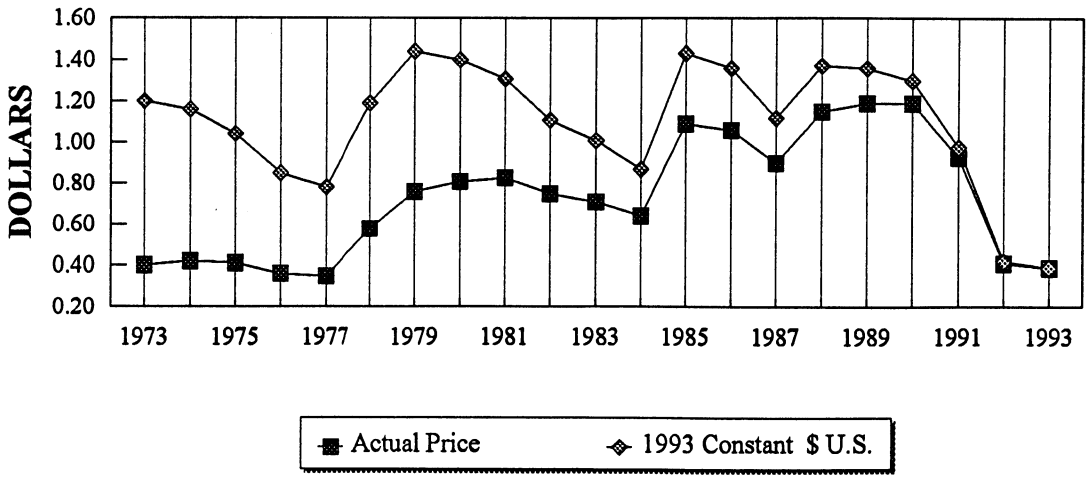
[6] Comprises only the rare earths derived from bastnasite as reported in Unocal Corp. annual report, 1990 and from company sources.

FIGURE 1
BASTNASITE CONCENTRATE PRICES



1/60% REO content.

FIGURE 2
MONAZITE CONCENTRATE PRICES



1/55% REO content.

FIGURE 3
U.S. RARE-EARTH MINE AND MILL EMPLOYMENT

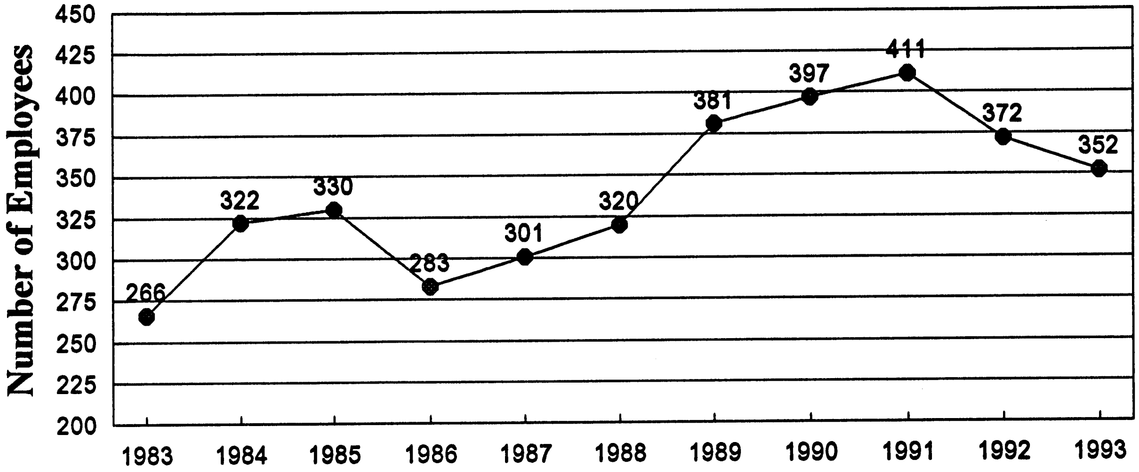


FIGURE 4
U.S. BASTNASITE CAPACITY UTILIZATION

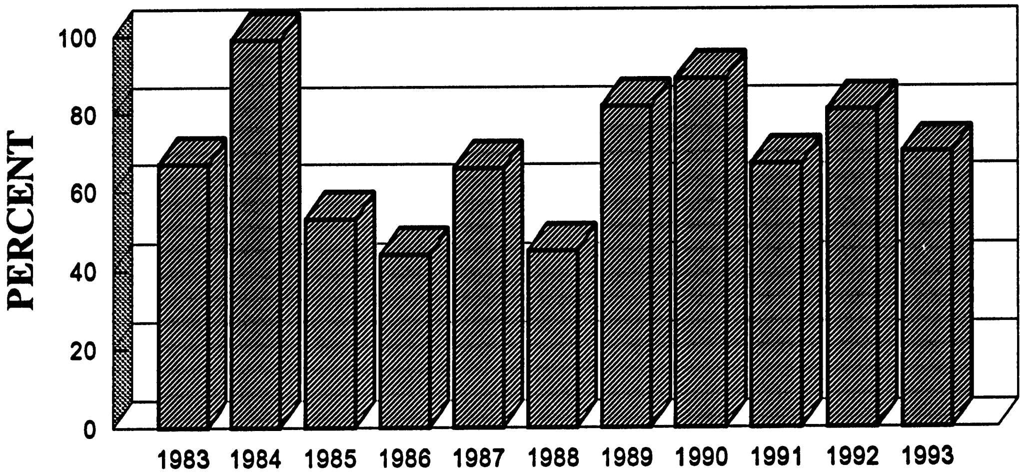


FIGURE 5
U.S. MONAZITE CAPACITY UTILIZATION

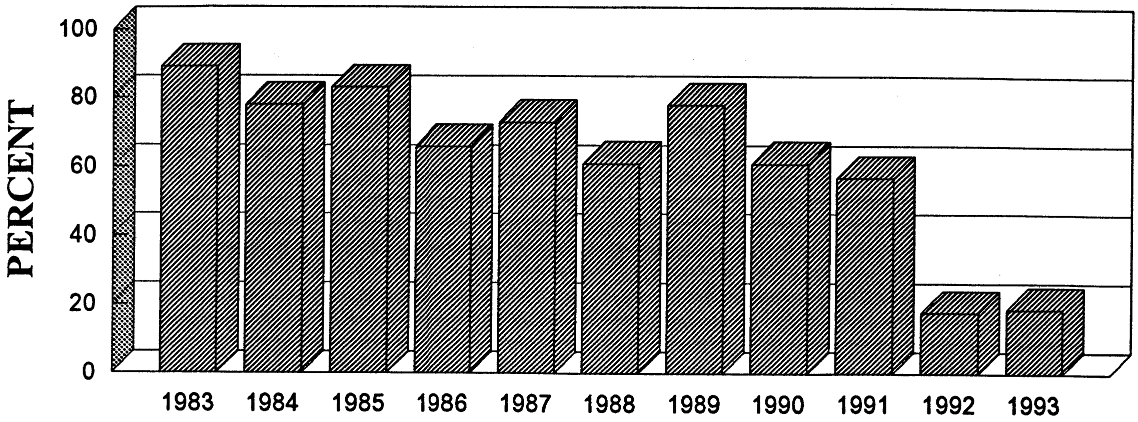
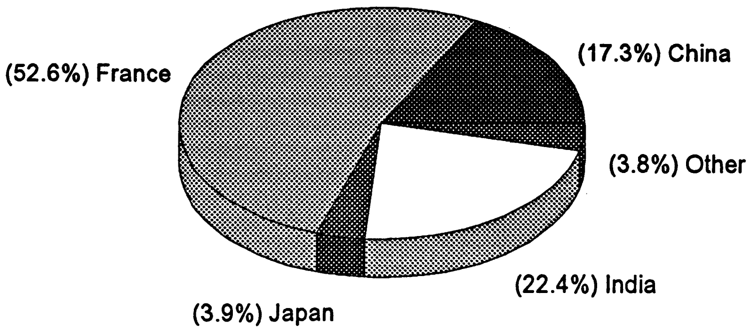


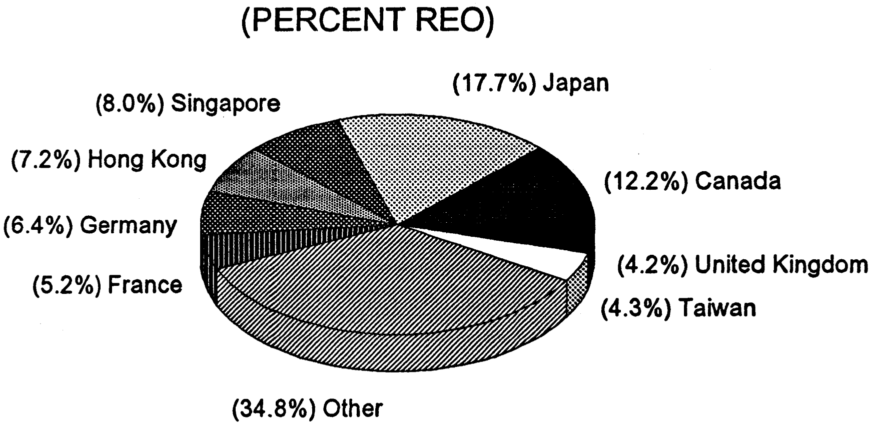
FIGURE 6
U.S. IMPORTS OF RARE EARTHS

(PERCENT REO)



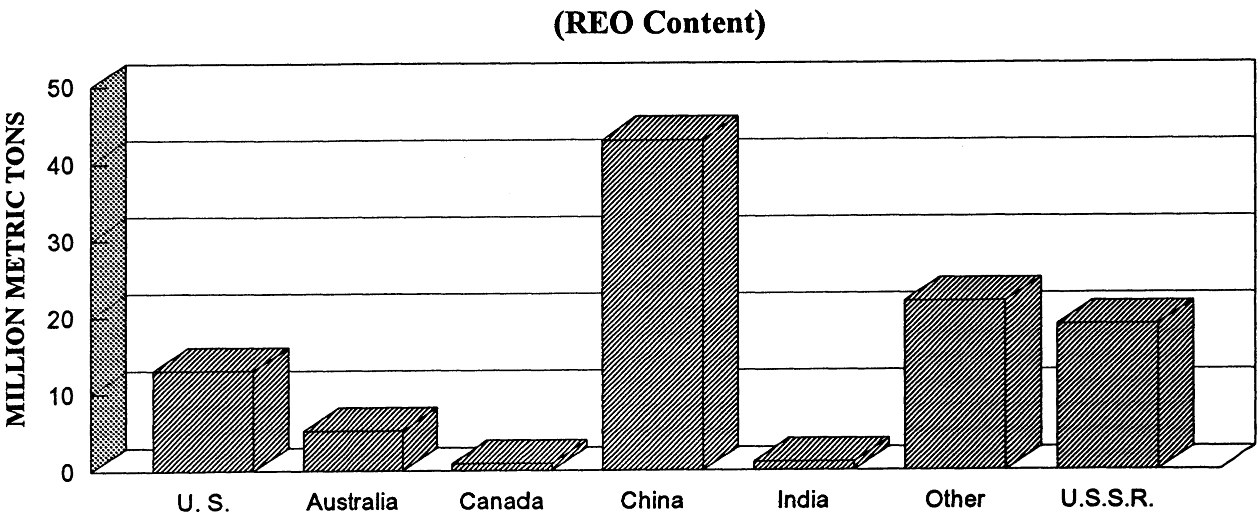
Source: Bureau of the Census.

FIGURE 7
U.S. EXPORTS OF RARE EARTHS



Source: Bureau of the Census

FIGURE 8
WORLD RESERVES OF RARE EARTHS



RECYCLING IRON AND STEEL SCRAP

By Gerald W. Houck

Mr. Houck, a physical scientist with 37 years of industry and U.S. Bureau of Mines experience, is the commodity specialist for iron and steel. Domestic survey data tables were prepared by Henry F. Sattlethight and David J. Kulha, Section of Metals Data.

Iron and steel scrap is a vital raw material for the production of new steel and cast iron products. Because of the ready availability of scrap from manufacturing operations and from the recovery of steel products that have reached the end of their useful lives, the steel industry and the foundry industry in the United States have been structured efficiently to recycle scrap, and, as a result, are highly dependent upon scrap.

The recycling of steel scrap plays an important role in the conservation of energy because remelting of steel scrap requires much less energy than the production of steel or iron products from iron ore. In addition, the consumption of steel scrap by remelting reduces the burden on landfill disposal facilities and prevents the accumulation of abandoned steel products in the environment.

Brokers, dealers, and other outside sources supplied domestic consumers in 1993 with 46.3 million metric tons[1] of all types of ferrous scrap at a delivered value of approximately $5 billion, while exporting 9.8 million tons (excluding used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) valued at $1.3 billion. In 1992, domestic consumers received 42.1 million tons (revised) at a delivered value of approximately $3.5 billion (revised); exports totaled 9.26 million tons valued at $1.1 billion. This represented a tonnage increase of about 10% for received quantities and a tonnage decrease of about 6% for exported quantities. The total value of these received and exported scrap grades increased about 20%.

DOMESTIC DATA COVERAGE

Domestic data for ferrous scrap were developed by the U.S. Bureau of Mines from voluntary monthly or annual surveys of U.S. scrap consuming operations. For manufacturers of pig iron and raw steel, about 90% of the known establishments responded to the surveys. Responses to surveys represented about 85% of scrap consumption. The remaining 15% of scrap consumption was estimated, based on prior reports and other information. For manufacturers of steel castings and iron foundries and miscellaneous users, about 40% of the known establishments responded to the annual survey, representing about 65% of estimated scrap consumption by these scrap consumers. Total consumption for these two classes of consumers was estimated using statistical methods.

ANNUAL REVIEW

Legislation and Government Programs

In the United States, there were four instances in 1993 where steel mills or foundries melted a radioactive source. This makes a total of 14 reported such occurrences since 1983. Twelve of the accidental meltings have involved cesium-137, a radioactive isotope commonly used, among other things, in industrial gauging devices.

When melting of a radioactive source occurs, the radioactive cesium volatilizes in the high temperature of the steelmaking furnace and is collected in the dust collection system of the furnace. The contaminated dust must be assayed for radioactivity levels, treated when necessary, and segregated either for recycling or disposal at a licensed radioactive waste disposal site. The cost to the mill has been estimated as between $5 million and $10 million.

Radioactive sources become mixed with iron and steel scrap because of improper controls and disposal of radioactive materials by persons licensed by the U.S. Nuclear Regulatory Commission (NRC) or by the States. In response to the problem of melting radioactive sources, protective measures have been mounted by NRC and by the industry. NRC publishes a warning poster to alert metal scrap industry and mill workers to the problem. In addition, NRC is considering a rulemaking to improve controls and accounting of radioactive sources by industrial gauge users. The Institute of Scrap Recycling Industries, the principal trade association of the scrap metal industry, has published an informational booklet and a Recommended Practice and Procedure for handling scrap that may be radioactive.

Increasingly, steel mills and scrap dealers are installing radiation detection devices to monitor incoming scrap for radiation. These can be effective. NRC and the Pennsylvania Department of Environmental Health have tabulated 79 instances between 1984 and June 1993, where radiation detection equipment detected a radioactive source mixed with incoming scrap. However, such equipment cannot provide 100% protection because the large volume and density of steel scrap tends to shield the radiation, sometimes to the point where even the most sophisticated radiation monitoring equipment cannot detect the source, and melting of radioactive sources has occurred at mills equipped with detection equipment.

Available Supply, Consumption, and Stocks

Raw steel production was 88.8 million tons in 1993 compared with 84.3 million tons in 1992. The shares of raw steel produced by electric and basic oxygen furnaces were, respectively, 39% and 61% in 1993 and 38% and 62% in 1991. Continuous cast steel production represented 86% of total raw steel production in 1993 compared with 79% in 1992. Raw steel production capability was 102.6 million tons in 1993 compared with 106.7 million tons in 1992. Raw steel capability utilization was 89% in 1993 and 82% in 1992.

Net shipments of all grades of steel mill products were 80.8 million tons in 1993 and 74.6 million tons in 1992. Imports of steel mill products increased from 15.5 million tons in 1992 to 17.7 million tons in 1993. Exports of steel mill products decreased from 3.89 million tons in 1992 to 3.60 million tons in 1993. The U.S. apparent supply of steel mill products increased from 86.2 million tons in 1992 to 92.0 million tons in 1993. Imports of steel mill products, as a share of the U.S. market, were 18% in 1992 and 19% in 1993. Pig iron production increased from 47.4 million tons in 1992 to 48.2 million tons in 1993.

Iron castings shipments totaled 7.9 million tons in 1993 compared with 7.4 million tons in 1992. Steel castings shipments (including investment castings) totaled 0.96 million tons in 1993 compared with 0.93 million tons in 1992.

In 1993, steel mills accounted for 81% of all scrap received from brokers, dealers, and other outside sources; steel foundries received 2%; and iron castings producers and miscellaneous users received 16%. The apparent total domestic consumption of ferrous scrap in 1993 was composed of 46.1 million tons net receipts (total receipts minus shipments) and 21.5 million tons of home scrap. Stocks were essentially unchanged. The 1993 total domestic consumption was 67.5 million tons; in 1992, the total domestic consumption was 63.2 million tons (revised).

The total market for U.S. produced scrap (net receipts plus exports minus imports) was 54.4 million tons in 1993 compared with 49.7 million tons (revised) in 1992.

Prices

The average composite delivered price per metric ton, calculated from prices per long ton published weekly and monthly by American Metal Market (AMM), for No. 1 heavy melting steel scrap was $112.44 in 1993, ranging from a low of $96.91 in January to a high of $133.26 in December. Calculated from prices per long ton published weekly by Iron Age Scrap Price Bulletin (IA), the average composite delivered price per metric ton of No. 1 heavy melting steel scrap was $109.98 in 1993, ranging from $95.79 in January to $131.22 in December. The average composite price for No. 1 heavy melting steel scrap in 1993 was higher than that in 1992, by 33% in AMM and by 31% in IA.

Based on weekly quotations by Iron Age for 18-8 (18% chromium, 8% nickel)-grade stainless steel scrap (bundles and solids) delivered to consumers in the Pittsburgh, PA, area, the average price decreased 16%, from $743 per ton in 1992 to $624 per ton in 1993.

In 1993, the average value for total ferrous scrap exports (excluding used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) increased 13% to $134.23 per ton compared with that of 1992, while that of total imports increased 1% to $113.80 per ton.

Foreign Trade

Foreign trade valuation continued to be reported on f.a.s. (free alongside ship) basis for exports and on Customs value basis for imports.

The trade surplus in 1993 for all classes of ferrous scrap (including used rails for rerolling and other uses and ships, boats, and other vessels for scrapping) was $1,165 million in value and 8.5 million tons in quantity. This represented an increase of 21% in value and 5% in quantity compared with the 1992 surplus of $965 million in value and 8.1 million tons in quantity.

Total U.S. exports of ferrous scrap (excluding used rails for rerolling and other uses; ships, boats, and other vessels for scrapping; stainless steel; and alloy steel) in 1993 went to 49 countries and totaled 9,226,782 tons valued at $1,105,593,600 for an average of $119.82 per ton. Six countries received 83% of the total quantity. The largest tonnages went to the Republic of Korea, 3,436,197 tons; Turkey, 1,309,640 tons; Canada, 1,219,718 tons; Malaysia, 606,753 tons; Mexico, 592,540 tons; and Japan, 483,395 tons. The value of scrap exports to these six countries was $888,535,080, 80% of the total value.

Total U.S. exports of stainless steel scrap in 1993 went to 30 countries and consisted of 238,000 tons valued at $147,226,190 averaging $618.60 per ton. Six countries received 91% of the total quantity. The largest tonnages went to the Republic of Korea, 67,061 tons; Canada, 53,829 tons; Japan, 44,324 tons; Spain, 34,592 tons; Belgium, 8,926 tons; and Taiwan, 7,668 tons. The value of stainless steel scrap exports to these six countries was $134,622,063, 91% of the total value.

U.S. exports of alloy steel scrap (excluding stainless steel) in 1993 were shipped to 39 countries. The total comprised 340,404 tons valued at $63,284,278 for an average of $185.91 per ton. Six countries received 81% of the total quantity. The largest tonnages went to Canada, 162,763 tons; China, 46,119 tons; Singapore, 22,520 tons; Mexico, 16,693 tons; Colombia, 14,012 tons; and Italy, 12,549 tons. The value of alloy steel scrap to these six countries was $50,230,723, which was 79% of the total value.

World Review

The United States continued to be the leading exporting country of iron and steel scrap. France, Germany, Netherlands, and the United Kingdom were also major exporters of ferrous scrap. Leading importing nations included Italy, Spain, Turkey, and the developing nations of Asia: China, Indonesia, India, Republic of Korea, Taiwan, and Thailand.

Nucor, Inc., a leading U.S. steel producer, in partnership with Simitri, a Brazilian iron ore mining company began construction of a plant in Trinidad and Tobago to produce iron-carbide, a form of direct-reduced iron. Startup was anticipated in late 1994. The capacity of the new plant will be about 300,000 tons per year. Nucor plans to use the iron carbide along with steel scrap at its sheet mills in Crawfordsville, IN, and Hickman, AR, where it will enable the production of low-residual steel, increasing the range of steel products produced.

OUTLOOK

The overall outlook for U.S. ferrous scrap through 1995 is expected to be continued growth. In addition to the two flat rolled steel plants operated by Nucor, several other new electric furnace steel plants were planned in the United States, and the reopening of at least two major electric furnace operations appears likely. In addition, the replacement of ingot casting facilities with continuous casting equipment has increased the effective capacity of the few remaining integrated flat roll plants, increasing their demand for scrap. As increased demand results in sustained higher price levels for ferrous scrap, substitutes in the form of pig iron and direct-reduced iron will increase in use. The higher price of these substitutes will be more acceptable when scrap prices are high. In addition, producers of flat-rolled steel and other products requiring low levels of residual elements in the steel increasingly will turn to these iron-ore-based products to dilute the residual content that is intrinsic in scrap. However, the availability of these substitutes will not result in reduced demand for scrap; rather, it will ensure and facilitate the use of scrap.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Monthly and annual publications on Iron and Steel, Iron Ore, and Iron and Steel Slag.

Other Sources

American Foundrymen's Society (AFS).
American Iron and Steel Institute (AISI).
American Metal Market.
Bureau International De La Recuperation (BIR).
Center for Materials Production (CMP).
Institute of Scrap Recycling Industries Inc. (ISRI).
International Iron and Steel Institute (IISI).
Metal Bulletin (London).
National Recycling Coalition (NRC).
Steel Can Recycling Institute (SCRI).
Steel Manufacturers Association (SMA).

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[1] All quantities are in metric tons unless otherwise specified.

TABLE 1
SALIENT U.S. IRON AND STEEL SCRAP, PIG IRON, AND DIRECT-REDUCED IRON STATISTICS[1]

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
Manufacturers of pig iron and raw steel and castings:[2]					
Ferrous scrap consumption	52,733	54,361	48,778	50,144	53,084
Pig iron consumption	50,210	49,337	44,095	47,263	48,092
Direct-reduced iron consumption	429	691	848	1,030	1,298
Net receipts of ferrous scrap[3]	34,246	35,402	32,208	32,613	36,782
Home scrap production[4]	18,507	18,943	16,569	16,713	16,409
Ending stocks of ferrous scrap, Dec. 31	3,379	3,385	3,359	3,062	3,223
Manufacturers of steel castings:[5]					
Ferrous scrap consumption	1,894	1,850	1,609	1,640	1,729
Pig iron consumption	20	21	14	13	9
Net receipts of ferrous scrap[3]	1,394	1,349	1,052	1,120	1,159
Home scrap production[4]	501	503	546	531	564
Ending stocks of ferrous scrap, Dec. 31	174	178	156	165	90
Iron foundries and miscellaneous users:					
Ferrous scrap consumption	13,270	13,085	11,126	11,444	12,658
Pig iron consumption	892	835	656	619	676
Direct-reduced iron consumption	22	18	12	11	5
Net receipts of ferrous scrap[3]	9,083	8,926	7,568	7,995	8,149
Home scrap production[4]	4,158	3,998	3,417	3,264	4,502
Ending stocks of ferrous scrap, Dec. 31	740	729	557	524	412
Totals, all manufacturing types:[6]					
Ferrous scrap consumption	[r]67,897	[r]69,296	[r]61,513	[r]63,228	67,472
Pig iron consumption	[r]51,122	[r]50,193	[r]44,765	[r]47,894	48,777
Direct-reduced iron consumption	450	709	860	1,041	1,303
Net receipts of scrap[3]	44,724	45,677	40,828	41,728	46,090
Home scrap production[4]	23,166	23,445	20,532	20,508	21,475
Ending stocks, Dec. 31:[6]					
Ferrous scrap at consumer plants	[r]4,293	[r]4,292	[r]4,072	[r]3,752	3,725
Pig iron at consumer and supplier plants	[r]246	[r]147	[r]190	[r]181	220
Direct-reduced iron at consumer plants	1	89	102	104	196
Exports:[7]					
Ferrous scrap (includes tinplate and terneplate)[8]	11,149	11,580	[r]9,502	9,262	9,805
Value	$1,748,643	$1,635,218	[r]$1,232,872	$1,099,802	$1,316,104
Pig iron (all grades)	11	14	16	33	27
Value	$1,334	$1,618	$1,700	$3,196	$3,035
Direct-reduced iron (all grades)	8	6	6	14	23
Value	$7,409	$5,894	$5,766	$6,233	$5,173
Imports for consumption:[7]					
Ferrous scrap (includes tinplate and terneplate)[8]	1,016	[r]1,324	1,073	1,316	1,545
Value	$149,109	[r]$171,658	$142,552	$147,616	$175,825
Pig iron (all grades)	443	347	434	497	828
Value	$73,184	$60,069	$75,261	$72,784	$116,736
Direct-reduced iron (all grades)	171	334	380	545	924
Value	$22,621	$40,974	$53,624	$56,445	$90,796

[r] Revised.

[1] Data are not entirely comparable due to changes in collection and estimation methods in 1993.

[2] Includes manufacturers of raw steel that also produce steel castings.

[3] Net receipts of scrap is defined as receipts from brokers, dealers, and other outside sources, plus receipts from other own-company plants, minus shipments.

[4] Home scrap production includes recirculating scrap resulting from current operations and obsolete home scrap.

[5] Some of these manufacturers produce iron castings.

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

[7] Source: Bureau of the Census. Export valuation is on a "free alongside ship" basis, and import valuation is on a customs basis.

[8] Excludes used rails for rerolling and other uses, and ships, boats and other vessels for scrapping.

TABLE 2
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1993, BY GRADE

(Thousand metric tons)

Grade	Receipts of scrap: From brokers, dealers and other outside sources	Receipts of scrap: From other own-company plants	Production of home scrap: Recirculating scrap from current operations	Production of home scrap: Obsolete scrap[1]	Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	603	30	323	—	949	12	46
Cut structural and plate	2,934	25	413	192	3,446	143	261
No. 1 heavy melting steel	6,436	844	4,390	227	10,066	1,744	619
No. 2 heavy melting steel	4,325	53	528	4	4,774	17	405
No. 1 and electric furnace bundles	5,376	553	1,900	1	7,304	583	367
No. 2 and all other bundles	1,301	12	70	—	1,380	9	71
Electric furnace, 1 foot and under (not bundles)	6	177	140	(3)	289	35	2
Railroad rails	367	26	21	—	421	(3)	24
Turnings and borings	1,457	9	106	—	1,531	17	99
Slag scrap	1,002	226	1,293	1	2,175	371	134
Shredded or fragmentized	6,766	645	7	(3)	7,313	6	416
No. 1 busheling	2,662	134	142	—	2,906	64	163
All other carbon steel scrap	2,231	361	4,450	35	6,428	755	229
Stainless steel scrap	541	3	458	2	1,007	14	34
Alloy steel (except stainless)	160	71	581	(3)	763	22	83
Ingot mold and stool scrap	69	11	193	83	196	180	60
Machinery and cupola cast iron	52	(3)	4	—	52	2	5
Cast-iron borings	161	—	1	(3)	149	1	10
Motor blocks	(4)	—	—	—	(4)	—	(4)
Other iron scrap	403	85	460	3	756	190	80
Other mixed scrap	822	86	379	2	1,180	79	115
Total[5]	37,675	3,350	15,858	551	53,084	4,243	3,223
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	365	(3)	93	(3)	454	(3)	19
Cut structural and plate	198	—	61	(3)	256	(3)	15
No. 1 heavy melting steel	111	9	43	—	158	—	18
No. 2 heavy melting steel	—	—	—	—	—	—	—
No. 1 and electric furnace bundles	15	—	—	—	15	—	1
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	39	7	(3)	—	47	—	1
Railroad rails	37	—	2	—	38	—	2
Turnings and borings	45	—	10	—	54	—	2
Slag scrap	1	—	5	—	10	—	3
Shredded or fragmentized	46	—	—	—	45	—	2
No. 1 busheling	58	—	(3)	—	61	—	3
All other carbon steel scrap	119	—	216	2	346	(3)	9
Stainless steel scrap	28	(3)	17	(3)	45	(3)	3

See footnotes at end of table.

TABLE 2—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1993, BY GRADE

(Thousand metric tons)

Grade	Receipts of scrap: From brokers, dealers and other outside sources	Receipts of scrap: From other own-company plants	Production of home scrap: Recirculating scrap from current operations	Production of home scrap: Obsolete scrap[1]	Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
MANUFACTURERS OF STEEL CASTINGS—Continued							
Alloy steel (except stainless)	57	—	95	—	156	—	9
Ingot mold and stool scrap	9	—	—	—	9	—	1
Cast-iron borings	(3)	—	1	—	1	—	(3)
Motor blocks	—	—	—	—	—	—	—
Other iron scrap	8	—	17	—	26	—	1
Other mixed scrap	7	—	1	1	9	1	(3)
Total[5]	1,143	17	562	2	1,729	1	90
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	852	1	21	(3)	873	—	20
Cut structural and plate	1,162	21	67	(3)	1,205	41	49
No. 1 heavy melting steel	209	3	26	—	237	3	3
No. 2 heavy melting steel	101	(3)	—	—	102	—	2
No. 1 and electric furnace bundles	93	175	—	—	265	—	7
No. 2 and all other bundles	244	—	2	—	244	2	10
Electric furnace, 1 foot and under (not bundles)	144	—	1	—	145	1	4
Railroad rails	199	—	—	(3)	200	—	14
Turnings and borings	166	106	8	—	275	3	18
Slag scrap	53	—	1	—	53	1	1
Shredded or fragmentized	1,124	164	3	—	1,289	—	56
No. 1 busheling	840	148	56	—	991	55	22
All other carbon steel scrap	186	(3)	3	—	189	(3)	6
Stainless steel scrap	14	—	7	—	22	(3)	1
Alloy steel (except stainless)	18	—	3	—	21	—	3
Ingot mold and stool scrap	93	5	94	—	199	—	4
Machinery and cupola cast iron	680	—	309	(3)	993	2	49
Cast-iron borings	267	93	39	1	410	3	7
Motor blocks	413	5	667	—	1,077	(3)	41
Other iron scrap	352	70	2,705	—	3,116	7	63
Other mixed scrap	265	(3)	489	(3)	754	1	31
Total[5]	7,476	792	4,501	1	12,658	119	412
TOTALS FOR ALL MANUFACTURING TYPES							
Carbon steel:							
Low-phosphorus plate and punchings	1,821	31	437	(3)	2,276	12	85
Cut structural and plate	4,294	45	542	192	4,908	184	326
No. 1 heavy melting steel	6,756	857	4,459	227	10,461	1,746	641
No. 2 heavy melting steel	4,426	53	528	4	4,876	17	408
No. 1 and electric furnace bundles	5,484	728	1,900	1	7,584	583	375
No. 2 and all other bundles	1,545	12	72	—	1,623	12	81
Electric furnace, 1 foot and under (not bundles)	190	185	141	(3)	481	35	7

See footnotes at end of table.

TABLE 2—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1993, BY GRADE

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap[1]			
TOTALS FOR ALL MANUFACTURING TYPES—Continued							
Carbon steel—Continued:							
Railroad rails	603	26	23	(3)	659	(3)	40
Turnings and borings	1,667	115	123	—	1,859	20	119
Slag scrap	1,056	226	1,299	1	2,237	372	138
Shredded or fragmentized	7,936	810	10	(3)	8,647	6	473
No. 1 busheling	3,560	283	198	—	3,959	119	187
All other carbon steel scrap	2,538	361	4,668	36	6,963	755	244
Stainless steel scrap	583	3	483	2	1,073	14	38
Alloy steel (except stainless)	235	71	679	(3)	940	22	96
Ingot mold and stool scrap	171	16	287	83	404	180	65
Machinery and cupola cast iron	732	(3)	313	(3)	1,045	4	54
Cast-iron borings	428	93	41	1	560	4	17
Motor blocks	413	5	667	—	1,077	(3)	41
Other iron scrap	763	154	3,182	3	3,898	196	143
Other mixed scrap	1,094	86	869	2	1,942	81	146
Total[5]	46,294	4,159	20,921	554	67,472	4,363	3,725

[1] Obsolete home scrap includes ingot molds, stools, and scrap from old equipment, buildings, etc.

[2] Home scrap includes recirculating scrap.

[3] Less than 1/2 unit.

[4] Withheld to avoid disclosing company proprietary data; included in "Other iron scrap."

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

TABLE 3
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1992, BY GRADE[r]

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap[1]			
MANUFACTURERS OF PIG IRON AND RAW STEEL AND CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	464	2	445	—	955	4	45
Cut structural and plate	2,208	65	416	60	2,734	66	181
No. 1 heavy melting steel	5,974	1,151	5,608	369	11,324	1,949	600
No. 2 heavy melting steel	3,962	88	627	8	4,806	10	351
No. 1 and electric furnace bundles	4,325	427	935	2	5,357	470	340
No. 2 and all other bundles	1,175	13	84	—	1,316	(3)	75
Electric furnace, 1 foot and under (not bundles)	13	217	163	—	362	36	4
Railroad rails	370	20	18	—	409	(3)	27
Turnings and borings	1,344	3	88	—	1,427	13	71
Slag scrap	941	197	1,543	1	2,132	586	115
Shredded or fragmentized	5,642	697	—	—	6,426	5	413
No. 1 busheling	2,295	125	100	(3)	2,457	66	184
All other carbon steel scrap	2,963	274	3,754	92	6,382	774	223
Stainless steel scrap	570	15	452	—	1,042	2	48
Alloy steel (except stainless)	115	104	505	—	691	27	85
Ingot mold and stool scrap	69	90	233	240	433	195	110
Machinery and cupola cast iron	45	(3)	5	—	48	3	4
Cast-iron borings	134	—	(3)	—	142	1	6
Motor blocks	(4)	—	—	—	(4)	—	(4)
Other iron scrap	266	31	513	3	601	237	77
Other mixed scrap	745	65	448	1	1,102	146	105
Total[5]	33,620	3,585	15,937	777	50,144	4,593	3,062
MANUFACTURERS OF STEEL CASTINGS							
Carbon steel:							
Low-phosphorus plate and punchings	299	—	95	1	403	(3)	18
Cut structural and plate	196	—	32	(3)	223	—	28
No. 1 heavy melting steel	85	(3)	61	(3)	146	—	9
No. 2 heavy melting steel	17	—	20	—	37	—	4
No. 1 and electric furnace bundles	(3)	—	—	—	(3)	—	1
No. 2 and all other bundles	—	—	—	—	—	—	—
Electric furnace, 1 foot and under (not bundles)	63	7	—	—	71	—	3
Railroad rails	50	—	—	—	49	—	1
Turnings and borings	14	—	10	—	23	2	1
Slag scrap	—	—	—	—	2	—	8
Shredded or fragmentized	16	—	(3)	—	16	—	(3)
No. 1 busheling	79	—	—	—	80	—	3
All other carbon steel scrap	224	(3)	180	—	386	(3)	29
Stainless steel scrap	21	(3)	20	—	42	(3)	6
Alloy steel (except stainless)	47	—	76	—	122	(3)	49

See footnotes at end of table.

TABLE 3—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1992, BY GRADE[r]

(Thousand metric tons)

Grade	Receipts of scrap: From brokers, dealers and other outside sources	Receipts of scrap: From other own-company plants	Production of home scrap: Recirculating scrap from current operations	Production of home scrap: Obsolete scrap[1]	Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
MANUFACTURERS OF STEEL CASTINGS—Continued							
Ingot mold and stool scrap	(3)	—	(3)	—	(3)	—	—
Machinery and cupola cast iron	(3)	—	5	—	5	—	1
Cast-iron borings	—	—	4	—	5	—	1
Motor blocks	—	—	—	—	(3)	—	—
Other iron scrap	3	—	16	—	18	—	2
Other mixed scrap	—	—	10	—	10	—	(3)
Total[5]	1,114	8	530	1	1,640	2	165
IRON FOUNDRIES AND MISCELLANEOUS USERS							
Carbon steel:							
Low-phosphorus plate and punchings	903	25	119	(3)	1,058	1	39
Cut structural and plate	1,106	10	35	(3)	1,177	(3)	50
No. 1 heavy melting steel	167	22	39	—	223	5	20
No. 2 heavy melting steel	135	(3)	37	—	164	9	3
No. 1 and electric furnace bundles	85	126	16	—	226	—	3
No. 2 and all other bundles	181	(3)	—	—	183	—	11
Electric furnace, 1 foot and under (not bundles)	48	4	1	—	53	—	(3)
Railroad rails	166	—	2	—	167	2	12
Turnings and borings	263	23	4	—	297	2	24
Slag scrap	44	—	3	—	44	3	2
Shredded or fragmentized	1,042	69	—	—	1,107	(3)	47
No. 1 busheling	362	82	24	—	521	(3)	15
All other carbon steel scrap	329	(3)	18	—	354	—	29
Stainless steel scrap	10	—	8	—	17	—	5
Alloy steel (except stainless)	29	—	3	—	32	2	10
Ingot mold and stool scrap	86	10	83	1	191	(3)	5
Machinery and cupola cast iron	830	137	204	52	1,242	3	88
Cast-iron borings	351	111	59	—	521	3	36
Motor blocks	386	40	518	—	946	11	30
Other iron scrap	471	27	1,713	28	2,235	14	52
Other mixed scrap	384	(3)	294	1	685	15	44
Total[5]	7,378	687	3,182	82	11,444	70	524
TOTALS FOR ALL MANUFACTURING TYPES							
Carbon steel:							
Low-phosphorus plate and punchings	1,666	27	659	1	2,415	5	102
Cut structural and plate	3,510	75	483	61	4,134	66	257
No. 1 heavy melting steel	6,226	1,172	5,708	369	11,693	1,955	629
No. 2 heavy melting steel	4,113	88	683	8	5,006	19	358
No. 1 and electric furnace bundles	4,410	553	951	2	5,584	470	344
No. 2 and all other bundles	1,356	13	84	—	1,499	(3)	86

See footnotes at end of table.

TABLE 3—Continued

U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF IRON AND STEEL SCRAP IN 1992, BY GRADE[r]

(Thousand metric tons)

Grade	Receipts of scrap		Production of home scrap		Consumption of both purchased and home scrap[2]	Shipments of scrap	Ending stocks, Dec. 31
	From brokers, dealers and other outside sources	From other own-company plants	Recirculating scrap from current operations	Obsolete scrap[1]			
TOTALS FOR ALL MANUFACTURING TYPES—Continued							
Carbon steel—Continued:							
Electric furnace, 1 foot and under (not bundles)	124	229	165	—	486	36	7
Railroad rails	585	20	20	—	626	2	40
Turnings and borings	1,621	26	103	—	1,747	17	96
Slag scrap	985	197	1,545	1	2,178	589	125
Shredded or fragmentized	6,699	766	(3)	—	7,550	5	460
No. 1 busheling	2,737	207	124	(3)	3,058	67	202
All other carbon steel scrap	3,516	275	3,953	92	7,122	774	281
Stainless steel scrap	601	16	480	—	1,101	2	59
Alloy steel (except stainless)	191	104	584	—	846	29	144
Ingot mold and stool scrap	156	100	316	241	624	196	115
Machinery and cupola cast iron	876	137	214	52	1,294	6	93
Cast-iron borings	485	111	63	(3)	667	3	43
Motor blocks	386	40	518	—	946	11	30
Other iron scrap	740	58	2,242	31	2,854	251	132
Other mixed scrap	1,128	65	753	2	1,797	161	148
Total[5]	42,113	4,279	19,648	859	63,228	4,665	3,752

[r] Revised.

[1] Obsolete home scrap includes ingot molds, stools, and scrap from old equipment, buildings, etc.

[2] Home scrap includes recirculating scrap.

[3] Less than 1/2 unit.

[4] Withheld to avoid disclosing company proprietary data; included in "Other iron scrap."

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

TABLE 4
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1993

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
Manufacturers of pig iron, raw steel, and castings:					
Pig iron	2,088	48,140	48,092	2,143	177
Direct-reduced iron	1,382	W	1,298	9	196
Manufacturers of steel castings:					
Pig iron	9	—	9	—	2
Direct-reduced iron	—	—	—	—	—
Iron foundries and miscellaneous users:					
Pig iron	677	—	676	(1)	42
Direct-reduced iron	5	—	5	—	(1)
Totals for all manufacturing types:[2]					
Pig iron	2,774	48,140	48,777	2,143	220
Direct-reduced iron	1,386	W	1,303	9	196

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

[1] Less than 1/2 unit.

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

TABLE 5
U.S. CONSUMER RECEIPTS, PRODUCTION, CONSUMPTION, SHIPMENTS, AND STOCKS OF PIG IRON AND DIRECT-REDUCED IRON IN 1992[r]

(Thousand metric tons)

	Receipts	Production	Consumption	Shipments	Stocks, Dec. 31
Manufacturers of pig iron, raw steel, and castings:					
Pig iron	2,109	47,431	47,263	2,274	123
Direct-reduced iron	1,024	W	1,030	5	104
Manufacturers of steel castings:					
Pig iron	11	—	13	1	4
Direct-reduced iron	—	—	—	—	—
Iron foundries and miscellaneous users:					
Pig iron	640	—	619	27	54
Direct-reduced iron	11	—	11	—	(1)
Totals for all manufacturing types:[2]					
Pig iron	2,760	47,431	47,894	2,302	181
Direct-reduced iron	1,034	W	1,041	5	104

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Receipts."

[1] Less than 1/2 unit.

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

TABLE 6

U.S. CONSUMPTION OF IRON AND STEEL SCRAP, PIG IRON, AND DIRECT-REDUCED IRON (DRI) IN 1993, BY TYPE OF FURNACE OR OTHER USE

(Thousand metric tons)

	Manufacturers of pig iron and raw steel and castings			Manufacturers of steel castings			Iron foundries and miscellaneous users			Totals for all manufacturing types[1]		
	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI
Blast furnace[2]	1,924	—	W	—	—	—	—	—	—	1,924	—	W
Basic oxygen process[3]	14,278	47,848	W	—	—	—	—	—	—	14,278	47,848	W
Electric furnace	36,740	136	837	1,725	9	—	4,210	375	2	42,674	519	839
Cupola furnace	—	—	—	—	—	—	8,389	292	2	8,389	292	2
Other (including air furnaces)[4]	141	24	—	5	—	—	60	10	—	206	34	—
Direct castings[5]	—	84	—	—	—	—	—	—	—	—	84	—
Total[1]	53,084	48,092	1,298	1,729	9	—	12,658	676	5	67,472	48,777	1,303

[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] Includes vacuum melting furnaces and miscellaneous uses.

[5] Includes ingot molds and stools.

TABLE 7

U.S. CONSUMPTION OF IRON AND STEEL SCRAP, PIG IRON, AND DIRECT-REDUCED IRON (DRI) IN 1992, BY TYPE OF FURNACE OR OTHER USE[r]

(Thousand metric tons)

	Manufacturers of pig iron and raw steel and castings			Manufacturers of steel castings			Iron foundries and miscellaneous users			Totals for all manufacturing types[1]		
	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI	Scrap	Pig iron	DRI
Blast furnace[2]	1,875	—	W	—	—	—	—	—	—	1,875	—	W
Basic oxygen process[3]	14,149	47,194	W	—	—	—	—	—	—	14,149	47,194	W
Electric furnace	33,979	19	791	1,635	13	—	4,902	397	1	40,516	429	792
Cupola furnace	22	1	—	—	—	—	6,507	214	10	6,529	215	10
Other (including air furnaces)[4]	119	—	—	4	—	—	35	7	—	159	7	—
Direct castings[5]	—	49	—	—	—	—	—	—	—	—	49	—
Total[1]	50,144	47,263	1,030	1,640	13	—	11,444	619	11	63,228	47,894	1,041

[r] Revised.

[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] Includes vacuum melting furnaces and miscellaneous uses.

[5] Includes ingot molds and stools.

TABLE 8
IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1993, BY REGION AND STATE

(Thousand metric tons)

Region and State	Receipts of scrap: From brokers, dealers, and other outside sources	Receipts of scrap: From other own company plants	Production of home scrap: Recirculating scrap resulting from current operations	Production of home scrap: Obsolete scrap[2]	Shipments of scrap[3]	New supply available for consumption[4]
New England and Middle Atlantic:						
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	240	—	27	(5)	(5)	267
New Jersey and New York	1,804	3	139	—	3	1,942
Pennsylvania	3,876	156	2,091	70	131	6,063
Total	5,920	159	2,257	70	134	8,272
North Central:						
Illinois	4,472	205	1,468	3	89	6,059
Indiana	3,292	413	6,423	87	2,646	7,569
Iowa, Nebraska, South Dakota	1,332	4	268	—	41	1,564
Kansas and Missouri	999	(5)	120	—	—	1,119
Michigan	3,221	732	1,878	2	141	5,692
Minnesota and Wisconsin	1,221	162	926	(5)	6	2,304
Ohio	5,536	1,059	2,806	344	893	8,851
Total[4]	20,073	2,576	13,889	435	3,815	33,158
South Atlantic:						
Delaware, Maryland, West Virginia	1,351	726	952	3	222	2,810
North Carolina, South Carolina, Virginia	2,185	90	452	(5)	1	2,725
Florida and Georgia	1,373	1	231	—	—	1,605
Total[4]	4,908	817	1,635	3	222	7,140
South Central:						
Alabama and Mississippi	2,396	8	886	32	73	3,248
Arkansas, Louisiana, Oklahoma	3,658	7	255	3	(5)	3,923
Kentucky and Tennessee	2,007	8	540	6	97	2,465
Texas	3,704	583	566	5	5	4,853
Total	11,765	606	2,247	46	175	14,489
Mountain and Pacific:						
Arizona, Colorado, Idaho, Montana, Utah	1,487	—	647	—	10	2,124
California, Oregon, Washington	2,140	(5)	246	(5)	6	2,381
Total[4]	3,628	(5)	893	(5)	17	4,505
Grand total[4]	46,294	4,159	20,921	554	4,363	67,565

[1] Supply available for consumption is a net figure computed by adding production to receipts and deducting scrap shipped during the year. The plus or minus difference in stock levels at the beginning and end of the year is not taken into consideration.

[2] Obsolete scrap includes ingot molds, stools, and scrap from old equipment, buildings, etc.

[3] Includes scrap shipped, transferred, or otherwise disposed of during the year.

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

[5] Less than 1/2 unit.

TABLE 9
IRON AND STEEL SCRAP SUPPLY[1] AVAILABLE FOR CONSUMPTION IN 1992, BY REGION AND STATE[r]

(Thousand metric tons)

Region and State	Receipts of scrap		Production of home scrap		Shipments of scrap[3]	New supply available for consumption[4]
	From brokers, dealers, and other outside sources	From other own company plants	Recirculating scrap resulting from current operations	Obsolete scrap[2]		
New England and Middle Atlantic:						
Connecticut, Massachusetts, New Hampshire, Rhode Island	177	(5)	37	1	—	215
New Jersey and New York	1,770	13	147	(5)	27	1,903
Pennsylvania	4,135	811	2,202	55	265	6,937
Total[4]	6,081	824	2,387	56	292	9,055
North Central:						
Illinois	4,254	290	1,438	4	133	5,853
Indiana	3,786	458	5,591	90	2,887	7,038
Iowa and Nebraska	1,220	40	289	—	—	1,549
Kansas and Missouri	812	6	149	5	1	971
Michigan	2,922	461	1,660	47	219	4,871
Minnesota and Wisconsin	1,058	147	724	—	9	1,919
Ohio	4,593	850	2,722	589	834	7,920
Total[4]	18,645	2,253	12,573	735	4,084	30,122
South Atlantic:						
Delaware, Maryland, West Virginia	955	405	1,082	2	154	2,290
North Carolina, South Carolina, Virginia	1,909	203	354	2	1	2,468
Florida and Georgia	1,308	3	138	—	—	1,449
Total	4,172	611	1,574	4	155	6,207
South Central:						
Alabama and Mississippi	2,086	(5)	1,063	9	88	3,069
Arkansas, Louisiana, Oklahoma	2,461	5	215	—	—	2,681
Kentucky and Tennessee	1,883	15	389	9	27	2,269
Texas	3,825	562	542	1	3	4,927
Total[4]	10,255	582	2,208	19	119	12,946
Mountain and Pacific:						
Arizona, Colorado, Utah	1,071	—	684	47	8	1,793
California, Oregon, Washington	1,889	9	222	(5)	7	2,114
Total[4]	2,959	9	906	47	15	3,906
Grand total[4]	42,113	4,279	19,648	859	4,665	62,235

[r] Revised.

[1] Supply available for consumption is a net figure computed by adding production to receipts and deducting scrap shipped during the year. The plus or minus difference in stock levels at the beginning and end of the year is not taken into consideration.

[2] Obsolete scrap includes ingot molds, stools, and scrap from old equipment, buildings, etc.

[3] Includes scrap shipped, transferred, or otherwise disposed of during the year.

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

[5] Less than 1/2 unit.

TABLE 10
U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1993, BY REGION AND STATE

(Thousand metric tons)

Region and State	Manufacturers of pig iron and raw steel and castings		Manufacturers of steel castings		Iron foundries and miscellaneous users		Totals for all manufacturing types[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, Vermont	1,707	4	7	(3)	522	14	2,236	18
Pennsylvania	5,160	2,749	293	2	543	60	5,996	2,811
Total[2]	6,867	2,752	300	2	1,065	74	8,232	2,829
North Central:								
Illinois	5,512	2,632	87	(3)	494	5	6,093	2,637
Indiana	6,143	17,340	79	(3)	1,326	114	7,549	17,454
Iowa, Kansas, Minnesota, Missouri Nebraska, South Dakota, Wisconsin	2,090	4	270	2	2,504	217	4,863	223
Michigan	2,873	5,593	18	(3)	2,782	92	5,673	5,685
Ohio	7,213	9,392	398	3	1,274	86	8,884	9,481
Total[2]	23,831	34,962	851	5	8,380	514	33,062	35,481
South Atlantic:								
Delaware, Maryland, Virginia, West Virginia	3,187	4,717	3	(3)	637	30	3,828	4,747
Florida, Georgia, North Carolina, South Carolina	2,936	(3)	2	1	384	11	3,322	12
Total[2]	6,123	4,717	5	1	1,021	42	7,150	4,760
South Central:								
Alabama, Kentucky, Mississippi, Tennessee	3,899	3,957	347	—	1,456	18	5,702	3,974
Arkansas, Louisiana, Oklahoma	3,765	W	26	—	159	W	3,950	50
Texas	4,473	W	64	(3)	360	W	4,897	34
Total[2]	12,137	4,015	437	(3)	1,975	42	14,550	4,058
Mountain and Pacific:								
Arizona, Colorado, Idaho, Montana, Utah	2,027	W	29	(3)	41	W	2,097	W
California, Oregon, Washington	2,098	W	107	(3)	173	W	2,378	W
Total	4,125	1,646	136	(3)	214	3	4,475	1,649
Grand total[2]	53,084	48,092	1,729	9	12,658	676	67,472	48,777

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

[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 11

U.S. CONSUMPTION OF IRON AND STEEL SCRAP AND PIG IRON[1] IN 1992, BY REGION AND STATE[r]

(Thousand metric tons)

Region and State	Manufacturers of pig iron and raw steel and castings		Manufacturers of steel castings		Iron foundries and miscellaneous users		Totals for all manufacturing types[2]	
	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron	Scrap	Pig iron
New England and Middle Atlantic:								
Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island	1,625	2	34	(3)	517	16	2,176	18
Pennsylvania	6,270	3,086	214	3	655	159	7,140	3,248
Total[2]	7,895	3,088	249	3	1,173	175	9,316	3,266
North Central:								
Illinois	5,003	2,331	64	—	774	37	5,841	2,368
Indiana	5,871	16,866	161	2	1,090	89	7,122	16,957
Iowa, Kansas, Minnesota, Missouri, Nebraska, Wisconsin	1,981	(3)	250	3	2,239	130	4,469	132
Michigan	2,707	5,694	4	(3)	2,256	70	4,968	5,765
Ohio	6,682	9,281	297	3	1,109	38	8,087	9,322
Total[2]	22,244	34,172	776	8	7,468	364	30,488	34,544
South Atlantic:								
Delaware, Maryland, Virginia, West Virginia	2,687	4,580	10	(3)	608	29	3,305	4,610
Florida, Georgia, North Carolina, South Carolina	2,688	—	4	—	229	4	2,921	4
Total[2]	5,375	4,580	14	(3)	837	33	6,226	4,614
South Central:								
Alabama, Kentucky, Mississippi, Tennessee	3,792	3,982	280	(3)	1,349	15	5,420	3,997
Arkansas, Louisiana, Oklahoma	2,814	W	38	(3)	64	W	2,916	7
Texas	4,419	W	70	(3)	376	W	4,864	28
Total[2]	11,025	3,992	387	(3)	1,789	40	13,201	4,032
Mountain and Pacific:								
Arizona, Colorado, Utah	1,801	W	55	(3)	31	W	1,888	W
California, Oregon, Washington	1,804	W	159	(3)	147	W	2,109	W
Total	3,605	1,430	214	1	178	7	3,997	1,438
Grand total[2]	50,144	47,263	1,640	13	11,444	619	63,228	47,894

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[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 12
U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1993, BY REGION AND STATE

(Thousand metric tons)

Region and State	Carbon steel[1]	Stainless steel	Alloy steel[2]	Cast iron[3]	Other grades of scrap	Total scrap[4]	Pig iron
New England and Middle Atlantic:							
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	12	—	—	2	(5)	14	1
New Jersey and New York	71	3	3	3	(5)	81	3
Pennsylvania	276	29	37	36	3	381	6
Total[4]	359	32	39	42	4	476	10
North Central:							
Illinois	356	(5)	4	18	10	389	10
Indiana	544	1	(5)	78	51	674	55
Iowa, Kansas, Missouri, Nebraska, South Dakota	162	(5)	4	6	10	183	9
Michigan	140	(5)	1	39	14	195	7
Minnesota and Wisconsin	69	1	(5)	7	1	78	5
Ohio	285	2	31	47	6	371	9
Total[4]	1,557	5	41	196	91	1,890	95
South Atlantic:							
Delaware, Maryland, Virginia, West Virginia	78	(5)	1	8	3	91	49
Florida, Georgia, North Carolina, South Carolina	159	(5)	(5)	24	5	189	10
Total[4]	238	(5)	2	32	8	280	59
South Central:							
Alabama, Kentucky, Mississippi, Tennessee	296	(5)	1	20	5	322	10
Arkansas, Louisiana, Oklahoma	256	(5)	1	2	(5)	258	16
Texas	248	(5)	9	19	2	278	3
Total[4]	799	1	11	41	7	858	29
Mountain and Pacific:							
Arizona, Colorado, Idaho, Montana, Utah	64	(5)	1	7	—	72	W
California, Oregon, Washington	108	(5)	2	3	37	150	W
Total[4]	172	1	3	10	37	222	27
Grand total[4]	3,124	38	96	321	146	3,725	220

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

[1] Excludes rerolling rails.

[2] Excludes stainless steel.

[3] Includes borings.

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

[5] Less than 1/2 unit.

TABLE 13
U.S. CONSUMER STOCKS OF IRON AND STEEL SCRAP AND PIG IRON, DECEMBER 31, 1992, BY REGION AND STATE[r]

(Thousand metric tons)

Region and State	Carbon steel[1]	Stainless steel	Alloy steel[2]	Cast iron[3]	Other grades of scrap	Total scrap[4]	Pig iron
New England and Middle Atlantic:							
Connecticut, Massachusetts, New Hampshire, Rhode Island	4	(5)	(5)	1	1	6	1
New Jersey and New York	91	3	45	12	—	152	2
Pennsylvania	238	44	38	36	2	359	8
Total[4]	333	47	83	50	3	517	10
North Central:							
Illinois	318	—	6	26	11	361	12
Indiana	463	2	2	79	18	563	80
Iowa, Kansas, Missouri, Nebraska	127	(5)	4	16	26	173	19
Michigan	124	(5)	1	36	30	191	8
Minnesota and Wisconsin	53	1	(5)	7	(5)	62	4
Ohio	302	8	40	55	2	407	8
Total[4]	1,387	11	53	220	87	1,757	131
South Atlantic:							
Delaware, Maryland, Virginia, West Virginia	88	2	1	6	1	99	10
Florida, Georgia, North Carolina, South Carolina	184	—	(5)	65	(5)	249	1
Total[4]	272	2	1	71	2	348	11
South Central:							
Alabama, Kentucky, Mississippi, Tennessee	244	—	1	35	8	287	16
Arkansas, Louisiana, Oklahoma	266	—	—	2	—	268	1
Texas	326	(5)	3	18	1	348	7
Total	836	(5)	4	55	9	903	24
Mountain and Pacific:							
Arizona, Colorado, Utah	71	(5)	2	7	—	80	W
California, Oregon, Washington	87	1	1	11	47	147	W
Total[4]	158	1	3	17	47	227	4
Grand total[4]	2,985	61	144	413	148	3,752	181

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1] Excludes rerolling rails.

[2] Excludes stainless steel.

[3] Includes borings.

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

[5] Less than 1/2 unit.

TABLE 14

U.S. AVERAGE MONTHLY PRICE AND COMPOSITE PRICE FOR NO. 1 HEAVY MELTING STEEL IN 1993, WITH ANNUAL AVERAGES FOR 1992 AND 1993

(Dollars per metric ton)

Month	Chicago	Philadelphia	Pittsburgh	Composite price
January	96.79	92.15	101.82	96.91
February	107.77	99.14	107.50	104.80
March	107.77	99.40	107.77	104.98
April	104.82	99.40	101.06	101.76
May	104.82	99.40	103.24	102.49
June	109.51	109.25	109.88	109.54
July	116.63	110.23	115.69	114.19
August	112.38	110.23	112.38	111.66
September	111.71	113.61	114.66	113.32
October	123.89	126.96	127.78	126.22
November	129.42	126.96	133.95	130.11
December	135.82	126.13	137.84	133.26
Annual average:				
1993	113.44	109.40	114.46	112.44
1992	87.13	79.56	87.32	84.67

Source: American Metal Market.

TABLE 15
U.S. EXPORTS OF IRON AND STEEL SCRAP,[1] BY COUNTRY[2]

(Thousand metric tons and thousand dollars)

Country	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Belgium	35	11,528	10	8,093	4	709	4	2,546	11	5,868
Brazil	57	7,687	12	1,540	(3)	61	3	424	6	750
Canada	937	106,296	939	109,220	806	98,636	1,163	130,845	1,436	172,279
China	[r]45	11,129	[r]66	11,372	37	9,930	215	39,523	514	82,861
Colombia	73	8,349	32	3,437	57	6,728	123	9,101	43	3,962
Egypt	70	7,501	45	5,083	5	675	(3)	22	(3)	43
Germany	27	21,371	40	7,831	6	1,397	5	1,583	14	1,922
Greece	140	17,103	26	3,218	98	10,932	(3)	6	—	—
Hong Kong	8	4,119	30	12,093	58	16,793	164	30,154	171	27,904
India	868	129,275	1,723	232,840	606	76,534	1,246	135,600	115	14,824
Indonesia	50	6,512	112	16,457	169	19,582	221	21,969	6	1,129
Italy	147	27,446	170	26,297	44	8,224	75	9,606	16	5,640
Japan	[r]433	139,245	481	119,866	340	92,386	161	53,889	537	94,010
Korea, Republic of	2,710	404,815	2,931	409,677	2,784	381,691	2,067	240,077	3,505	451,613
Malaysia	290	42,034	221	34,114	242	29,855	107	10,427	607	79,502
Mexico	[r]520	63,585	568	72,186	[r]673	[r]56,894	566	63,465	610	75,943
Netherlands	29	22,932	17	14,442	6	4,249	8	5,206	8	3,404
Pakistan	79	14,107	111	17,213	162	20,432	112	12,190	128	17,578
Peru	43	5,102	44	5,088	129	11,966	95	8,742	44	5,489
Philippines	23	2,422	26	3,533	98	11,547	4	999	11	2,527
Saudi Arabia	225	26,288	252	31,728	261	27,368	(3)	24	(3)	22
Singapore	27	4,922	57	10,071	1	388	28	3,324	3	1,053
South Africa, Republic of	(3)	22	—	—	24	727	46	2,448	39	3,829
Spain	597	119,784	236	35,685	118	18,640	119	34,451	35	18,667
Sweden	40	17,489	3	2,671	3	2,752	4	3,103	3	1,461
Taiwan	369	64,386	481	71,761	800	100,990	473	55,513	404	55,779
Thailand	145	27,892	71	13,948	82	11,745	126	16,747	113	16,901
Turkey	2,926	393,503	[r]2,747	335,781	1,776	196,626	2,019	192,034	1,310	151,927
United Kingdom	31	11,703	23	5,275	69	7,195	18	2,987	5	1,207
Venezuela	74	8,166	45	5,243	6	1,108	75	8,366	69	8,552
Other	[r]128	[r]21,932	[r]58	[r]9,457	[r]36	[r]6,113	[r]13	[r]4,429	43	9,459
Total[4]	11,149	1,748,643	11,580	1,635,218	[r]9,502	[r]1,232,872	9,262	1,099,802	9,805	1,316,104

[r] Revised.

[1] Excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping. Export valuation is on a "free alongside ship" (f.a.s.) basis.

[2] The U.S. exported scrap to the following number of countries: 63 in 1989; 60 in 1990; 57 in 1991; 59 in 1992; and 60 in 1993.

[3] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 16
U.S. EXPORTS OF IRON AND STEEL SCRAP,[1] BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	Code	1989		1990		1991		1992		1993	
		Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Boston, MA	04	630	82,928	911	109,920	539	58,257	624	59,142	743	85,582
Buffalo, NY	09	181	28,650	86	19,852	36	13,592	67	15,025	90	23,261
Chicago, IL	39	164	17,951	125	14,746	42	5,269	35	4,548	19	3,193
Cleveland, OH	41	124	13,452	77	8,505	36	2,894	40	3,361	(2)	3
Columbia - Snake	29	209	30,528	172	25,699	72	11,995	82	11,653	119	18,490
Detroit, MI	38	880	105,798	358	46,465	224	31,434	345	42,035	264	39,344
Honolulu, HI	32	20	3,002	44	4,964	50	5,942	112	12,792	91	11,520
Houston-Galveston, TX	53	140	61,663	134	21,130	139	51,534	79	35,597	126	46,495
Laredo, TX	23	352	43,517	363	46,937	554	44,482	398	47,664	473	58,658
Los Angeles, CA	27	1,559	274,725	1,546	246,925	1,395	210,348	1,477	190,798	1,523	219,118
Miami, FL	52	210	26,442	240	27,925	267	29,825	215	20,993	87	10,600
New Orleans, LA	20	1,051	217,649	972	199,823	532	106,233	271	59,005	208	46,254
New York, NY	10	1,778	287,384	1,967	274,886	1,713	205,943	1,396	154,979	1,599	193,762
Norfolk, VA	14	116	22,565	218	32,374	181	26,097	139	17,428	254	31,768
Pembina, ND	34	322	28,316	299	27,767	276	27,063	401	39,353	537	57,092
Philadelphia, PA	11	983	122,183	1,070	124,523	917	94,546	739	69,857	707	84,746
Portland, ME	01	312	40,129	317	36,526	329	32,804	318	29,607	287	32,533
Providence, RI	05	415	53,005	347	42,503	208	22,242	244	23,616	373	46,424
San Francisco, CA	28	714	110,730	842	126,775	751	102,609	990	119,164	823	124,655
Seattle, WA	30	342	58,675	360	53,566	356	49,562	427	53,162	389	55,166
Tampa, FL	18	315	44,753	580	69,560	403	44,598	296	29,520	337	39,943
Other	—	331	74,600	554	73,848	482	55,600	568	60,404	757	87,496
Total[3]		11,149	1,748,643	11,580	1,635,218	9,502	1,232,872	9,262	1,099,802	9,805	1,316,104

[1] Excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping. Export valuation is on a "free alongside ship" (f.a.s.) basis.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 17
U.S. EXPORTS OF IRON AND STEEL SCRAP, BY CLASS[1]

(Thousand metric tons and thousand dollars)

Class	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
No. 1 heavy melting scrap	2,530	308,485	2,479	297,504	2,263	243,849	2,118	205,378	1,908	228,285
No. 2 heavy melting scrap	953	109,101	804	91,587	766	79,869	742	67,853	694	78,902
No. 1 bundles	93	12,990	157	19,596	85	8,609	121	11,332	186	24,348
No. 2 bundles	[r]420	41,505	340	32,489	401	34,717	186	13,780	256	26,318
Shredded steel scrap	3,496	486,999	3,674	482,465	2,161	247,519	2,853	290,736	2,767	341,388
Borings, shovelings and turnings	674	55,765	247	20,442	173	13,191	226	16,221	162	14,173
Cut plate and structural	532	76,036	845	115,365	572	68,243	397	43,440	542	71,885
Tinned iron or steel	144	19,052	207	26,392	47	9,667	68	13,874	109	19,926
Remelting scrap ingots	39	8,355	60	7,831	31	6,123	7	1,373	2	612
Stainless steel scrap	265	320,683	233	212,368	232	196,380	223	153,702	238	147,226
Other alloy steel scrap	511	108,918	313	61,484	419	58,124	329	64,148	340	63,284
Other steel scrap[2]	[r]382	[r]64,059	[r]1,003	[r]111,478	[r]758	[r]81,900	[r]907	[r]108,115	1,020	124,453
Iron scrap	1,110	136,694	1,218	156,217	1,593	184,681	1,085	109,851	1,582	175,305
Total[3]	11,149	1,748,643	11,580	1,635,218	[r]9,502	[r]1,232,872	9,262	1,099,802	9,805	1,316,104
Ships, boats, and other vessels for scrapping	114	16,698	23	3,842	114	8,158	92	7,622	162	13,213
Used rails for rerolling and other uses[4]	55	20,062	48	14,385	48	12,355	22	5,998	43	11,760
Total exports[3]	11,319	1,785,403	11,651	1,653,445	[r]9,664	[r]1,253,385	9,376	1,113,422	10,010	1,341,077

[r] Revised.

[1] Export valuation is on a "free alongside ship" (f.a.s.) basis.

[2] Includes tinplate and terneplate.

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

[4] Totals for 1989-93 contain mixed (used plus new) rails: exports contain 1,191 metric tons valued at $8,664,660 in 1989; 5,979 metric tons valued at $4,439,351 in 1990; 6,828 metric tons valued at $3,963,245 in 1991; 2,376 metric tons valued at $1,783,731 in 1992; and 7,142 metric tons valued at $4,239,220 in 1993.

Source: Bureau of the Census.

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,[1] BY COUNTRY[2]

(Thousand metric tons and thousand dollars)

Country	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Bahamas, The	1	107	6	452	5	372	(3)	18	(3)	8
Belgium	—	—	—	—	(3)	170	(3)	15	(3)	31
Brazil	(3)	42	1	416	4	1,436	1	509	9	559
Canada	863	121,454	1,084	134,150	893	104,016	913	92,744	1,155	128,921
China	(3)	72	1	261	(3)	42	(3)	18	3	362
Colombia	(3)	2	(3)	209	(3)	280	(3)	205	(3)	94
Costa Rica	—	—	(3)	3	(3)	5	(3)	2	(3)	10
Dominican Republic	(3)	43	(3)	88	(3)	77	(3)	13	(3)	20
France	27	207	(3)	258	(3)	86	(3)	163	(3)	12
Germany	3	1,215	[r]9	[r]928	2	2,609	(3)	533	2	686
Israel	(3)	28	5	131	(3)	94	(3)	42	(3)	31
Jamaica	1	103	(3)	30	(3)	11	8	379	10	976
Japan	60	5,885	67	7,170	52	6,331	88	12,313	43	4,968
Korea, Republic of	4	3,243	2	1,766	1	766	(3)	207	—	—
Lithuania[4]	—	—	—	—	—	—	—	—	2	217
Mexico	52	13,217	64	18,732	64	18,552	67	18,309	93	17,905
Netherlands	3	1,512	1	97	—	—	(3)	282	(3)	239
Panama	(3)	82	(3)	40	(3)	58	(3)	10	(3)	4
Philippines	—	—	(3)	11	—	—	2	977	—	—
Russia[4]	—	—	—	—	—	—	(3)	110	—	—
Singapore	—	—	27	72	(3)	67	1	26	(3)	2
Sweden	(3)	211	9	43	—	—	—	—	(3)	201
Switzerland	—	—	7	10	(3)	41	(3)	127	(3)	32
Trinidad and Tobago	(3)	275	(3)	37	(3)	12	(3)	22	(3)	93
Ukraine[4]	—	—	—	—	—	—	—	—	1	581
U.S.S.R.[5]	—	—	(3)	2,741	(3)	412	—	—	—	—
United Kingdom	(3)	905	28	1,347	9	950	4	920	1	229
Venezuela	(3)	124	12	2,499	39	5,912	229	19,303	223	19,457
Other	[r]1	[r]385	[r](3)	[r]167	[r]1	[r]255	[r](3)	[r]370	(3)	184
Total[6]	1,016	149,109	[r]1,324	[r]171,658	1,073	142,552	1,316	147,616	1,545	175,825

[r] Revised.

[1] Excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping. Import valuation is on a customs basis.

[2] The U.S. imported scrap from the following number of countries: 31 in 1989; 30 in 1990; 38 in 1991; 37 in 1992; and 34 in 1993.

[3] Less than 1/2 unit.

[4] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[5] Dissolved in Dec. 1991.

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

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP,[1] BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	Code	1989		1990		1991		1992		1993	
		Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Baltimore, MD	13	25	842	(2)	532	24	1,692	81	2,338	49	1,586
Buffalo, NY	09	124	18,912	104	24,121	90	17,792	122	18,278	215	27,295
Charleston, SC	16	—	—	(2)	44	—	—	59	6,804	41	3,682
Chicago, IL	39	(2)	127	26	1,088	49	2,156	17	1,291	16	1,375
Cleveland, OH	41	7	1,340	43	2,286	27	1,905	75	4,717	61	5,457
Detroit, MI	38	382	56,831	565	59,727	386	44,940	377	39,328	533	60,739
El Paso, TX	24	14	2,219	11	1,979	8	1,577	31	2,336	21	3,087
Laredo, TX	23	20	8,600	29	11,838	32	13,277	27	13,487	57	11,666
New Orleans, LA	20	13	1,686	26	5,812	44	6,884	100	12,091	135	12,610
New York, NY	10	28	904	10	933	1	1,027	2	1,460	1	187
Ogdensburg, NY	07	15	4,727	48	6,108	55	8,446	21	4,833	22	5,305
Pembina, ND	34	10	2,910	13	3,097	3	1,527	4	1,600	6	1,150
San Diego, CA	25	17	2,125	23	4,555	21	3,314	9	3,374	17	3,162
Seattle, WA	30	348	40,274	323	39,230	307	30,373	330	26,909	343	32,943
Other	—	13	7,612	103	10,308	26	7,642	61	8,770	28	5,581
Total		1,016	149,109	1,324	171,658	1,073	142,552	1,316	147,616	1,545	175,825

[1] Excludes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping. Import valuation is on a customs basis.

[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS FOR CONSUMPTION OF IRON AND STEEL SCRAP, BY CLASS[1]

(Thousand metric tons and thousand dollars)

Class	1989		1990		1991		1992		1993	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
No. 1 heavy melting scrap	36	4,091	51	5,412	53	5,249	43	3,974	40	4,436
No. 2 heavy melting scrap	11	1,163	11	1,093	9	899	6	505	3	252
No. 1 bundles	65	8,130	141	16,208	94	10,464	80	8,482	126	12,811
No. 2 bundles	6	726	13	1,451	5	530	10	1,104	13	1,304
Shredded steel scrap	56	12,361	46	6,296	31	3,302	45	4,631	80	10,403
Borings, shovelings and turnings	15	1,389	29	2,960	31	2,888	37	3,383	71	6,210
Cut plate and structural	5	614	8	955	11	1,132	7	671	43	4,033
Tinned iron or steel	11	1,903	8	1,782	10	2,240	28	7,063	13	1,424
Remelting scrap ingots	5	2,234	8	1,389	20	5,114	128	16,542	194	20,031
Stainless steel scrap	53	29,826	102	31,284	33	23,139	76	21,807	49	20,210
Other alloy steel scrap	206	19,522	166	13,261	93	13,867	135	21,215	200	23,483
Other steel scrap[2]	451	53,438	585	70,460	585	61,227	656	49,941	632	61,107
Iron scrap	97	13,712	155	19,106	98	12,501	66	8,300	84	10,120
Total[3]	1,016	149,109	[r]1,324	[r]171,658	1,073	142,552	1,316	147,616	1,545	175,825
Ships, boats, and other vessels for scrapping	(4)	4	—	—	2	60	—	31	—	82
Used rails for rerolling and other uses[5]	89	14,844	154	25,148	93	16,173	78	15,583	70	13,571
Total imports[3]	1,105	163,957	1,479	196,806	1,169	158,784	1,393	163,231	1,615	189,478

[r] Revised.

[1] Import valuation is on a customs basis.

[2] Includes tinplate and terneplate.

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

[4] Less than 1/2 unit.

[5] Contains 3,674 metric tons of mixed (used plus new) rails valued at $1,065,953 in 1989 and no mixed rails for all following years.

Source: Bureau of the Census.

TABLE 21
U.S. EXPORTS OF USED RAILS FOR REROLLING AND OTHER USES,[1] BY COUNTRY

Country	1989		1990		1991		1992		1993	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Bolivia	—	—	1,623	$374,638	13	$12,866	—	—	—	—
Brazil	—	—	39	46,682	489	211,184	(2)	$10,062	72	$59,543
Canada	3,670	$773,898	6,572	3,965,944	5,233	2,762,169	1,976	466,545	10,390	4,231,937
Chile	21	48,727	—	—	—	—	16	23,165	473	194,952
Dominican Republic	395	218,980	60	65,135	282	187,181	17	15,850	—	—
Germany	476	173,070	—	—	—	—	71	74,717	23	20,150
Guatemala	2,087	287,940	3,547	694,041	—	—	—	—	3	2,611
Mexico	47,691	14,568,525	35,681	8,810,270	40,486	[r]8,572,268	18,515	4,649,017	29,865	6,596,601
Panama	86	19,707	76	35,517	602	197,787	4	3,512	—	—
Taiwan	3	13,140	—	—	—	—	674	118,350	1,090	184,150
Other	[r]577	[r]3,957,853	[r]784	[r]392,469	[r]419	[r]411,516	[r]414	[r]636,777	627	470,319
Total	55,006	20,061,840	48,382	14,384,696	47,524	[r]12,354,971	21,687	5,997,995	42,543	11,760,263

[r] Revised.

[1] Exports for 1989-93 contain mixed (used plus new) rails: 1,191 metric tons valued at $8,664,660 in 1989; 5,979 metric tons valued at $4,439,351 in 1990; 6,828 metric tons valued at $3,963,245 in 1991; 2,376 metric tons valued at $1,783,731 in 1992; and 7,142 metric tons valued at $4,239,220 in 1993. Export valuation is on a "free alongside ship" (f.a.s.) basis.

[2] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 22
U.S. IMPORTS FOR CONSUMPTION OF USED RAILS FOR REROLLING AND OTHER USES,[1] BY COUNTRY

Country	1989		1990		1991		1992		1993	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	—	—	6	$7,234	—	—	—	—	—	—
Canada	80,121	$13,521,929	151,879	23,421,711	93,011	$16,152,456	77,030	$15,215,964	70,019	$13,527,264
Finland	—	—	—	—	—	—	10	13,247	—	—
France	(2)	1,599	—	—	(2)	2,460	(2)	1,416	—	—
Germany	5	4,881	2,439	1,641,592	—	—	5	10,194	(2)	1,717
Israel	—	—	—	—	2	5,650	—	—	—	—
Japan	25	15,202	158	77,265	—	—	(2)	1,632	—	—
Korea, Republic of	—	—	—	—	—	—	473	238,804	82	41,991
Luxembourg	—	—	—	—	—	—	9	5,250	—	—
Mexico	—	—	—	—	20	12,000	30	96,900	—	—
U.S.S.R.[3]	8,958	1,290,199	—	—	—	—	—	—	—	—
United Kingdom	5	10,674	—	—	—	—	—	—	—	—
Total[4]	89,115	14,844,484	154,483	25,147,802	93,033	16,172,566	77,558	15,583,407	70,101	13,570,972

[1] Imports contain 3,674 metric tons of mixed (used plus new) rails valued at $1,065,953 for 1989, and no mixed rails for all following years. Import valuation is on a customs basis.

[2] Less than 1/2 unit.

[3] Dissolved in Dec. 1991.

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

Source: Bureau of the Census.

TABLE 23
U.S. EXPORTS OF DIRECT-REDUCED IRON, BY COUNTRY

Country	1991				1992				1993			
	Metallic iron content, weight percent				Metallic iron content, weight percent				Metallic iron content, weight percent			
	More than 80%		Minimum of 99.94%		More than 80%		Minimum of 99.94%		More than 80%		Minimum of 99.94%	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Argentina	333	$239,803	214	$136,820	300	$212,233	179	$105,178	503	$110,679	54	$30,160
Aruba	—	—	—	—	—	—	—	—	484	51,329	—	—
Brazil	660	459,347	62	38,475	1,682	359,847	7	5,000	4,968	527,077	1,273	326,815
Canada	394	273,549	25	10,550	579	220,638	25	19,530	974	103,250	94	37,606
Germany	184	156,900	85	200,990	121	23,437	164	127,515	37	3,960	9	6,998
Ghana	170	121,686	38	25,581	—	—	—	—	83	8,844	10	4,411
Hong Kong	260	140,997	—	—	479	54,182	412	210,393	—	—	356	75,000
Indonesia	—	—	—	—	84	40,250	379	171,027	—	—	—	—
Israel	—	—	58	39,999	—	—	44	33,676	—	—	231	179,364
Italy	19	87,276	—	—	—	—	1	4,496	—	—	445	340,243
Japan	31	89,793	731	1,338,187	247	26,102	1,343	743,427	88	9,286	787	351,975
Korea, Republic of	38	35,132	4	36,269	520	68,024	[r]567	[r]1,681,071	726	97,362	1,327	1,127,320
Mexico	534	476,416	267	260,939	1,506	333,222	252	106,578	4,969	526,417	266	155,263
Netherlands	—	—	182	233,354	—	—	250	200,815	—	—	50	80,300
Nicaragua	—	—	—	—	—	—	430	333,240	—	—	—	—
Saudi Arabia	145	170,577	19	35,475	778	82,481	—	—	—	—	—	—
Taiwan	—	—	29	27,598	32	3,443	4	3,000	623	67,184	283	211,571
United Arab Emirates	(1)	4,051	37	20,925	519	54,829	—	—	—	—	—	—
United Kingdom	5	24,603	223	138,424	1,225	182,212	134	104,661	—	—	23	27,856
Venezuela	168	104,481	356	208,035	812	198,132	401	246,348	2,900	307,302	230	170,774
Other	[r]577	[r]482,150	[r]83	[r]147,280	[r]486	[r]162,415	[r]143	[r]115,199	441	48,502	307	186,393
Total	3,517	2,866,761	2,414	2,898,901	9,370	2,021,447	[r]4,735	[r]4,211,154	16,796	1,861,192	5,745	3,312,049

[r] Revised.

[1] Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 24
U.S. IMPORTS FOR CONSUMPTION OF DIRECT-REDUCED IRON, BY COUNTRY

Country	1991				1992				1993			
	Metallic iron content, weight percent				Metallic iron content, weight percent				Metallic iron content, weight percent			
	More than 80%		Minimum of 99.94%		More than 80%		Minimum of 99.94%		More than 80%		Minimum of 99.94%	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	—	—	1	$1,678	—	—	1	$2,097	—	—	1	$2,400
Belgium	100	$11,940	38	48,478	—	—	—	—	—	—	—	—
Brazil	—	—	4,301	5,550,936	18	$2,068	—	—	—	—	—	—
Canada	—	—	207	101,963	151	16,288	91	68,101	18	$2,328	109	43,708
China	—	—	9	11,400	—	—	7	9,103	—	—	1	1,371
France	—	—	—	—	—	—	—	—	1,295	137,304	400	126,930
Germany	—	—	7	8,622	—	—	3	14,041	—	—	1	4,686
Italy	—	—	7	2,155	—	—	—	—	—	—	228	72,789
Japan	40	4,270	711	717,235	23,725	2,217,025	200	311,771	10,494	942,387	749	916,698
Korea, Republic of	—	—	1	1,318	—	—	—	—	—	—	—	—
Mexico	20	1,986	16	6,694	—	—	2	2,540	—	—	1	1,515
Netherlands	—	—	—	—	—	—	2	2,870	—	—	—	—
Peru	—	—	7	19,203	—	—	5	24,528	—	—	4	3,600
Russia[1]	—	—	—	—	22,510	1,800,519	1,238	1,596,650	51,170	5,049,854	18,916	1,528,963
Spain	—	—	273	91,990	—	—	927	299,568	—	—	1,615	519,498
Sweden	21	24,360	15	18,017	—	—	—	—	993	105,260	465	226,608
Switzerland	—	—	—	—	—	—	1	2,050	—	—	—	—
Taiwan	—	—	—	—	—	—	2	3,170	—	—	—	—
U.S.S.R.[2]	19,345	2,050,634	1,677	2,165,334	—	—	—	—	—	—	—	—
United Kingdom	—	—	14	13,803	—	—	147	109,066	—	—	221	131,993
Venezuela	345,148	38,507,445	7,961	4,264,618	495,685	49,963,448	—	—	837,365	80,978,406	—	—
Total	364,674	40,600,635	15,245	13,023,444	542,089	53,999,348	2,626	2,445,555	901,335	87,215,539	22,711	3,580,759

[1] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[2] Dissolved in Dec. 1991.

Source: Bureau of the Census.

TABLE 25
U.S. EXPORTS OF PIG IRON,[1] BY COUNTRY

Country	1989		1990		1991		1992		1993	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Australia	17	$22,330	—	—	—	—	—	—	185	$16,270
Austria	—	—	97	$8,511	—	—	—	—	—	—
Belgium	—	—	—	—	104	$9,121	—	—	—	—
Canada	7,695	926,158	2,447	543,473	960	219,992	1,319	$226,872	1,240	244,712
China	—	—	—	—	—	—	—	—	162	14,278
Costa Rica	—	—	—	—	—	—	—	—	275	24,235
Dominican Republic	—	—	23	11,065	169	20,539	470	46,900	—	—
Egypt	—	—	—	—	—	—	4,227	372,029	—	—
Finland	—	—	—	—	134	11,802	—	—	—	—
Germany	—	—	—	—	305	26,898	90	9,020	—	—
Ghana	320	81,324	145	41,052	207	54,799	482	126,213	102	25,284
Japan	—	—	183	20,582	9	6,581	169	61,070	138	12,201
Korea, Republic of	18	5,280	1,974	60,944	21	21,502	2,164	170,988	—	—
Mexico	2,591	292,830	2,719	321,143	11,624	1,132,358	22,460	2,047,290	23,899	2,553,045
Netherlands	—	—	397	35,000	52	4,617	—	—	57	22,000
Pakistan	—	—	—	—	329	28,977	—	—	—	—
Singapore	—	—	—	—	325	28,660	208	18,297	854	75,143
Taiwan	—	—	—	—	—	—	1,063	95,277	164	31,678
United Kingdom	15	5,841	5,643	497,353	1,212	107,015	45	17,362	—	—
Venezuela	—	—	686	60,416	—	—	—	—	—	—
Other	—	—	140	18,703	71	27,610	45	4,320	35	16,633
Total	10,656	1,333,763	14,454	1,618,242	15,522	1,700,471	32,742	3,195,638	27,111	3,035,479

[1] Includes the following grades of pig iron: less than or equal to 0.5% phosphorus content; greater than 0.5% phosphorus content; and alloy grade. Export valuation is on a "free alongside ship" (f.a.s.) basis.

Source: Bureau of the Census.

TABLE 26

U.S. IMPORTS FOR CONSUMPTION OF PIG IRON,[1] BY COUNTRY

Country	1989		1990		1991		1992		1993	
	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value	Quantity (metric tons)	Value
Belgium	151	$263,953	—	—	—	—	—	—	—	—
Brazil	310,197	41,377,743	219,041	$31,700,595	327,603	$51,969,870	308,610	$39,212,989	392,871	$55,245,812
Canada	120,597	29,164,006	124,939	27,665,583	84,254	18,019,473	85,013	19,314,931	61,889	13,791,921
Gabon	87	21,158	—	—	—	—	—	—	—	—
India	—	—	—	—	132	231,131	—	—	—	—
Japan	6,039	967,115	28	34,973	—	—	—	—	26,349	5,326,669
Korea, Republic of	68	192,811	—	—	—	—	—	—	—	—
Latvia[2]	—	—	—	—	—	—	—	—	67,064	7,652,932
Lithuania[2]	—	—	—	—	—	—	—	—	10,026	790,420
Malaysia	—	—	200	50,800	—	—	—	—	—	—
Mexico	—	—	1	2,797	80	15,084	—	—	89	15,317
Norway	5,726	1,196,742	3,001	595,599	236	411,726	—	—	—	—
Russia[2]	—	—	—	—	—	—	14,030	1,133,168	154,953	15,964,975
South Africa, Republic of	—	—	—	—	21,243	3,269,680	77,607	11,670,317	69,627	11,413,631
Switzerland	—	—	4	18,446	—	—	6,288	943,875	10,970	886,020
Ukraine[2]	—	—	—	—	—	—	—	—	34,330	5,647,828
U.S.S.R.[3]	—	—	—	—	770	1,344,304	4,999	508,764	—	—
Total	442,865	73,183,528	347,214	60,068,793	434,318	75,261,268	496,547	72,784,044	828,168	116,735,525

[1] Includes the following grades of pig iron: less than or equal to 0.5% phosphorus content; greater than 0.5% phosphorus content; and alloy grade. Import valuation is on a customs basis.

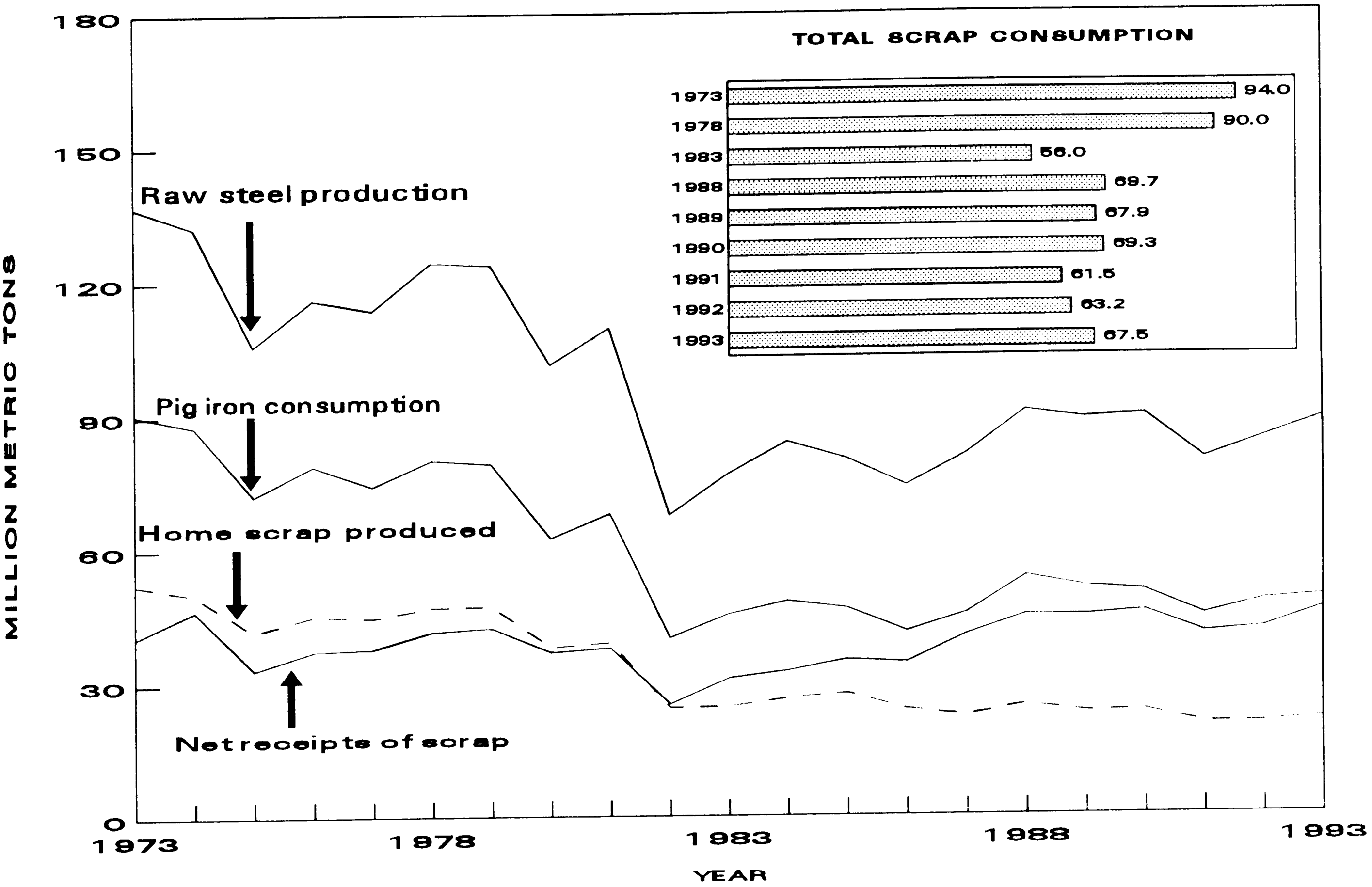
[2] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[3] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

FIGURE 1

RAW STEEL PRODUCTION (AISI), FOR ALL TYPES OF MANUFACTURERS: TOTAL IRON AND STEEL SCRAP CONSUMPTION, PIG IRON CONSUMPTION, HOME SCRAP PRODUCTION, AND NET SCRAP RECEIPTS



Sources: American Iron and Steel Institute and U.S. Bureau of Mines.

RECYCLING—NONFERROUS METALS

By James F. Carlin, Jr., Daniel Edelstein, Stephen M. Jasinski, John F. Papp, Patricia A. Plunkert, and Gerald R. Smith

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INTRODUCTION[1]

Recycling, a significant factor in the supply of many of the key metals used in our society, provides environmental benefits in terms of energy savings, reduced volumes of waste, and reduced emissions associated with the energy savings.

The estimated value of recycled nonferrous metals in 1993 was about $7.3 billion and is an increasingly important component of economic activity in the United States. Table 1 shows salient U.S. recycling statistics for selected metals. Table 2 shows salient U.S. apparent supply and recycling statistics for those same metals. Figure 1 shows a general flow scheme for recycling.

As part of its Commodities and Materials Program, the USBM provides information and analysis on more than 100 raw and/or processed minerals. Collected data are assessed by commodity specialists, and information is disseminated to government, industry, and academia through consultative services and more than 100 recurring publications. This publication examines and reports on minerals and materials trends as well as environmental aspects of the entire life cycle of minerals use.

The USBM's Research Directorate conducted research in 1993 on recycling of consumer products, advanced materials, and metallurgical residues and effluents currently discarded. The Bureau also conducted research on impurity control during recycling and design for reuse or waste minimization. To increase the efficiency of recycling, the USBM investigated the control of impurities such as magnesium, zinc, and lithium in aluminum scrap and the removal of copper from ferrous scrap. The USBM also investigated methods to remove heavy-metal contaminants from mineral processing and manufacturing waste and to stabilize those heavy metals not removed. The USBM in cooperation with the American Iron and Steel Institute initiated a research project to dewater steelmaking sludges, currently landfilled or stockpiled on site, in order to recycle the contained iron units.

Because of the increasing importance of recycling to domestic metal supply and the intense public interest, the USBM initiated this separate chapter on nonferrous metal recycling as part of its Annual Report series in 1991. A separate chapter on iron and steel scrap already had been part of this series for many years. The focus of this chapter is on aluminum, copper, lead, tin, and zinc recycling.

ALUMINUM[2]

Domestic Data Coverage

Domestic recycling data for aluminum are developed by the U.S. Bureau of Mines from a voluntary survey, "Aluminum Scrap," of U.S. operations. Of the 92 companies and/or plants to which monthly or annual survey requests were sent, 85 responded, representing 94% of the total scrap consumed shown in table 5.

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The U.S. Bureau of Mines estimated that more than 2.9 million metric tons (Mt) of metal was recovered from purchased aluminum scrap in 1993. Forty-five percent of this recovered metal came from new (manufacturing) scrap and 55% from old scrap (discarded aluminum products). The metal recovered from old scrap satisfied 25% of the total domestic aluminum metal demand for the year. The predominant type of purchased scrap was aluminum used beverage can (UBC) scrap, accounting for approximately one-half of the old scrap consumed.

According to a survey conducted by the Aluminum Association Inc., the Institute of Scrap Recycling Industries, and the Can Manufacturers Institute, 59.5 billion aluminum UBC's were recycled in 1993, equivalent to a recycling rate of 63.1%. This was the fifth consecutive year that the recycling rate for aluminum UBC's exceeded 60%.

The London Metal Exchange (LME) reported that aluminum alloy ingot held at its U.S. warehouses at yearend 1993 decreased to 980 tons, a mere fraction of the 10,120 tons of alloy held at yearend 1992. Increased demand by the domestic automotive diecasting industry reportedly contributed to this significant decrease in LME alloy inventories. *(See tables 3, 4, 5, and 6.)*

Markets and Prices.—Purchase prices for aluminum scrap, as quoted by American Metal Market (AMM), fluctuated during the year and closed the year at lower levels than at the beginning of the year. The yearend price ranges for selected types of aluminum scrap were as follows: mixed low-copper-content aluminum clips, 39.5 to 40.5 cents per pound; old sheet and cast, 34.5 to 35.5 cents per pound; and clean dry aluminum turnings, 34 to 35 cents per pound.

Prices for UBC's trended downward for most of the year and closed about 6 cents per pound lower than at the beginning of the year. Aluminum producers' buying price range for processed and delivered UBC's, as quoted by AMM, began the year at 40 to 42 cents per pound. The price range at the end of the year widened and decreased to 33 to 37 cents per pound.

In mid-July, AMM discontinued the publication of secondary aluminum ingot prices and substituted an indicator price series. The yearend 1993 indicator prices for selected secondary aluminum ingots were as follows: alloy 380 (1% zinc content), 61.96 cents per pound; alloy 360 (0.6% copper content), 67 cents per pound; alloy 413 (0.6% copper content), 67.09 cents per pound; and alloy 319, 64.52 cents per pound.

The LME began cash trading of a secondary aluminum contract in January. The 1993 annual average price, based on 11 months of trading, was 45.13 cents per pound. Metals Week published an annual average U.S. price of 55.46 cents per pound for A-380 alloy (3% zinc content), the alloy comparable to that traded on the LME.

Foreign Trade.—Exports of aluminum scrap continued to decrease in 1993, reaching their lowest level in 9 years. Japan continued to be the principal destination of exported aluminum scrap, accounting for more than 40% of the total.

Imports for consumption increased compared with those of the previous year. Canada remained the major shipping country to the United States, supplying almost 60% of the total aluminum scrap imports in 1993. *(See tables 7 and 8.)*

World Review.—According to preliminary estimates published by the World Bureau of Metal Statistics in August 1994, world production of secondary aluminum was about 5.6 Mt in 1993. According to its statistics, the United States was the world's largest producer of secondary aluminum, followed by Japan and Germany.

Outlook

As the public and industry become more sensitive to the issue of waste management, the benefits of recycling should become more evident. The aluminum industry, with its long history of recycling experience and its vast network of collection centers, should be well-positioned to take advantage of this increased interest. The domestic and world secondary aluminum industries are expected to continue to expand. In the short term, the growing acceptance of aluminum beverage cans (with their very short life cycle) in overseas markets could lead to a more rapid growth rate in the recovery of aluminum in countries outside the United States, where the aluminum beverage can already dominates the market. In the long term, as more and more aluminum is used in products with longer life cycles, such as automobiles, more scrap will enter the market for recovery, and increase the secondary production levels in both the domestic and world markets of the future.

COPPER AND COPPER ALLOY SCRAP[4]

Background

Definitions, Grades and Specifications.—The Institute of Scrap Recycling Industries, Inc. (ISRI) recognizes about 53 classes of copper alloy scrap. Although there are several grades within each, the major unalloyed scrap categories are No. 1 copper, which contains greater than 99% copper, and No. 2 copper, which contains a minimum of 94% copper. There are special designations for low copper content scrap such as skimmings, ashes, and residues, which contain 12% to 30% copper, and even lower copper content scrap including electronic scrap, refining slags, printed circuit board, and metal-laden waste liquors. In addition, there are numerous copper alloy scrap designations.

Copper and copper alloy scrap may be recovered from post consumer used, wornout or obsolete products (old scrap), or it may be generated during the manufacture of finished products (new scrap). The Bureau of Mines generally measures only that scrap which enters into trade. Manufacturing scrap that is reprocessed internally by the producer or consumer (home or run-around scrap) is generally discounted when measuring scrap demand.

A manufacturer consuming brass mill products such as sheet, strip or rod, may have product yields as low as 40%. New scrap, generated in the form of borings, turnings, stampings, and off-spec products, is readily recycled at brass mills into semifabricates. This mill-return scrap is frequently sold back to the brass mill on long-term buy-back arrangements.

Resources.—Since World War II, the ever-increasing reservoir of copper products has satisfied between 19% and 33% of annual U.S. apparent industrial consumption in the form of old scrap. By 1993, this domestic reservoir of unreclaimed products contained over 70 Mmt of copper. While some of this copper has been disposed in landfills or dissipated to the environment and is not readily recovered, as much as 70% of this copper is still in use or abandoned in place, and hence theoretically available for recycling. Dissipative uses of copper, principally as copper chemicals, constitute only about 0.5% of current copper demand. It is estimated that between 30% and 50% of the unrecovered products have been disposed in landfills.

Estimation of the recycling efficiency for copper is complicated by the varied life cycle of its different end uses and by trade in manufactured products containing copper. Copper in electrical plants and machinery averages 30 years; in nonelectrical machinery, 15 years; in housing, 40 or more years; and in transportation, 10 years. In 1992, the recycling efficiency for copper (old scrap consumed divided by the quantity of old scrap theoretically available using average product sector life-cycles, and adjusted for net scrap trade) was estimated by the U.S. Bureau of Mines to be about 30%. This ignores net trade in copper contained in manufactured and semimanufactured products. By the same calculations, if all the copper that was theoretically available from old scrap were recycled in the United States, old scrap could account for almost three-fourths of domestic apparent consumption. In 1993, old scrap accounted for only 22% of apparent consumption. The rate of old scrap recovery is limited not only by copper's long life and its essential uses, but also by the sensitivity of scrap collection to market prices.

New (manufacturing) scrap, on the other hand, has a short life, about 30 days, and its recovery is limited by domestic manufacturing rates and efficiencies. This wide difference in turnaround and availability has resulted in a gradual increase of new scrap versus old scrap as a component in all scrap collected in the United States.

Technology.—Because of the variety of grades and alternative routes to recycling, an elaborate infrastructure has developed to collect, upgrade, and process copper-bearing scrap prior to shipment to the consumer. For example, copper cables and wires, a prime and valued source of higher grades of unalloyed scrap, must be processed manually or through sophisticated chopping operations, to remove unwanted insulation. While chopped wire is shipped in barrels, stripped cable and other bulky scrap must be sheared and baled to facilitate transport and feed to secondary smelters. Previously, burning of the cable to remove insulation and other combustibles prior to recycling was acceptable; environmental regulation of emissions now generally precludes this.

While No. 1 copper may be consumed directly (remelt) or processed through a refinery, No. 2 copper generally requires refining before it is consumed. Low-grade scrap is generally processed through multi-step smelting and electrolytic refining to produce refined copper, though some, such as electric circuit board scrap, may be treated hydrometallurgically to produce chemical products such as copper sulfate and copper oxide. Electrolytically refined secondary copper is generally interchangeable with primary refined copper and is suitable for wire and cable manufacture. While lower grades of alloy scrap may be processed through smelting, higher grades of sorted scrap are directly consumed (direct melt) in the production of copper alloy products.

Processing complex copper-containing materials, such as drosses, flue dust, catalysts, slimes from electroplating waste water, and metal-rich slags from converter processes requires a versatile production process. Secondary smelters use a three-stage smelting process similar to that employed in primary processing: a first stage primary smelting blast or reverberatory furnace, followed by a converter and anode furnace. Depending on grade, scrap may enter the flowstream at any of the three furnaces.

Alloy copper scrap may be directly consumed at ingot makers, brass mills, or foundries and miscellaneous manufacturers. The scrap is melted in reverberatory or electric induction furnaces, and impurities are skimmed off as dross. Pure metal or master alloy ingots may be added to adjust the composition of the melt before casting into slabs, ingots, billets, etc., or various foundry products.

Economic Factors.—Copper scrap prices are closely correlated to the price of refined copper. However, the price paid for scrap at each level of processing must be sufficiently discounted to allow for all subsequent processing costs. Thus, a scrap collector who must perform such functions as sorting, shipping, chopping, baling, etc. will pay less for scrap than does the consumer. Because of these inherent costs associated with the initial collection and processing of scrap, low refined copper prices will squeeze processing and profit margins and reduce the quantity of scrap that can be economically recovered. The spread between refiner's buying price for No. 2 scrap and refiner's selling price (producer price) for refined copper has varied from 9 cents in 1970 to over 30 cents in the late 1980's. The low spreads in the early 1970's were caused by price controls placed on U.S. copper during this period. The very high spreads of the late 1980's were the result of high refined copper prices and a good supply of scrap.

Structural and Environmental Factors.—Domestic production and consumption of brass and bronze ingot, products from copper-based scrap, declined markedly between the late 1960's and early 1980's owing to substitution of aluminum and plastics for brass and bronze castings, increased import penetration, and the imposition of environmental control regulations on both ingot makers and the consuming 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. After a period of stabilization and even growth in the late 1980's, contraction in this industry resumed in the early 1990's as a response to numerous environmental regulations including: stricter atmospheric lead emissions standards and worker exposure limits; water discharge regulations; and land-fill disposal restrictions for contaminated foundry sands.

Lead associated with copper scrap continued to pose additional obstacles to the recycling of copper alloy scrap. New drinking water standards required the lowering of the lead content of potable water supplies and may require the complete elimination of lead from brass used in plumbing fixtures for potable water supplies. The addition of up to 8% lead in brass castings and rod greatly improves machineability and casting characteristics. While research to develop new low-lead or lead-free alloys was underway, little effort was being expended to develop the technology to remove lead from existing alloys. Without new technology, these materials could be precluded as feed stock for low-lead or lead free alloy production.

The existence of lead stabilizers in the PVC coverings of copper wire and cable posed a threat to recycling of these materials. The lead-content could result in the waste or "fluff" from wire chopping operations being regulated as a hazardous waste, adding to handling and disposal costs.

Annual Review

The oversupply of copper that led to rising global inventories during 1992 persisted into 1993, for while world refined production and capacity increased slightly, world demand for refined copper remained stagnant. According to data collected by the International Copper Study Group (ICSG) total world consumption of refined copper remained unchanged in 1993 at 11.1 Mmt. Demand in Western Europe was particularly poor, falling by almost 10%. Weak demand in Japan was partially offset by growth in other Asian markets. Refined copper demand in the United States and Canada, however, ran counter to the world trend, rising by 8.5% and 19%, respectively. As a result of these trends, prices for copper and copper scrap moved downward throughout the year, except for a mid-year period when prices were artificially high, reportedly owing to market manipulation. In 1993, the major copper consuming nations or areas of the world were Europe (36%), the United States (21%), and the Middle East and Asia (35%).

In the United States, five secondary smelters and six fire refineries were processing scrap during 1993. Nine electrolytic refineries operated during the year, three of which were dedicated facilities processing secondary anode. Several others purchased or toll-refined secondary anode. About 28 ingot makers consumed copper and copper alloy scrap in the production of brass and bronze ingots and master alloys. Direct-melt scrap was consumed at about 35 brass mills and 160 foundries, chemical plants, and miscellaneous consumers of copper.

In 1993, old scrap consumption, converted to refined metal and alloys, was 555,000 tons of copper, unchanged from that of 1992, and was equivalent to 22% of U.S. apparent consumption. Purchased new scrap, derived from copper fabricating operations, yielded 731,000 tons of copper, up slightly from that of the previous year, and accounted for 57% of copper recovered from all scrap. Of the total copper recovered from copper-, aluminum-, zinc-, and nickel-based scrap, copper smelters and refiners recovered 36%; brass mills, 46%; brass and bronze ingot makers, 10%; and miscellaneous manufacturers, foundries, and chemical plants, 8%. Unalloyed scrap accounted for 51% of copper-based scrap consumed, as shown on table 13.

About 77% of the copper contained in new scrap was consumed at brass mills. Copper in all old and new refined or remelted scrap comprised 39% of total U.S. copper supply and had an equivalent refined value of $2.6 billion. *(See tables 9-16.)*

Market and Prices.—Copper scrap prices trended lower in 1993 following the decline in refined copper prices. With falling prices, however, the scrap discount to refined copper narrowed. In January, the month of peak refined prices, the average brass mill buying price for no. 1 scrap of 94.1 cents per pound, as shown in table 17, was discounted by 11.3 cents from the domestic producer price. The discount averaged about 9 cents during the remainder of the year, except for a period in September and October, when market manipulations reportedly led to artificially high refined prices and an increase in the no. 1 scrap discount to about 14 cents per pound.

The overall U.S. copper market showed a strong recovery from the depressed 1992 level, with demand for refined copper rising by 8.5%. Copper recovered from scrap, on the other hand, was unchanged. A surplus of refined copper led to plentiful supplies, lower prices, and as noted above, narrower processing margins, all of which encouraged the consumption of refined copper at the expense of scrap. Consumption of copper based scrap at brass mills was stagnant, while consumption of refined copper rose by more than 10%. On a tonnage basis, most of the incremental refined demand was from copper wire rod mills, which are almost 100% dependent on refined copper for their feed stock. Domestic foundries experienced a decrease in shipments and a decline in both refined copper and scrap consumption. Foundry consumption of brass ingot, a product of brass scrap, was unchanged. Fire-refined copper *(see table 11)*, the only area of scrap consumption to experience significant growth, increased owing to the strength of tube mill shipments; tube mills are the major consumers of fire-refined copper.

Foreign Trade.—The United States was a net exporter of copper scrap, and one of the largest international sources for copper scrap, followed by France, Germany, and the United Kingdom. U.S. exports of copper scrap have been increasing since the 1960's, when the Asian nations began to industrialize. In 1993 China, Hong Kong, Japan, Korea, Singapore, and Taiwan, combined, accounted for 56% and 63%, respectively, of U.S. unalloyed and alloyed scrap exports. In 1993, exports to China, the largest recipient of domestic scrap, declined significantly. Over-buying of copper during 1993, devaluation of the Chinese currency, imposition of higher tariffs, and a reported shortage of available foreign exchange, combined to significantly reduce Chinese purchases of U.S. scrap. Canada and Mexico were the leading sources for U.S. imports of copper and copper alloy scrap and accounted for 70% of imports in 1993. *(See tables 18 and 19.)*

World Review.—The Western European countries made up the largest single market for scrap in the world. Germany, Italy, France, and the United Kingdom were the leading consumers. The United States was second after the European Community (EC) in total scrap consumption. Asia, mostly Japan, was the third largest scrap consuming area of the world. Copper scrap accounted for an estimated 43% of total annual copper consumption (refined consumption plus estimated copper content of direct-melt scrap) in Western Europe, compared with about 39% of total annual copper consumption in the United States. Consumption of scrap, on a tonnage basis and as a percentage of total copper consumption, has been increasing in Europe over the past several years, principally owing to expansion of secondary refined production in Germany and Italy. In 1993, 20% of refined copper in the United States and 47% of the refined copper produced in Western Europe was derived from copper scrap. In Japan, only about 8% of refined production was from scrap, but, owing to the large quantity of direct melt scrap consumed, about 25% of total copper consumption. In 1993, secondary refined production accounted for about 16% of the world's refined copper production.

Outlook

Over the next decade, copper scrap will continue to be a premium material for the U.S. semifabricating industry. Because scrap is usually a lower-cost alternative to primary metal, it will continue to be of great interest to Far Eastern countries as they expand their industries.

In the United States, however, the recovery of copper from old scrap remained stagnant in 1993, and did not share in the strong growth in copper demand. Old scrap as a percentage of apparent consumption declined from 25% in 1991, to 22% in 1993. The recovery of copper (old scrap) from the large and growing reservoir of copper products in use may be limited by the following factors: (1) copper prices, (2) life of products, (3) available recovery technologies, and (4) changing end-use patterns. In the latter case, electrical applications have been gaining an increasing share of domestic consumption. The long life cycle of building and transmission wire, the growth of consumer electronics, which are difficult to recycle, and the trend toward greater product reliability, could, in the short term, reduce old scrap availability. Increased production efficiencies have significantly affected the availability of new scrap. Industry analysts have observed that the amount of new scrap being generated by manufacturing plants has been cut by as much as 50%. Another factor that will affect copper scrap consumption and processing over the next decade is the limitation on lead in copper plumbing alloys, the result of legislation limiting the content of lead in plumbing fixtures used in potable drinking water supply systems. Leaded brass scrap is the prime feed material to the ingot-making and foundry industries. While extensive research was being conducted on low-lead or lead-free alternative alloys, technology to remove lead from leaded brass scrap was lagging and could prove a future limitation to the recycling of this material.

LEAD[5]

Refined lead is a soft, heavy metal, one of the first metals used by humankind. It has a low melting point, which makes it among the easiest metals to cast, it is the most corrosion-resistant common metal, and it has useful electrical properties. In terms of tonnage of metal consumed, demand for lead is surpassed only by that of aluminum, copper, iron, and zinc. The United States is the world's largest producer and consumer of refined lead. The domestic demand for lead has changed significantly over the past 20 years. In 1972, dissipative uses of lead, particularly in gasoline additives, pigments, ammunition, and chemicals, amounted to more than 400 thousand tons, or about 30% of the reported consumption of 1.35 million tons. In 1993, following the phase-out of lead-based gasoline additives and pigments for interior paint, dissipative use accounted for about 10% of the total demand of 1.36 million tons.

About 67% of the lead used domestically is recovered from scrap. In 1993, approximately 904 thousand metric tons of metal valued at $463 million was recovered from both new and old scrap. The United States exported about 54 thousand tons of lead scrap in 1993, with a value of $14 million. Corresponding imports of lead scrap for the year totaled 90 tons, worth $39 thousand. *(See tables 20, 21, 22, and 23.)*

In 1993, old scrap accounted for 93%, and new scrap for 7%, of the total of 904,000 tons of lead scrap recovered. Of the total old scrap recovered, nearly 95% was supplied from used batteries. The battery industry dominates the lead scrap field just as it dominates the primary lead usage category. In recent years, integrated battery manufacturers/secondary smelters have expanded smelting capacity to fill a vacuum left by the closure of small and medium sized nonintegrated battery breakers, and/or secondary smelters that have closed because of environmental-related pressure. Similarly, the independent scrap dealer is playing a diminished role, as battery manufacturers are entering into buy-back arrangements with retail outlets, both as a marketing tool for new batteries and as a means of ensuring feedstock to their smelters and downstream manufacturing operations.

Domestic Data Coverage

Domestic data for lead scrap are developed by the U.S. Bureau of Mines from voluntary monthly and annual surveys. The larger companies are canvassed monthly and the smaller ones annually. Of the 38 companies producing secondary lead, exclusive of lead in copper-base alloys, to which a survey request was sent, 26 responded, representing 80% of the total refinery production of secondary lead. Production and consumption for the nonrespondents were estimated using prior-year levels adjusted for general industry trends.

Annual Review

Legislation that would affect secondary lead producers was reintroduced in the U.S. House of Representatives in 1993. The legislation, entitled "The Lead-Based Paint Hazard Trust Fund Act of 1993", essentially a revamping of a 1992 bill, proposed a unitary tax of 45 cents per pound on all primary and secondary lead produced domestically and imported. The intent of this legislation was to provide a dedicated revenue of $1 billion per year for use in protecting against lead-based paint hazards in accordance with Title 10 of the Housing and Community Development Act of 1992. By yearend 1993, no significant advancement of the bill had occurred.

Domestic secondary production in 1993 was estimated to have declined by about 1.5% from a near record high in 1992. Secondary lead accounted for 73% of domestic lead production in 1993, reflecting a continued high level of lead-acid battery recycling. Battery Council International statistics indicated that the recycling rate for lead-acid batteries had been 94.4% in 1992.

A significant part of the decline in secondary production in 1993 was in the recovery of lead by nonbattery recyclers. These recyclers, who mainly produced specialty alloys for such uses as solders, brass or bronze ingots, and bearing metals, continued to experience higher costs and lower profit margins in their operations.

Several industry actions occurred in 1993 that will affect lead recycling industry capacity in the United States. RSR Corp., Dallas, TX, announced plans to build a new $60 million auto and industrial lead-acid battery recycling plant in Aiken County, SC. The facility was to be the first greenfield lead-acid battery recycling operation in the southeastern United States and was to be capable of processing 6 million batteries annually. The source of obsolete batteries was expected to come from an eight-State area in the southern United States through existing conversion agreements with battery scrap dealers. RSR expected permitting and construction time for the new facility to take from 3 to 5 years.

GNB Battery Technologies Inc., Atlanta, GA, announced in late 1993 that it was suspending indefinitely plans for a proposed greenfield secondary lead smelter in Waynesboro, GA. The decision coincided with a fine that had been levied by Environmental Protection Agency (EPA) on GNB's facility in Columbus, GA. In a subsequent agreement with EPA, the company planned to begin installation of new pollution control equipment at the Columbus facility.

Refined Metals Corp., Longview, TX, closed indefinitely its secondary smelters in Memphis, TN, and Beech Grove, IN, at the beginning of the year. The combined capacity of the two smelter operations was about 50,000 tons per year.

Outlook

While overall economic growth was somewhat slower than anticipated in 1993, the automotive sector, and its related demand for lead-acid batteries, remained strong through 1994 and was expected to continue as such in the short term. Total vehicle production in the United States rose by more than 10% to about 10.8 million units in 1993, and increased by another 12% in 1994.

The U.S. lead market tightened in 1994 as consumption rose by about 8% and a shorter supply of lead pushed prices higher. Similar market factors are expected to exist in the short term. Secondary production of lead was expected to increase to about 75% of domestic production in this period, as higher prices encouraged more recycling.

TIN[6]

Tin was one of the earliest metals known to humankind. Tin occurs in nature principally as the oxide mineral cassiterite. Tin metal is commonly used as a protective coating or as an alloying metal with other metals. Metal is generally used as the starting point for most uses of tin. The major uses for tin are as follows: cans and containers, 32%; electrical, 22%; construction, 10%; and transportation, 11%; other uses account for the remaining 25%. Tinplating currently uses no scrap tin, but most other fabricated end-use items, especially solder and brass/bronze, use substantial quantities of tin scrap.

About 25% of the domestic supply of tin metal is metal recovered from both new and old tin scrap. In 1993, 11,700 tons of metal valued at an estimated $90 million was recovered from new and old tin scrap.

Old tin scrap is collected at hundreds of domestic scrap yards, at nine tinplate and can detinning plants, and at most municipal collection centers. New tin scrap is generated mainly in the tin mills at six steel plants, numerous brass and bronze plants, and numerous soldermaking plants.

Detinning facilities are unique to the tin scrap industry, in that no other major metal industry has such large-scale facilities to remove plated metal. There are nine domestic detinning plants scattered across the country. Until about 1989, they processed almost solely new tinplate scrap that originated in the tin mills of steel plants and canmaking plants. Since 1989, with new technology that shreds used tin cans, some of the detinning facilities have the capability of also detinning old tin cans. Only in the detinning process does free tin metal see its way to the marketplace; all the alloy forms of tin are merely recycled within their own product-line industries and thus reappear as regenerated alloys. *(See tables 24, 25, 26, and 27.)*

Most tin scrap processing facilities are close to the tin-using industries and to densely populated areas. Most are in the Midwest and Northeast.

Domestic Data Coverage

Domestic scrap data for tin are developed by the USBM from a voluntary survey of the U.S. tin scrap industry. The smaller side of this industry is covered by a canvass sent to five detinning companies monthly; all five responded or are estimated for. The larger side of the tin scrap industry, involving the alloys of tin, is covered largely by a canvass of the copper and lead scrap industries (tin's major coalloys) from which estimates are made for the tin content.

Background

Secondary tin was derived 40% from new scrap and 60% from old scrap. New tin scrap consists mostly of forms of tinplate (side scrap, flitters, cobbles, skeletal punch-outs from can-making etc), drosses from soldering skims, and plating residues and sludges from tinplating lines. Old tin scrap consists mostly of used brass/bronze items (often faucets, fixtures, etc.) and used soldered items (electronic solders from computers, television and radio sets, etc. and plumbing solders from houses and office buildings); since about 1989 some used tin cans have been detinned, and the scrap tin recovered qualifies as old tin scrap.

The solder industry traditionally has consumed large amounts of tin scrap to make solder products. Tin scrap accounts for 42% of the total tin used for solder. The brass/bronze industry, although a smaller user of tin than the solder industry, also traditionally has been a major consumer of tin scrap. Scrap accounts for 52% of the total tin used for brass/bronze.

The average life of tin in its end uses is estimated at 20 years. It is estimated that about 10% of the tin placed in use in any year is dissipated in that same year. Tin in such chemical products as wood preservatives, marine boat hull antifoulant paints, fungicides, tin oxides, and tin tetrachlorides sprayed on glass bottles is quickly dissipated. Some longer lasting tin products also release tin to the environment while in use. For example, tinned electrical copper cables lose tin through weathering or corrosion, whether overhead or underground. The tin in some other end uses is dissipated, even though the products are disposed of in a controlled way; an example would be the used tin cans collected by municipal trash departments and placed in landfills. Currently, about 15% of the domestic requirement for tin is satisfied by old scrap.

Technology.—Tin recycling processes vary according to the nature of the tin scrap. Tin-plated products such as tinned kitchen trays, tinned electrical copper cables, tinplate, or tin cans typically are treated in a batch process at elevated temperatures with a sodium hydroxide solution for a considerable period of time. Typically, an electric current is applied in a reversal of the original plating process. The tinned product is made anodic and electrodes in the batch are made cathodic. Positively charged tin ions leave the tinned product and travel through the electrolytic bath to the negatively charged electrode, where the tin is plated and then can be used as scrap tin for a variety of uses.

For tin alloys, generally there is no attempt to recover the tin as a separate element. Instead, during the alloy refining process the matte is analyzed periodically, and as needed, tin is added to bring the molten batch to the desired specifications.

Secondary tin generally is utilized in the various alloys of tin, especially brass/bronze and solder. These alloys often take the shape of a bar or ingot, but also sometimes appear as rod, wire, plate, pellets, or powder. Traditionally, the brass/bronze industry utilizes the largest percentage of scrap tin to total tin.

Economic Factors.—Scrap prices are generally available only within the industry. But occasionally, publications such as American Metal Market publish some alloy scrap prices and prices for baled old tin can scrap.

There is an active international market in some forms of tin scrap. Generally, the United States has been the world's leading generator of tin scrap, and in some years substantial amounts are exported.

Annual Review

The Steel Can Recycling Institute (SCRI), based in Pittsburgh, PA, announced that henceforth it will be called The Steel Recycling Institute (SRI). The name change reflected a broadening of its mission to encompass not only steel cans (which had been its sole focus since its 1988 founding), but all steel products ranging from appliances to cars. Since SCRI's 1988 inception, the steel can recycling rate had grown from 15% to more than 40%. The overall steel recycling rate has been over 60% for more than 20 years and currently stands at 66%.

The SRI announced that a landmark year was achieved in 1992 for steel can recycling. In 1992, for the first time ever, more than 1 million tons of steel cans were recycled domestically, resulting in a 41% recycling rate. In 1991, the recycling rate was 34%. In the past 5 years, this recycling rate has steadily increased. The SRI delineated the following specific container recycling rates: a) In 1992, more than 12 billion steel food cans were recycled. With a recycling rate of 44%, the steel food can continues to be the Nation's most recycled food container. In 1991, about 36% were recycled; b) the 1992 recycling rate for steel beverage cans (sometimes called bimetal cans) was about 50%. In 1991, about 46% were recycled; and c) in 1992, about 15% of all steel general line cans (paint, aerosol, varnish, etc cans) were recycled. In 1991, about 12% were recycled. The 1 million tons of cans recycled in 1992 equates to about 14 billion steel cans.

In March 1993, in Florida, a 5-month campaign by the SRI to show the State's environmental regulators that steel cans in the State were being recycled at a rate greater than 50%, was successful. Florida had instituted a new advance disposal fee (ADF) on containers that have a recycling rate in the State below 50%. The levy was set at 1 cent per container starting in July 1993, and could increase to 2 cents per container in October 1995. Aluminum cans had earlier been granted exemption due to their high recycling rate, while glass and plastic containers failed to qualify. The stakes were high for steel cans in Florida, where about 106,000 tons of steel containers were distributed in 1991. The SRI was able to demonstrate that steel cans in Florida had a 54% recycling rate.

During the year, the SRI began an initiative calling for increased recycling of all empty paint and aerosol cans. Both items are virtually all tinplate products. SRI targeted these two types of containers as ones that municipalities operating curbside and drop-off recycling programs must include in their efforts if the steel industry is to reach their goal of recycling two out of every three cans by 1995. Paint cans and aerosol cans are categorized as general-line cans (as distinguished from beverage or food cans) in the container industry. Recycling operators have often displayed a reluctance to collect used paint cans and aerosol cans due to the fact that some of them contain residues that could be troublesome to remove. SRI cited two recent studies, one by the Texas Water Commission and the other by S.C. Johnson Wax Co., that reportedly blunted such reluctance.

World Review.—The United States, France, Germany, Japan, and the United Kingdom, generally lead the world in tin recycling activity and innovation. Environmental pressures in those countries for the past 20 years have acted as a powerful incentive.

In contrast to the United States and Europe, where detinning has long been a substantial activity, Japanese industry does little or no detinning because it feels that the tin coating on tinplate has become so thin in the past 20 years that detinning is not economical, and not necessary since the Japanese steel industry uses old tin cans and manufacturers' tin plate scrap as feed for its furnaces. Nippon Steel Corp., the world's largest steelmaker and perhaps the world's largest tinplate producer, was reported to be rapidly increasing the quantity of used steel cans it purchases for recycling at its Kimitsu plant. Nippon began recycling used steel cans at Kimitsu in 1984, and planned to reach a level of 2,000 tons of tinplate scrap recycled by 1995. During 1993, the weight of cans it recycled was reported to have increased to more than 1,000 tons monthly.

Outlook

The near- and long-term outlook for tin recycling is positive, with modest growth expected, about 1% annually. Tin is a high-value industrial metal; as tinplate, one of its main uses, it is easily separated magnetically for recycling. Tin consumption is expected to grow about 1% annually. Scrap is expected to grow from 25% of total metal consumed in 1993 to 27% annually by the year 2000. A major incentive is expected to be environmental legislation, mostly at the local and State level. If tin prices remain relatively high compared with prices of other major metals, the industry will have sufficient incentive to recycle this costly metal.

ZINC[7]

Zinc is the fourth most widely used metal after aluminum, copper, and iron. About three-fourths of consumption is in metal form and one-fourth in compound form. More than 90% of the metal is used for galvanizing steel and for alloys; the remainder is used to produce dust, oxide, and various chemicals. Most metal products find widespread use in the automotive, construction, electrical, and machinery sectors of the economy. Compounds are similarly dispersed in distribution and use, but are mainly used in agricultural, chemical, paint, pharmaceutical, and rubber sectors of the economy.

Annual Review

Nearly one-third of the 1.37 million tons of zinc consumed annually by domestic industries is secondary zinc. In 1993, about 355,000 tons of secondary zinc, valued at about $361 million, was recovered in refined metal, alloys, dusts, and chemicals. Scrap containing about 46,000 tons of zinc and valued at $18 million was exported in 1993, whereas 38,000 tons of zinc in scrap, valued at $14 million, was imported.

Recycled zinc was derived 70% from new scrap and 30% from old scrap. New zinc scrap was generated mainly in galvanizing and diecasting plants, brass mills, and manufacturing facilities when basic zinc materials are consumed. In consisted mostly of drosses, skims, furnace dusts, and residues (from galvanizing and diecasting operations, brass mills, and chemical plants) and clippings from the processing (stamping, trimming, etc.) of galvanized steel sheet and strip, rolled zinc, and brass sheet. Old scrap consisted almost entirely of diecastings, (mainly from scrapped automobiles), brass products, and rolled zinc items, such as gutters, roofing, and engraving plates. Zinc recovery from the burning of tires for energy is small but growing, whereas recovery from both old and new galvanized steel scrap has increased dramatically. Old zinc and brass scrap were collected at hundreds of domestic scrap yards, at more than 200 U.S. automobile and appliance shredding operations, and at numerous municipal collection centers. In 1993, there were 4 primary and 10 secondary smelters that processed scrap, drosses, skims, and/or steelworking electric arc furnace (EAF) dust into slab zinc, zinc alloys, and zinc dust. Seven other plants processed skims, drosses, scrap, and residues into zinc sulfate and/or chloride chemicals. Secondary brass and bronze were recycled at more than 500 secondary smelters, foundries, and ingot makers. A plant in Illinois produced American-process zinc oxide from oxidic secondary materials. Most secondary zinc plants are in the Eastern and Midwestern United States; one plant in Pennsylvania is, by far, the single largest processor secondary zinc. Crude zinc concentrates extracted from EAF dust are produced at six plants. *(See tables 27-29.)*

Background

Technology.—Because of wide differences in the character and content of zinc-bearing scrap, zinc recycling processes vary widely. Zinc-containing metals generally are separated from other materials initially by physical means such as magnetic separation, sink-floating, and hand sorting. In the case of mixed nonferrous metal shredder scrap, zinc can be separated from higher-melting point metals such as aluminum and copper, by selective melting in a sweat furnace. Zinc in galvanized scrap is largely recovered in furnace dust when the scrap is charged into a steelmaking furnace; however one commercial process has been developed to strip zinc from galvanized scrap with a caustic leach prior to recycling the substrate steel to the steelmaking process.

Clean new scrap, mainly brass and rolled zinc clippings and reject diecastings, generally only require remelting before reuse. Drosses, fragmentized diecastings, and mixed high-grade scrap typically are remelted, followed by zinc distillation with recovery as metal, dust, or oxide. Sometimes, high-purity drosses are simply melted and reacted with various fluxes to release the metallic content; often the recovered metal can be used directly as a galvanizing brightener or master alloy. Medium and low-grade skims, oxidic dust, ash, and residues generally undergo an intermediate reduction-distillation-pyrometallurgical step to upgrade the zinc product before further treatment; or they are leached with acid, alkaline, or ammoniacal solutions to extract zinc, which is subsequently recovered as a compound by precipitation-crystallization or as a saleable chemical retained in solution. Almost all of the zinc in EAF dusts is first recovered in an upgraded, impure zinc oxide product; however, several commercial EAF-dust-treatment plants are able to bypass the intermediate step and recover zinc metal directly. The upgraded zinc oxide pyrometallurgical production is almost always shipped to a primary pyrometallurgical zinc smelter for refinement to metal. For the most part, the zinc metals, alloys, dust, and chemical recovered from secondary materials are comparable in quality to those derived from primary materials.

Recovery efficiency is very high from simple remelting, but declines as the number of processing steps increases and, generally, as the zinc content of the scrap declines. Zinc recovery from most secondary processes ranges between 40% and 85%; however, oxide materials, slags, and residues resulting from initial processes may in turn be recycled, resulting in further zinc recovery.

Secondary Refined Products.—Zinc materials made from zinc-base scrap are slab zinc, alloys, dusts, and compounds. Brass scrap, on the other hand, typically is remelted and, with alloy adjustment, recast as brass. Zinc chloride and sulfate compounds are produced largely by acid leaching of zinc skims, drosses, and chemical residues. Impure zinc oxide products and zinc bearing slags are sometimes used as trace element additives in fertilizers and animal feeds. Zinc in brass is the principal form of secondary recovery, although in the past few years, secondary slab zinc has risen substantially because it has been the principal zinc product of EAF dust recycling.

Markets and Prices.—Prices paid for scrap and secondary materials are generally negotiated, often on the basis of a daily or average London Metal Exchange price for zinc metal. Bids are required for U.S. Department of Defense scrap sales. Prices depend on factors such as geographic location, quantity available, quality, grade, the presence of other components or elements, and environmental difficulties in handling, transporting, or treating. In the case of EAF, the dust generator usually pays the dust processor a fee to recycle the material. Typically, there is a basic charge for dust with 20% zinc content; generators of dust with lower zinc content pay more, whereas generators of dust with higher zinc content pay less. Zinc and brass scrap prices are generally not available, although average daily, weekly, or monthly prices for a few specific common types are published in American Metal, Market, Metal Bulletin, and Metal Bulletin Monthly.

Outlook

Driven by public concern for the environment and legislation intended to protect the environment, domestic and world secondary zinc recovery is expected to increase as a percentage of zinc consumption in the next decade. However, the prospect for recovery equivalent to more than 35% to 40% of consumption is relatively poor because of the dissipative nature and diversity of zinc uses. Galvanizing has been the major growth area for zinc, and greater secondary zinc recovery can be expected from this source in the future. Increased processing of low-zinc EAF dust, from other steelmaking processes, and energy-generating tire burning appear to be other sources for near term gains in secondary zinc output. Increased zinc recovery from the recycling of carbon-zinc and alkaline batteries, and municipal incinerator dusts and residues are longer term possibilities. Secondary zinc recycling could dramatically increase after the year 2000 if a substantial number of electric cars, powered by zinc-air batteries, becomes a reality.

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[2] Prepared by P. Plunkert, physical scientist, Branch of

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[4] Prepared by D. Edelstein, physical scientist, Branch of Metals.

[5] Prepared by G. R. Smith, physical scientist, Branch of Metals.

[6] Prepared by J. F. Carlin, Jr., physical scientist, Branch of Metals.

[7] Prepared by S. M. Jasinski, physical scientist, Branch of Metals.

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TABLE 1
SALIENT U.S. RECYCLING STATISTICS FOR SELECTED METALS

Year	Recycled metal[1] by source of supply					
	Quantity (metric tons)			Value (thousand dollars)		
	New scrap[2]	Old scrap[3]	Total scrap[4]	New scrap	Old scrap	Total scrap[4]
			ALUMINUM[5]			
1989	1,043,000	1,011,000	2,054,000	2,020,000	1,958,000	3,978,000
1990	1,034,000	1,359,000	2,393,000	1,688,000	2,218,000	3,906,000
1991	969,000	1,317,000	2,286,000	1,270,000	1,727,000	2,997,000
1992	[r]1,144,000	[r]1,612,000	[r]2,756,000	[r]1,451,000	2,044,000	[r]3,495,000
1993	1,312,000	1,632,000	2,944,000	1,542,000	1,919,000	3,461,000
			COPPER[6]			
1989	[r]761,000	548,000	1,308,000	2,198,000	1,581,000	3,779,000
1990	[r]774,000	537,000	1,311,000	2,101,000	1,457,000	3,558,000
1991	[r]682,000	518,000	1,201,000	1,645,000	1,250,000	2,894,000
1992	[r]723,000	555,000	1,278,000	1,712,000	1,313,000	3,025,000
1993	731,000	555,000	1,286,000	1,475,000	1,120,000	2,595,000
			LEAD[7]			
1989	49,612	841,729	891,341	40,611	689,227	729,630
1990	48,104	874,093	922,197	46,185	839,227	885,412
1991	54,970	829,654	884,624	38,538	581,645	620,183
1992	[r]55,424	860,917	916,341	37,879	588,378	626,257
1993	60,298	843,262	903,560	33,127	463,281	496,408
			NICKEL[8]			
1989	—	—	[r]52,131	—	—	[r]693,768
1990	—	—	[r]57,367	—	—	[r]508,507
1991	—	—	[r]53,521	—	—	[r]436,497
1992	—	—	[r]55,871	—	—	[r]391,166
1993	—	—	54,702	—	—	289,561
			TIN[9]			
1989	2,795	11,545	14,340	[r]32,042	164,394	196,436
1990	4,035	13,200	17,275	34,337	112,329	146,666
1991	5,114	7,982	13,096	41,534	64,827	106,361
1992	[r]4,894	8,853	13,747	43,389	78,438	121,825
1993	4,453	7,219	11,672	34,350	55,687	90,037
			ZINC[10]			
1989	230,000	117,000	347,000	415,964	211,600	627,564
1990	232,000	109,000	341,000	381,000	179,273	560,273
1991	233,000	119,000	353,000	271,114	138,445	409,559
1992	234,000	132,000	366,000	301,000	170,000	471,000
1993	246,000	109,000	355,000	250,287	110,900	361,187

[r] Revised.

[1] Recycled metal is metal recovered from purchased scrap.

[2] New scrap is scrap that results from the manufacturing process, including metal and alloy production.

[3] Old scrap is scrap that results from consumer products.

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

[5] Quantity is the calculated metallic recovery from aluminum-based scrap, estimated for full industry coverage. Value is estimated based on average annual U.S. market price for primary aluminum metal.

[6] Recoverable copper values in scrap based on annual averages for refined copper.

[7] Transaction value estimated to be London Metal Exchange (LME) average cash value plus 6.5 cents/lb.

[8] Nickel scrap is nickel contained in ferrous and nonferrous scrap receipts. Value is estimated as average annual LME cash price of nickel cathode.

[9] Value estimated based upon Platt's Metals Week (PMW) Tin Composite price. Reevaluation of the tin canvass in 1991 resulted in a substantial lowering of estimated old scrap.

[10] Value based on average annual U.S. zinc metal price published in PMW; for 1989-90, the PMW average prices were based on U.S. or North American Producers' High Grade zinc delivered prices and for 1991-93, the LME spot prices for Special High Grade zinc plus premiums based on market conditions.

TABLE 2
SALIENT U.S. APPARENT SUPPLY AND RECYCLING STATISTICS FOR SELECTED METALS

Year	Quantity (metric tons)		Percent recycled	Value (thousand dollars)		Percent recycled
	Apparent supply[1]	Recycled metal[2]		Apparent supply[3]	Recycled metal	
			ALUMINUM[4]			
1989	6,000,000	2,054,000	34	11,620,000	3,978,000	34
1990	6,298,000	2,393,000	38	10,280,000	3,906,000	38
1991	6,012,000	2,286,000	38	7,881,000	2,997,000	38
1992[r]	6,869,000	2,756,000	40	8,710,000	3,495,000	40
1993	7,852,000	2,944,000	37	9,231,000	3,461,000	37
			COPPER[5]			
1989	[r]2,945,000	[r]1,308,000	44.4	[r]8,506,000	[r]3,779,000	44.4
1990	[r]2,924,000	[r]1,311,000	44.8	7,940,000	[r]3,558,000	44.8
1991	[r]2,731,000	[r]1,201,000	44.0	[r]6,582,000	[r]2,894,000	44.0
1992	[r]3,028,000	1,277,000	42.2	7,171,000	3,025,000	42.2
1993	3,256,000	1,286,000	39.5	6,573,000	2,595,000	39.5
			LEAD[6]			
1989[r]	1,384,725	891,341	64.4	1,133,502	729,630	64.4
1990[r]	1,345,381	922,197	68.5	1,291,716	885,412	68.5
1991[r]	1,283,474	884,624	68.9	899,804	620,183	68.9
1992[r]	1,325,408	916,341	69.1	905,827	626,257	69.1
1993	1,390,464	903,560	65.0	763,909	496,408	65.0
			NICKEL[7]			
1989[r]	157,103	52,131	33.18	2,090,753	693,768	33.18
1990[r]	170,042	57,367	33.74	1,507,269	508,507	33.74
1991[r]	156,663	53,521	34.16	1,277,683	436,497	34.16
1992	[r]159,373	[r]55,871	[r]35.06	1,115,807	391,166	[r]35.06
1993	159,313	54,702	34.34	843,310	289,561	34.34
			TIN[8]			
1989	47,285	14,340	30	[r]541,924	196,436	[r]30
1990	53,430	17,275	32	454,680	146,666	32
1991	39,606	13,096	33	[r]316,869	106,361	[r]33
1992	37,321	[r]13,747	37	330,994	[r]121,825	37
1993	42,906	11,672	27	330,977	90,037	27
			ZINC[9]			
1989	1,311,000	347,000	26.5	2,370,097	627,564	26.5
1990	1,240,000	341,000	27.5	2,039,056	560,273	27.5
1991	1,165,000	353,000	30.3	1,355,361	409,559	30.3
1992	1,276,000	366,000	28.7	1,642,000	471,000	28.7
1993	1,367,000	355,000	28.2	1,400,000	361,187	28.2

[r] Revised.

[1] Apparent supply is production plus net imports plus stock changes. Production is primary production plus recycled metal (see table 1, footnote 1). Net imports are imports minus exports. Apparent supply is calculated on a contained weight basis.

[2] Recycled metal is metal recovered from purchased scrap.

[3] Same as apparent supply defined above but calculated on a monetary value basis.

[4] Monetary values estimated based on the U.S. market price for primary aluminum ingot. Recycle calculated as metal recovered from reported purchased new and old scrap estimated for full industry coverage.

[5] Copper recovered for consumption valued on average annual refined prices.

[6] Lead processors are segregated by primary and secondary producers. This segregation permits inclusion of stock changes in recycle lead supply. Transaction value for U.S. primary production and net imports estimated to be London Metal Exchange (LME) average cash plus 6.5 cents/lb. Stock adjustments value based on actual proportion of stock change to secondary production.

[7] Value of apparent supply and recycle estimated as average annual LME cash price of nickel cathode.

[8] Value estimated based upon Platt's Metals Week (PMW) Composite price.

[9] Value based on average annual U.S. zinc metal price published in PMW; for 1989-90, the PMW average prices were based on U.S. or North American Producers' High Grade zinc delivered prices and for 1991-93, the LME spot prices for Special High Grade zinc plus premiums based on market conditions.

TABLE 3
U.S. APPARENT ALUMINUM SUPPLY AND CONSUMPTION

(Thousand metric tons)

	1989	1990	1991	1992	1993
Primary production	4,030	4,048	4,121	4,042	3,695
Change in stocks:[1]					
Aluminum industry	+61	+2	+45	-100	-171
LME stocks in U.S. warehouses	—	—	-168	-46	+46
National Defense Stockpile	—	—	—	-55	—
Imports	1,470	1,514	1,490	1,725	2,545
Secondary recovery:[2]					
New scrap	1,043	1,034	969	[r]1,144	1,312
Old scrap	1,011	1,359	1,317	1,612	1,632
Total supply	7,615	7,957	7,774	[r]8,322	9,059
Less total exports	1,615	1,659	1,762	1,453	1,207
Apparent aluminum supply available for domestic manufacturing	6,000	6,298	6,012	[r]6,869	7,852
Apparent consumption[3]	4,957	5,264	5,043	5,725	6,540

[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).

TABLE 4
U.S. CONSUMPTION OF AND RECOVERY FROM PURCHASED NEW AND OLD ALUMINUM SCRAP,[1] BY CLASS

(Metric tons)

Class	Consumption	Calculated recovery	
		Aluminum	Metallic
1992			
Secondary smelters	945,627	760,064	815,548
Integrated aluminum companies	1,365,751	1,139,971	1,215,115
Independent mill fabricators	553,318	473,818	505,679
Foundries	85,529	70,298	75,555
Other consumers[r]	9,899	9,899	9,899
Total[r]	2,960,124	[2]2,454,049	2,621,796
Estimated full industry coverage[3]	[r]3,112,000	2,580,000	[r]2,756,000
1993			
Secondary smelters	1,134,840	881,726	946,036
Integrated aluminum companies	1,344,522	1,120,756	1,194,230
Independent mill fabricators	607,569	523,833	559,077
Foundries	89,925	74,256	79,881
Other consumers	9,558	9,558	9,558
Total	3,186,414	2,610,129	2,788,782
Estimated full industry coverage[3]	3,365,000	2,754,000	2,944,000

[r] Revised.

[1] Excludes recovery from other than aluminum-base scrap.

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

[3] Rounded.

TABLE 5

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1993

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
Secondary smelters:				
New scrap:				
Solids	[r]4,779	96,359	96,886	4,252
Borings and turnings	[r]4,321	114,277	114,632	3,966
Dross and skimmings	[r]2,580	131,131	128,507	5,204
Other[3]	[r]1,035	127,935	122,852	6,118
Total	[r]12,715	469,702	462,877	19,540
Old scrap:				
Castings, sheet, clippings	[r]13,358	516,789	515,192	14,955
Aluminum-copper radiators	[r]946	8,263	8,110	1,099
Aluminum cans[4]	[r]1,149	101,079	100,812	1,416
Other[5]	[r]453	46,039	46,238	254
Total	[r]15,906	672,170	670,352	17,724
Sweated pig	229	1,680	1,611	298
Total secondary smelters	[r]28,850	1,143,552	1,134,840	37,562
Integrated aluminum companies, foundries, independent mill fabricators, other consumers:				
New scrap:				
Solids	[r]11,182	669,430	667,650	12,962
Borings and turnings	385	32,960	33,054	291
Dross and skimmings	39	11,486	11,511	14
Other[3]	[r]7,094	232,592	228,402	11,284
Total	[r]18,700	946,468	940,617	24,551
Old scrap:				
Castings, sheet, clippings	[r]8,337	314,535	315,384	7,488
Aluminum-copper radiators	[r]358	2,089	2,284	163
Aluminum cans	[r]23,714	757,104	770,148	10,670
Other[5]	[r]226	12,372	11,860	738
Total	[r]32,635	1,086,100	1,099,676	19,059
Sweated pig	268	11,348	11,281	335
Total integrated aluminum companies, etc.	[r]51,603	2,043,916	2,051,574	43,945
All scrap consumed:				
New scrap:				
Solids	[r]15,961	765,789	764,536	17,214
Borings and turnings	[r]4,706	147,237	147,686	4,257
Dross and skimmings	[r]2,619	142,617	140,018	5,218
Other[3]	[r]8,129	360,527	351,254	17,402
Total new scrap	[r]31,415	1,416,170	1,403,494	44,091
Old scrap:				
Castings, sheet, clippings	[r]21,695	831,324	830,576	22,443
Aluminum-copper radiators	[r]1,304	10,352	10,394	1,262
Aluminum cans	[r]24,863	858,183	870,960	12,086
Other[5]	[r]679	58,411	58,098	992
Total old scrap	[r]48,541	1,758,270	1,770,028	36,783

See footnotes at end of table.

TABLE 5—Continued

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF PURCHASED NEW AND OLD ALUMINUM SCRAP[1] AND SWEATED PIG IN 1993

(Metric tons)

Class of consumer and type of scrap	Stocks, Jan. 1	Net receipts[2]	Consumption	Stocks, Dec. 31
All scrap consumed—Continued:				
Sweated pig	497	13,028	12,892	633
Total of all scrap consumed	[r]80,453	3,187,468	3,186,414	81,507

[r] Revised.

[1] Includes imported scrap. According to reporting companies, 8.41% of total receipts of aluminum-base scrap, or 265,305 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 6

PRODUCTION AND SHIPMENTS OF SECONDARY ALUMINUM ALLOYS BY INDEPENDENT SMELTERS IN THE UNITED STATES

(Metric tons)

	1992		1993	
	Production	Net shipments[1]	Production	Net shipments[1]
Die-cast alloys:				
13% Si, 360, etc. (0.6% Cu, maximum)	41,921	[r]44,703	45,539	44,724
380 and variations	[r]465,503	[r]465,009	517,948	516,863
Sand and permanent mold:				
95/5 Al-Si, 356, etc. (0.6% Cu, maximum)	78,089	67,146	85,064	84,406
No. 12 and variations	W	W	W	W
No. 319 and variations	[r]52,852	[r]52,931	67,373	65,654
F-132 alloy and variations	52,652	51,483	24,025	25,844
Al-Mg alloys	645	644	639	641
Al-Zn alloys	3,086	2,881	3,218	3,468
Al-Si alloys (0.6% to 2.0% Cu)	10,680	10,705	10,840	11,018
Al-Cu alloys (1.5% Si, maximum)	1,664	1,588	1,738	1,726
Al-Si-Cu-Ni alloys	1,352	1,326	1,360	1,395
Other	[r]2,707	[r]2,771	3,792	3,812
Wrought alloys: Extrusion billets	[r]71,486	[r]65,861	80,914	84,880
Miscellaneous:				
Steel deoxidation	3,345	3,413	—	—
Pure (97.0% Al)	59	69	—	—
Aluminum-base hardeners	93	97	93	93
Other[2]	34,262	33,433	34,244	35,233
Total	[r]820,396	[r][3]804,063	876,787	879,757
Less consumption of materials other than scrap:				
Primary aluminum	65,351	—	79,643	—
Primary silicon	35,573	—	39,192	—
Other	3,620	—	4,601	—
Net metallic recovery from aluminum scrap and sweated pig consumed in production of secondary aluminum ingot[4]	[r]715,852	XX	753,351	XX

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

[4] No allowance made for melt-loss of primary aluminum and alloying ingredients.

TABLE 7
U.S. EXPORTS OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Belgium	—	—	—	—	567	$337	567	$337
Brazil	9	$43	—	—	956	1,200	966	1,243
Canada	—	—	112	$138	45,503	50,729	45,615	50,867
China	63	90	103	335	7,885	6,240	8,051	6,665
Finland	—	—	—	—	3,543	3,211	3,543	3,211
France	—	—	—	—	1,975	2,111	1,975	2,111
Germany	241	307	11	28	159	322	411	657
Hong Kong	1,136	913	—	—	7,710	5,558	8,845	6,471
Italy	—	—	—	—	533	533	533	533
Japan	37,088	41,826	58	55	102,689	103,037	139,835	144,919
Korea, Republic of	1,261	1,847	995	1,173	14,882	15,695	17,138	18,714
Mexico	9,514	12,020	79	81	16,417	16,307	26,010	28,409
Netherlands	—	—	2	4	522	594	524	598
Philippines	—	—	—	—	126	144	126	144
Taiwan	2,532	2,156	105	152	28,218	21,356	30,855	23,663
Thailand	1,019	763	44	143	929	683	1,992	1,590
United Kingdom	349	529	728	722	957	934	2,035	2,185
Other	1,204	974	1,144	1,203	3,872	5,104	6,220	7,281
Total[1]	54,416	61,468	3,381	4,034	237,443	234,095	295,239	299,598
1993:								
Belgium	—	—	—	—	26	24	26	24
Brazil	—	—	—	—	707	779	707	779
Canada	—	—	154	134	46,342	47,159	46,496	47,292
China	17	17	14	27	7,542	5,436	7,573	5,479
Finland	—	—	—	—	5,920	4,400	5,920	4,400
France	—	—	—	—	582	785	582	785
Germany	—	—	—	—	85	217	85	217
Hong Kong	455	331	—	—	7,510	5,284	7,965	5,615
Italy	—	—	3	3	52	53	55	56
Japan	26,989	32,495	134	111	65,158	62,226	92,280	94,831
Korea, Republic of	280	291	38	40	7,844	9,478	8,162	9,809
Mexico	4,820	6,582	—	—	13,486	13,400	18,306	19,982
Netherlands	78	118	—	—	195	187	272	305
Philippines	9	28	—	—	126	101	135	129
Taiwan	1,379	1,445	183	555	14,736	9,628	16,298	11,628
Thailand	—	—	—	—	1,028	1,125	1,028	1,125
United Kingdom	—	—	16	15	213	409	229	424
Other	1,489	1,664	455	606	3,547	6,239	5,491	8,509
Total[1]	35,514	42,970	996	1,491	175,098	166,929	211,609	211,390

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

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1992:								
Australia	—	—	—	—	19	$12	19	$12
Bahamas, The	—	—	—	—	205	84	205	84
Bermuda	—	—	10	$4	—	—	10	4
Brazil	—	—	—	—	330	368	330	368
Canada	1,038	$1,277	15,720	14,676	152,034	167,724	168,792	183,677
China	1,053	1,013	—	—	—	—	1,053	1,013
Colombia	—	—	89	78	268	274	357	352
Germany	2,987	3,486	—	—	1,829	2,067	4,816	5,554
Guatemala	—	—	46	23	602	339	648	362
Honduras	—	—	—	—	100	49	100	49
Jamaica	—	—	—	—	697	394	697	394
Japan	—	—	—	—	85	372	85	372
Mexico	303	99	21,375	19,059	21,954	18,839	43,632	37,997
Netherlands	1,516	1,820	17	14	709	987	2,243	2,821
Panama	2	1	1,307	1,132	986	954	2,295	2,087
South Africa, Republic of	—	—	—	—	20	7	20	7
Spain	—	—	—	—	63	174	63	174
Taiwan	288	261	—	—	—	—	288	261
U.S.S.R.[2]	932	619	—	—	4,987	4,189	5,919	4,808
United Kingdom	886	1,098	—	—	753	639	1,639	1,737
Venezuela	2,584	2,769	4,780	3,339	13,357	10,356	20,721	16,464
Other[r]	540	708	745	633	10,090	7,433	11,374	8,775
Total[1]	12,128	13,152	44,089	38,958	209,089	215,262	265,306	267,372
1993:								
Australia	—	—	53	27	247	169	300	196
Bahamas, The	—	—	—	—	354	102	354	102
Bermuda	—	—	—	—	—	—	—	—
Brazil	—	—	—	—	4	14	4	14
Canada	225	223	21,872	17,421	156,612	148,323	178,710	165,967
China	—	—	—	—	199	183	199	183
Colombia	—	—	711	571	329	320	1,041	891
Germany	8,060	8,672	—	—	1,125	1,100	9,185	9,772
Guatemala	—	—	56	46	847	298	902	344
Honduras	—	—	—	—	136	97	136	97
Jamaica	—	—	—	—	482	255	482	255
Japan	—	—	84	53	165	446	250	499
Mexico	159	43	19,201	15,842	27,187	22,124	46,547	38,009
Netherlands	3,646	4,883	20	18	1,262	1,214	4,928	6,116
Panama	14	10	1,331	1,129	769	662	2,115	1,801
Russia	1,176	1,181	—	—	17,454	16,999	18,629	18,180
South Africa, Republic of	—	—	—	—	21	4	21	4
Spain	359	368	—	—	31	40	390	408
Taiwan	—	—	—	—	—	—	—	—
Ukraine	110	698	—	—	—	—	110	698

See footnotes at end of table.

TABLE 8—Continued

U.S. IMPORTS FOR CONSUMPTION OF ALUMINUM SCRAP, BY COUNTRY

Country	Remelt scrap ingot		Used beverage container scrap		Other aluminum waste and scrap		Total[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
United Kingdom	2,101	2,364	60	53	2,564	2,199	4,725	4,615
Venezuela	3,196	3,100	7,077	4,015	15,467	9,785	25,739	16,899
Other	618	682	1,384	1,035	11,775	9,315	13,777	11,032
Total[1]	19,664	22,224	51,849	40,210	237,030	213,649	308,542	276,082

[r] Revised.

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

[2] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

Source: Bureau of the Census.

TABLE 9

COPPER RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1989	1990	1991	1992	1993
KIND OF SCRAP					
New scrap:					
Copper-base	737,088	750,707	660,550	[r]697,471	702,360
Aluminum-base	23,761	23,092	21,692	25,242	28,403
Nickel-base	45	42	47	72	117
Zinc-base	—	—	—	—	—
Total	760,894	773,841	682,289	[r]722,785	730,880
Old scrap:					
Copper-base	530,499	502,326	495,397	[r]523,172	521,434
Aluminum-base	16,957	34,303	22,921	31,372	33,323
Nickel-base	78	77	61	46	41
Zinc-base	27	26	22	18	17
Total	547,561	536,732	518,401	[r]554,608	554,815
Grand total	1,308,455	1,310,573	1,200,690	[r]1,277,393	1,285,695
FORM OF RECOVERY					
As unalloyed copper:					
At electrolytic plants	376,595	328,196	318,182	331,057	337,221
At other plants	112,687	121,705	107,905	[r]111,446	132,380
Total	489,282	449,901	426,087	[r]442,503	469,601
In brass and bronze	774,770	800,771	727,618	[r]776,981	753,968
In alloy iron and steel	630	578	567	1,495	654
In aluminum alloys	41,719	56,489	44,277	[r]55,923	61,049
In other alloys	106	114	120	199	206
In chemical compounds	1,948	2,720	2,021	292	217
Total[1]	819,173	860,672	774,603	[r]834,890	816,094
Grand total	1,308,455	1,310,573	1,200,690	[r]1,277,393	1,285,695

[r] Revised.

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

TABLE 10

COPPER RECOVERED AS REFINED COPPER AND IN ALLOYS AND OTHER FORMS FROM COPPER-BASE SCRAP PROCESSED IN THE UNITED STATES, BY TYPE OF OPERATION

(Metric tons)

Type of operation	From new scrap		From old scrap		Total[1]	
	1992	1993	1992	1993	1992	1993
Ingot makers	32,350	34,708	100,884	92,102	133,234	126,810
Refineries[2]	107,161	112,707	[r]326,023	347,081	[r]433,184	459,788
Brass and wire-rod mills	534,383	534,786	66,421	50,701	600,805	585,488
Foundries and manufacturers	[r]23,284	19,941	[r]29,856	31,602	[r]53,140	51,543
Chemical plants	292	217	—	—	292	217
Total[1]	[r]697,471	702,360	[r]523,185	521,486	[r]1,220,656	1,223,846

[r] Revised.

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

[2] Electrolytically refined and fire-refined scrap based on source of material at smelter level.

TABLE 11

PRODUCTION OF SECONDARY COPPER AND COPPER-ALLOY PRODUCTS IN THE UNITED STATES, BY ITEM PRODUCED FROM SCRAP

(Metric tons)

Item produced from scrap	1992	1993
UNALLOYED COPPER PRODUCTS		
Electrolytically refined copper	331,057	337,221
Fire-refined copper	[r]102,127	122,567
Copper powder	8,826	9,182
Copper castings	[r]493	631
Total[1]	[r]442,503	469,601
ALLOYED COPPER PRODUCTS		
Brass and bronze ingots:		
Tin bronzes	14,006	15,205
Leaded red brass and semired brass	109,565	91,439
High-leaded tin bronze	9,223	10,084
Yellow brass	6,768	7,417
Manganese bronze	5,992	6,763
Aluminum bronze	7,504	7,932
Nickel silver	2,691	2,233
Silicon bronze and brass	6,135	7,075
Copper-base hardeners and master alloys	8,127	7,858
Miscellaneous	3,421	5,444
Total[1]	173,433	161,450
Brass mill and wire rod mill products	738,008	732,713
Brass and bronze castings	[r]44,691	43,864
Brass powder	283	263
Copper in chemical products	292	217
Grand total[1]	[r]1,399,211	1,408,108

[r] Revised.

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

TABLE 12
COMPOSITION OF SECONDARY COPPER-ALLOY PRODUCTION IN THE UNITED STATES

(Metric tons)

	Copper	Tin	Lead	Zinc	Nickel	Aluminum	Total
Brass and bronze ingot production:[1]							
1992	[r]140,897	[r]5,331	[r]9,010	[r]17,873	290	31	[2]173,433
1993	130,752	4,815	8,190	17,332	319	42	161,450
Secondary metal content of brass mill products:							
1992	601,355	498	4,920	129,517	(3)	(3)	738,008
1993	590,482	612	6,054	133,827	(3)	(3)	732,713
Secondary metal content of brass and bronze castings:							
1992	[r]39,435	1,004	1,441	[r]2,368	[r]115	[r]328	[r]44,691
1993	38,934	837	1,419	2,458	78	138	43,864

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

[1] About 96% from scrap and 4% from other than scrap in 1992 and in 1993.

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

[3] Withheld to avoid disclosing company proprietary data; included in "Total."

TABLE 13

CONSUMPTION OF COPPER-BASE SCRAP IN 1993

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December	Total[1]
No. 1 wire and heavy:													
Smelters, refiners and ingot makers	11,074	15,931	12,168	12,345	13,165	15,079	12,019	15,748	15,321	22,264	17,505	14,966	177,585
Brass and wire-rod mills	24,746	20,327	23,004	24,436	22,311	24,082	21,736	21,921	22,814	25,343	22,309	21,334	274,362
Foundries and misc. manufacturers	2,386	2,386	2,386	2,386	2,386	2,386	2,386	2,386	2,386	2,386	2,386	2,386	28,633
No. 2 mixed heavy and light:													
Smelters, refiners and ingot makers	27,124	24,745	29,588	26,919	29,618	34,090	28,521	30,257	25,408	30,533	24,821	26,346	337,970
Brass and wire-rod mills	4,183	4,109	3,430	3,522	3,839	2,992	3,231	3,071	3,893	3,424	3,254	3,142	42,090
Foundries and misc. manufacturers	466	466	466	466	466	466	466	466	466	466	466	466	5,592
Total unalloyed scrap:													
Smelters, refiners and ingot makers	38,198	40,675	41,755	39,264	42,783	49,169	40,540	46,005	40,729	52,798	42,327	41,313	515,556
Brass and wire-rod mills	28,930	24,436	26,434	27,958	26,150	27,074	24,967	24,992	26,707	28,767	25,563	24,476	316,453
Foundries and misc. manufacturers	2,852	2,852	2,852	2,852	2,852	2,852	2,852	2,852	2,852	2,852	2,852	2,852	34,225
Red brass:[2]													
Smelters, refiners and ingot makers	4,004	4,822	3,738	3,836	3,317	3,874	2,587	3,534	3,911	3,770	3,354	3,423	44,169
Brass mills	546	529	495	440	448	481	450	502	422	434	495	366	5,607
Foundries and misc. manufacturers	970	970	970	970	970	970	970	970	970	970	970	970	11,639
Leaded yellow brass:													
Smelters, refiners and ingot makers	2,040	2,012	2,321	2,065	2,225	2,080	1,655	2,052	2,203	1,948	1,807	1,637	24,044
Brass mills	25,791	24,943	29,307	25,823	25,126	24,635	22,116	24,726	25,364	29,675	25,351	26,090	308,948
Foundries and misc. manufacturers	163	163	163	163	163	163	163	163	163	163	163	163	1,955
Yellow and low brass:													
All plants	6,735	7,101	7,823	7,513	6,872	5,963	4,797	5,146	5,961	5,698	5,514	5,434	74,558
Cartridge cases and brass:													
All plants	4,534	5,499	4,295	4,489	4,388	4,773	4,051	4,657	4,349	5,190	3,981	4,139	54,345

See footnotes at end of table.

TABLE 13—Continued
CONSUMPTION OF COPPER-BASE SCRAP IN 1993

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December	Total[1]
Auto radiators:													
Smelters, refiners and ingot makers	6,444	6,178	5,854	5,261	5,166	5,212	4,526	5,348	5,612	5,659	5,246	5,225	65,731
Foundries and misc. manufacturers	508	508	508	508	508	508	508	508	508	508	508	508	6,097
Bronzes:													
Smelters, refiners and ingot makers	1,162	1,381	1,250	1,044	919	1,201	953	1,219	1,026	1,087	1,048	816	13,106
Brass mills and misc. manufacturers	945	1,045	1,134	1,064	766	930	836	847	846	669	726	710	10,518
Nickel-copper alloys:													
All plants	1,198	1,213	1,401	1,395	1,028	1,196	904	1,141	1,056	1,282	1,498	1,497	14,811
Low grade and residues:													
Smelters, refiners and miscellaneous manufacturers	13,074	15,919	12,525	15,366	13,928	11,780	14,821	15,257	11,529	13,803	11,743	11,562	161,306
Other alloy scrap:[3]													
Smelters, refiners and ingot makers	3,154	2,503	2,991	2,164	2,393	1,844	2,269	2,377	1,804	2,545	1,817	2,063	27,922
Brass mills and misc. manufacturers	541	405	473	554	460	419	495	502	500	604	412	448	5,813
Total alloyed scrap:[1]													
Smelters, refiners and ingot makers	33,242	36,131	32,147	33,198	31,277	29,335	30,066	33,041	29,390	32,132	28,272	27,965	376,197
Brass mills	36,356	36,851	40,891	37,249	35,191	34,483	29,827	33,701	34,623	39,665	34,152	34,876	427,867
Foundries and misc. manufacturers	2,209	2,209	2,209	2,209	2,209	2,209	2,209	2,209	2,209	2,209	2,209	2,209	26,506
Total scrap:[1]													
Smelters, refiners and ingot makers	71,440	76,807	73,903	72,463	74,061	78,503	70,605	79,047	70,119	84,930	70,598	69,278	891,754
Brass and wire-rod mills	65,285	61,286	67,325	65,207	61,342	61,557	54,793	58,692	61,330	68,432	59,715	59,352	744,316
Foundries and misc. manufacturers	5,061	5,061	5,061	5,061	5,061	5,061	5,061	5,061	5,061	5,061	5,061	5,061	60,732

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

[2] Includes composition turnings, silicon bronze, railroad car boxes, cocks and faucets, gilding metal, and commercial bronze.

[3] Includes refinery brass, beryllium copper, and aluminum bronze.

TABLE 14

CONSUMPTION OF PURCHASED COPPER-BASE SCRAP[1] IN 1993

(Metric tons, gross weight)

Period	Smelters and refineries		Ingot makers		Brass and wire-rod mills		Foundries, etc.		Total scrap used
	New scrap	Old scrap	New scrap	Old scrap	New scrap	Old scrap	New scrap[e]	Old scrap[e]	
January	15,051	39,875	3,771	12,743	59,387	5,898	2,100	3,000	141,825
February	15,500	43,563	4,060	13,684	58,271	3,015	2,100	3,000	143,193
March	14,998	42,391	3,909	12,605	63,616	3,709	2,100	3,000	146,328
April	14,065	42,822	3,715	11,861	62,069	3,138	2,100	3,000	142,770
May	15,331	43,588	3,506	11,636	59,164	2,178	2,100	3,000	140,503
June	17,097	45,520	3,695	12,191	58,087	3,470	2,100	3,000	145,160
July	12,762	45,453	3,483	8,907	50,204	4,589	2,100	3,000	130,498
August	15,615	48,399	3,961	11,072	55,889	2,803	2,100	3,000	142,839
September	13,707	41,218	3,896	11,298	58,041	3,289	2,100	3,000	136,549
October	18,520	50,986	4,094	11,330	64,764	3,668	2,100	3,000	158,462
November	13,907	42,522	4,461	9,708	57,544	2,171	2,100	3,000	135,413
December	12,832	43,077	3,989	9,380	57,292	2,060	2,100	3,000	133,730
Total	179,385	529,414	46,540	136,415	704,328	39,988	25,200	36,000	1,697,270

[e] Estimated.

[1] Consumption at brass and wire-rod mills assumed equal to receipts.

TABLE 15
CLOSING STOCKS OF COPPER-BASE SCRAP IN 1993

(Metric tons, gross weight)

Scrap type and processor	January	February	March	April	May	June	July	August	September	October	November	December
Smelters, refiners and ingot makers:												
Unalloyed scrap:												
No. 1 wire and heavy	9,351	8,556	9,797	11,203	10,356	10,502	10,849	9,732	10,795	5,598	6,884	7,210
No. 2 mixed heavy and light	10,924	9,808	9,158	11,533	9,815	9,236	12,042	15,809	16,927	14,031	13,947	12,132
Total unalloyed scrap	20,275	18,364	18,955	22,736	20,171	19,738	22,891	25,541	27,722	19,629	20,831	19,342
Alloyed scrap:												
Red brass[1]	2,694	2,220	2,323	2,142	2,340	2,396	2,922	3,034	2,785	2,647	2,683	2,482
Leaded yellow brass	1,017	1,223	956	1,096	1,063	1,284	1,758	1,528	1,150	1,231	1,373	1,457
Yellow and low brass[2]	1,253	1,398	1,260	1,312	1,324	1,332	1,419	1,325	1,174	1,171	1,211	1,248
Auto radiators	2,048	1,827	1,591	1,604	1,669	1,872	2,309	2,286	1,981	1,840	1,752	2,013
Bronzes	1,030	1,129	1,091	941	819	875	901	787	812	791	700	632
Nickel-copper alloys	334	403	365	465	504	486	452	380	420	406	337	327
Low grade and residues	9,072	9,136	9,316	10,858	10,177	9,297	9,424	8,554	9,181	8,494	8,673	9,448
Other alloy scrap[3]	1,800	2,055	1,575	2,031	1,880	2,105	1,742	1,426	1,698	1,335	1,313	1,529
Total alloy scrap	19,248	19,391	18,477	20,449	19,776	19,647	20,927	19,320	19,201	17,915	18,042	19,136
Total scrap	39,523	37,755	37,432	43,185	39,947	39,385	43,818	44,861	46,923	37,544	38,873	38,478
Brass and wire-rod mills:												
Unalloyed scrap	14,172	11,795	12,387	11,748	10,744	11,137	12,549	11,897	11,906	10,414	10,417	12,659
Alloyed scrap	29,343	29,929	28,484	22,610	22,107	22,908	21,744	22,858	24,326	26,605	23,252	24,561
Total scrap	43,515	41,724	40,871	34,358	32,851	34,045	34,293	34,755	36,232	37,019	33,669	37,220
Foundries and other manufacturers:[4]												
Unalloyed scrap	2,836	2,836	2,836	2,836	2,836	2,836	2,836	2,836	2,836	2,836	2,836	2,836
Alloyed scrap	2,801	2,801	2,801	2,801	2,801	2,801	2,801	2,801	2,801	2,801	2,801	2,801
Total scrap	5,637	5,637	5,637	5,637	5,637	5,637	5,637	5,637	5,637	5,637	5,637	5,637
All plants:												
Unalloyed scrap	37,283	32,995	34,178	37,320	33,751	33,711	38,276	40,274	42,464	32,879	34,084	34,837
Alloyed scrap	51,392	52,121	49,762	45,860	44,684	45,356	45,472	44,979	46,328	47,321	44,095	46,498
Total scrap	88,675	85,116	83,940	83,180	78,435	79,067	83,748	85,253	88,792	80,200	78,179	81,335

[1] Includes composition turnings, silicon bronze, zincy bronze, railroad car boxes, cocks and faucets, gilding metal and commercial bronze.

[2] Includes cartridge cases and brass.

[3] Includes refinery brass, beryllium copper, phosphor copper and aluminum bronze.

[4] Stocks for January-November estimated based on stocks at end of year.

TABLE 16

FOUNDRIES AND MISCELLANEOUS MANUFACTURERS CONSUMPTION OF BRASS INGOT AND REFINED COPPER AND COPPER SCRAP IN THE UNITED STATES, BY GEOGRAPHIC DIVISION AND STATE

(Metric tons)

Geographic division and State	Tin bronzes	Leaded red brass and semi-red brass	Yellow, leaded and low brass[3]	Manganese bronze	Nickel silver[1]	Aluminum bronze	Hardeners and master alloys[4]	Total brass ingot[2]	Refined copper consumed	Copper scrap consumed
1989	34,367	85,752	7,811	6,594	1,654	5,593	3,661	145,434	41,471	64,068
1990	38,150	78,302	7,433	5,672	1,849	5,062	3,269	139,737	46,149	72,811
1991	37,208	61,770	7,416	4,493	1,179	4,856	2,725	119,646	37,984	56,652
1992	[r]29,154	[r]66,773	7,522	[r]4,046	[r]1,225	3,816	[r]2,767	[r]115,303	[r]41,439	[r]65,698
1993:										
Atlantic:										
Middle: New Jersey, New York, Pennsylvania	7,550	6,840	491	605	50	278	31	15,845	4,596	10,594
South: Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia	7,051	2,843	210	274	119	282	9	10,787	12,932	3,980
Central:										
East North: Illinois, Indiana, Michigan, Ohio, Wisconsin	11,341	28,521	3,251	2,098	400	669	2,458	48,737	8,941	32,156
South: Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas	2,941	11,827	214	116	1	303	213	15,616	7,412	3,513
West North: Iowa, Kansas, Minnesota, Missouri, Nebraska	2,276	5,524	1,725	218	12	847	65	10,667	2,496	3,760
Mountain and Pacific:										
Arizona, California, Colorado, Idaho, Montana, Oregon, Utah, Washington, Wyoming	1,275	6,623	1,067	627	51	1,388	204	11,235	469	6,365
New England:										
Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island	386	802	576	189	253	392	32	2,629	935	137
Total[2]	32,820	62,981	7,533	4,126	886	4,158	3,012	115,516	37,781	60,505

[r] Revised.

[1] Includes copper nickel and nickel bronze and brass.

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

[3] Includes silicon bronze and brass.

[4] Includes special alloys.

TABLE 17
MONTHLY AVERAGE PRICES FOR COPPER SCRAP AND ALLOY-INGOT, BY TYPE

(Cents per pound)

Year and month	Brass mills No. 1 scrap	Refiners		Dealers' buying (New York)		Alloy-ingot (New York)	
		No. 1 scrap	No. 2 scrap	No. 2 scrap	Red brass turnings and borings	No. 115 brass (85-5-5-5)	Yellow brass (405)
1992:							
January	94.08	90.87	82.43	76.23	60.55	122.00	118.75
February	98.11	94.33	85.58	81.58	58.00	122.00	118.75
March	99.63	96.41	87.06	83.05	58.91	122.00	118.75
April	98.49	95.28	86.35	82.35	59.00	122.00	118.75
May	98.76	95.29	87.20	83.20	59.00	122.00	118.75
June	101.98	98.00	89.97	85.88	59.00	122.00	118.75
July	108.85	104.09	96.61	92.60	59.00	123.70	121.48
August	108.18	103.49	96.44	92.56	59.00	124.50	122.75
September	102.89	98.42	91.43	87.43	57.02	124.50	122.75
October	96.33	91.49	84.65	80.83	52.55	122.23	119.11
November	91.74	87.49	80.55	76.39	53.37	122.00	118.75
December	92.95	88.43	82.07	78.07	50.14	122.00	118.75
Average	99.33	95.30	87.53	83.35	57.13	122.58	119.67
1993:							
January	94.08	NA	82.33	76.23	60.55	122.00	118.50
February	92.92	NA	85.22	81.63	49.00	122.00	118.50
March	91.84	NA	82.11	78.11	49.00	122.00	118.50
April	84.02	NA	72.97	68.97	47.05	120.97	117.57
May	76.35	NA	65.65	61.65	44.40	119.50	116.25
June	78.86	NA	66.63	62.62	44.00	119.50	116.25
July	83.01	NA	68.67	61.71	44.24	119.50	116.25
August	82.58	NA	71.05	63.99	43.95	119.50	116.25
September	74.49	NA	63.68	56.76	42.10	119.50	116.25
October	71.35	NA	57.29	53.27	39.81	119.50	116.25
November	71.01	NA	57.11	50.00	39.00	119.50	116.25
December	74.84	NA	62.89	51.10	39.55	120.25	116.92
Average	81.28	NA	69.63	63.84	45.22	120.31	116.98

NA Not available.

Source: American Metal Market.

TABLE 18
U.S. EXPORTS OF COPPER SCRAP, BY COUNTRY

Country or Territory	Unalloyed copper scrap				Copper-alloy scrap			
	1992		1993		1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Belgium	99	$111	3,134	$1,403	3,066	$7,061	800	$2,503
Brazil	172	356	155	272	652	665	429	672
Canada	26,864	26,119	42,763	39,308	17,603	27,479	11,440	20,346
China	23,870	19,054	13,206	12,428	53,030	41,254	41,088	26,730
Germany	216	232	294	322	1,051	1,400	974	1,956
Hong Kong	8,464	7,664	9,996	7,686	7,278	8,158	4,229	4,050
India	97	124	690	695	14,420	16,303	39,423	30,126
Indonesia	31	19	77	57	490	609	693	611
Italy	138	216	231	278	1,029	1,416	124	147
Japan	25,469	39,259	25,279	44,028	11,834	16,650	17,868	28,856
Korea, Republic of	12,422	19,468	10,424	16,307	21,756	25,801	26,014	29,056
Mexico	300	318	430	459	2,985	4,903	724	925
Netherlands	47	32	377	657	443	766	330	373
Singapore	1,057	1,099	1,184	844	730	779	862	974
Sweden	—	—	—	—	1,572	3,265	645	1,229
Taiwan	1,784	1,468	1,082	759	4,647	5,938	4,399	2,188
Thailand	36	65	160	336	941	1,340	963	1,555
Trinidad and Tobago	—	—	—	—	249	273	—	—
United Arab Emirates	—	—	—	—	95	131	73	40
United Kingdom	35	25	102	110	703	907	761	492
Venezuela	4	11	—	—	407	205	—	—
Other	91	191	169	197	[r]457	[r]751	509	809
Total[1]	101,195	115,830	109,753	126,147	145,441	166,052	152,349	153,639

[r] Revised.

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

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF COPPER SCRAP, BY COUNTRY

Country or Territory	Unalloyed copper scrap		Copper-alloy scrap		
	Quantity (metric tons)	Value[1] (thousands)	Gross weight (metric tons)	Copper content[e] [2] (metric tons)	Value (thousands)
1992	52,398	$96,193	116,352	83,773	$187,951
1993:					
Barbados	102	144	26	18	53
Belgium	—	—	982	707	869
Canada	14,564	25,462	87,636	63,098	140,922
Chile	4,995	9,419	—	—	—
Colombia	36	38	320	231	425
Costa Rica	640	531	225	162	224
Dominican Republic	624	879	931	670	1,368
Finland	—	—	5,217	3,756	8,432
France	35	117	398	286	740
Germany	4,511	8,075	1,860	1,339	3,309
Guatemala	394	353	250	180	219
Honduras	348	262	381	275	309
Hong Kong	—	—	96	69	157
Jamaica	719	680	528	380	353
Malaysia	94	89	395	285	652
Mexico	12,988	19,159	25,155	18,112	29,274
Netherlands	268	652	885	637	1,520
Netherlands Antilles	12	16	552	398	595
Nicaragua	339	323	832	599	894
Panama	500	786	751	541	1,070
Peru	147	126	276	199	281
Philippines	—	—	117	84	124
Poland	—	—	201	145	336
Russia	—	—	945	680	1,553
Singapore	—	—	85	61	124
South Africa, Republic of	12	39	541	390	915
Spain	1,409	2,185	9,127	6,572	14,263
Sweden	—	—	915	659	2,530
Switzerland	—	—	159	114	357
Taiwan	(3)	2	802	577	697
Trinidad and Tobago	145	172	186	134	222
United Kingdom	1,071	2,454	5,806	4,181	10,063
Venezuela	1,372	1,486	6,234	4,488	8,276
Other	452	630	1,263	907	1,983
Total[4]	45,772	74,079	154,075	110,934	233,107

[e] Estimated.

[1] C.i.f. value at U.S. port.

[2] Under the Harmonized Tariff System that was implemented Jan. 1989, copper content is no longer available. Content is estimated to be 72% of gross weight.

[3] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 20

STOCKS AND CONSUMPTION OF NEW AND OLD LEAD SCRAP IN THE UNITED STATES, BY TYPE OF SCRAP

(Metric tons, gross weight)

Type of scrap	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31[1]
			New scrap	Old scrap	Total[1]	
1992						
Smelters, refiners, others:						
Soft lead[2]	506	20,373	—	20,522	20,522	357
Hard lead	365	W	—	9,048	9,048	W
Cable lead	W	11,028	—	W	W	789
Battery-lead	19,934	994,268	—	992,279	992,279	21,922
Mixed common babbitt	188	575	—	651	651	112
Solder and tinny lead	W	W	—	W	W	W
Type metals	129	8,351	—	8,268	8,268	211
Drosses and residues	1,695	68,813	67,169	573	67,742	2,766
Total	25,202	1,123,795	67,169	1,053,677	1,120,846	28,151
1993						
Smelters, refiners, others:						
Soft lead[2]	357	14,288	—	14,399	14,399	246
Hard lead	W	W	—	8,342	8,342	W
Cable lead	789	5,772	—	W	W	W
Battery-lead	21,922	952,646	—	953,884	953,884	20,684
Mixed common babbitt	112	660	—	711	711	61
Solder and tinny lead	W	W	—	W	W	W
Type metals	211	W	—	3,749	3,749	W
Drosses and residues	2,766	73,675	75,288	93	75,381	1,059
Total	28,151	1,066,085	75,288	994,180	1,069,468	24,768

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

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

[2] Includes remelt lead from cable sheathing plus other soft lead scrap processing.

TABLE 21

SECONDARY METAL RECOVERED[1] FROM LEAD AND TIN SCRAP IN THE UNITED STATES

(Metric tons)

	Lead	Tin	Antimony	Other	Total[2]
1992					
Refined pig lead[3]	452,920	—	—	—	452,920
Refined pig tin[4]	—	137	—	—	137
Lead and tin alloys:					
Antimonial lead	424,535	704	11,353	W	436,592
Lead-base babbitt	375	78	41	—	494
Solder	(5)	(5)	—	—	(5)
Type metal	860	47	121	4	1,031
Other alloys, including cable lead	21,905	2,783	86	W	24,774
Total[2]	447,674	3,612	11,600	W	462,885
Tin content of chemical products	—	W	—	—	W
Grand total[2]	900,594	3,749	11,600	W	915,942
1993					
Refined pig lead[3]	436,340	—	—	—	436,340
Refined pig tin[4]	—	75	—	—	75
Lead and tin alloys:					
Antimonial lead	444,954	796	12,083	W	457,833
Lead-base babbitt	330	50	38	—	419
Solder	(5)	(5)	(5)	W	(5)
Type metal	849	43	118	3	1,012
Other alloys, including cable lead	15,858	3,846	74	—	19,778
Total[2]	461,992	4,736	12,312	W	479,040
Tin content of chemical products	—	W	—	—	W
Grand total[2]	898,332	4,811	12,312	W	915,455

W Withheld to avoid disclosing company proprietary data.

[1] Most of the figures herein represent actual reported recovery of metal from scrap.

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

[3] Includes remelt lead.

[4] Includes remelt tin.

[5] Included with "Other alloys, including cable lead" to avoid disclosing company proprietary data.

TABLE 22

LEAD RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1992	1993
KIND OF SCRAP		
New scrap:		
Lead-base	48,274	52,295
Copper-base	^{r}7,147	^{e}8,000
Tin-base	3	3
Total	^{r}55,424	60,298
Old scrap:		
Battery-lead	^{r}784,255	798,176
All other lead-base	68,051	37,086
Copper-base	^{r}8,611	^{e}8,000
Tin-base	—	—
Total	^{r}860,917	843,262
Grand total	^{r}916,341	903,560
FORM OF RECOVERY		
As soft lead	452,920	425,572
In antimonial lead	424,535	444,954
In other lead alloys	^{r}23,125	17,031
In copper-base alloys	^{r}15,758	^{e}16,000
In tin-base alloys	3	3
Total	^{r}916,341	903,560
Value[1] thousands	^{r}\$709,084	\$632,263

^{e}Estimated. ^{r}Revised.

[1] Value based on average quoted price of common lead.

TABLE 23

U.S. EXPORTS AND IMPORTS OF LEAD, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
EXPORTS				
Scrap (gross weight):				
Antigua and Barbuda	39	$14	1	$20
Austria	26	6	2	31
Bahamas, The	23	68	119	54
Belgium	135	384	30	3
Brazil	2,392	417	4,679	643
Canada	48,771	8,386	38,683	6,838
China	820	500	1,549	372
Colombia	471	105	452	84
Costa Rica	—	—	30	24
Dominican Republic	26	60	(1)	4
France	168	69	14	3
Germany	269	117	105	35
Ghana	174	38	—	—
Hong Kong	109	37	656	323
India	1,379	292	970	237
Indonesia	126	20	—	—
Ireland	192	74	—	—
Israel	59	10	(1)	5
Japan	111	461	520	511
Korea, Republic of	1,457	949	2,682	3,000
Malaysia	68	36	134	59
Mexico	2,381	833	2,034	1,008
Netherlands	30	27	21	32
Philippines	1,337	74	107	42
Spain	314	42	26	15
Taiwan	572	584	522	149
Thailand	104	571	189	23
United Arab Emirates	—	—	39	4
United Kingdom	648	482	457	219
Venezuela	921	160	4	80
Other	[r]91	[r]350	76	613
Total[2]	63,212	15,165	54,101	14,431
IMPORTS FOR CONSUMPTION				
Reclaimed scrap, including ash and residues (lead content):[3]				
Canada	216	54	58	29
Other	20	11	31	11
Total[2]	236	65	90	39

[r] Revised.

[1] Less than 1/2 unit.

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

[3] Also includes other lead-bearing materials containing greater than 10% by weight of copper, lead, or zinc (any one).

Source: Bureau of the Census.

TABLE 24
SECONDARY TIN RECOVERED FROM SCRAP PROCESSED AT DETINNING AND OTHER RECOVERY PLANTS IN THE UNITED STATES

		1992	1993
Tinplate scrap treated	metric tons	W	W
Tin recovered in the form of:			
Metal[1]	do.	137	112
Compounds (tin content)	do.	W	W
Total	do.	137	112
Weight of tin compounds produced	do.	W	W
Average quantity of tin recovered per metric ton of tinplate scrap used	kilograms	2.23	2.01
Average delivered cost of tinplate scrap	per metric ton	$91.85	$118.90

W Withheld to avoid disclosing company proprietary data.

[1] This data is felt to represent 39% and 22%, respectively, of actual industry activity due to non-reporting firms.

TABLE 25
TIN RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY FORM OF RECOVERY

(Metric tons unless otherwise specified)

Form of recovery	1992	1993
Tin metal[1]	137	112
Bronze and brass[e] [2]	[r]12,781	10,670
Lead and tin alloys:		
Antimonial lead	704	796
Babbitt	78	51
Type metal	47	43
Other alloys[3]	W	W
Total	829	890
Tin content of chemical products	W	W
Grand total	[r]13,747	11,672
Value (thousands)[e] [4]	[r]$121,825	$90,037

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

[1] Includes tin metal recovered at detinning and other plants. This data is felt to represent 39% and 22%, respectively, of actual industry activity due to non-reporting firms.

[2] Includes tin recovered from copper-, lead-, and tin-base scrap.

[3] Includes foil, solder, terne metal, and cable lead.

[4] Based on Platt's Metals Week composite price.

TABLE 26

U.S. STOCKS, RECEIPTS, AND CONSUMPTION OF NEW AND OLD SCRAP AND TIN RECOVERED, BY TYPE OF SCRAP

(Metric tons)

Type of scrap	Gross weight of scrap						Tin recovered [e] [1]		
	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31			
			New	Old	Total		New	Old	Total
1992									
Copper-base scrap	11,011	139,178	33,357	111,151	144,508	5,681	1,547	3,927	5,474
Brass mills[2]	—	19,912	19,912	—	19,912	—	500	—	500
Foundries and other plants	[r]2,548	[r]21,820	[r]9,482	[r]12,329	[r]21,811	[r]2,557	439	[r]585	[r]1,024
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	2,486	[r]4,512	[r]6,998
Lead-base scrap[r]	23,794	1,083,022	67,169	1,012,848	1,080,017	26,799	1,763	4,304	6,067
Tin-base scrap[3]	7	55	W	38	W	W	645	37	682
Grand total[r]	XX	XX	XX	XX	XX	XX	4,894	8,853	13,747
1993									
Copper-base scrap	5,681	131,536	29,512	101,519	131,031	6,186	1,463	3,426	4,889
Brass mills[2]	—	26,263	26,263	W	26,263	—	613	—	613
Foundries and other plants	2,557	20,859	9,620	11,524	21,144	2,272	401	470	871
Total tin from copper-base scrap	XX	XX	XX	XX	XX	XX	2,477	3,896	6,373
Lead-base scrap	26,799	1,036,891	75,288	965,279	1,040,567	23,123	1,976	3,280	5,256
Tin-base scrap[3]	W	46	W	44	W	W	W	43	43
Grand total	XX	XX	XX	XX	XX	XX	4,453	7,219	11,672

[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; U.S. Bureau of Mines not at liberty to publish separately.

TABLE 27

STOCKS AND CONSUMPTION OF NEW AND OLD ZINC SCRAP IN THE UNITED STATES IN 1993, 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	333	3,376	—	3,494	3,494	215
Flue dust	W	8,985	4,499	4,477	8,976	W
Fragmentized diecastings	W	W	—	W	W	W
Galvanizer's dross	1,305	64,853	63,631	—	63,631	2,527
Old zinc[1]	81	1,132	—	1,031	1,031	182
Remelt die-cast slab	W	20,298	—	20,227	20,227	W
Remelt zinc[2]	W	W	W	—	W	W
Skimmings and ashes[3]	4,741	38,860	37,583	—	37,583	6,018
Steelmaking dust	W	W	W	W	W	W
Other[4]	5,046	71,423	28,090	43,409	71,499	5,050
Total	11,506	208,927	133,803	72,638	206,441	13,992

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

[1] Includes engraver's plates and rod and die scrap.

[2] Includes new clippings.

[3] Includes sal skimmings and die-cast skimmings.

[4] Includes chemical residues and solutions and electrogalvanizing anodes.

TABLE 28

PRODUCTION OF ZINC PRODUCTS FROM ZINC-BASE SCRAP IN THE UNITED STATES

(Metric tons)

Product	1989	1990	1991	1992	1993
Electrogalvanizing anodes	W	W	W	W	W
Redistilled slab zinc	97,904	95,708	122,457	127,623	141,472
Remelt die-cast slab	4,167	5,144	W	W	W
Other metal alloys	272	257	W	W	W
Other zinc metal products	15,564	11,804	8,686	15,661	13,713
Secondary zinc in chemical products	57,575	56,135	65,746	73,277	64,979
Zinc dust	24,909	24,105	22,750	20,962	16,506

W Withheld to avoid disclosing company proprietary data, included in "Other zinc metal products."

TABLE 29

ZINC RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

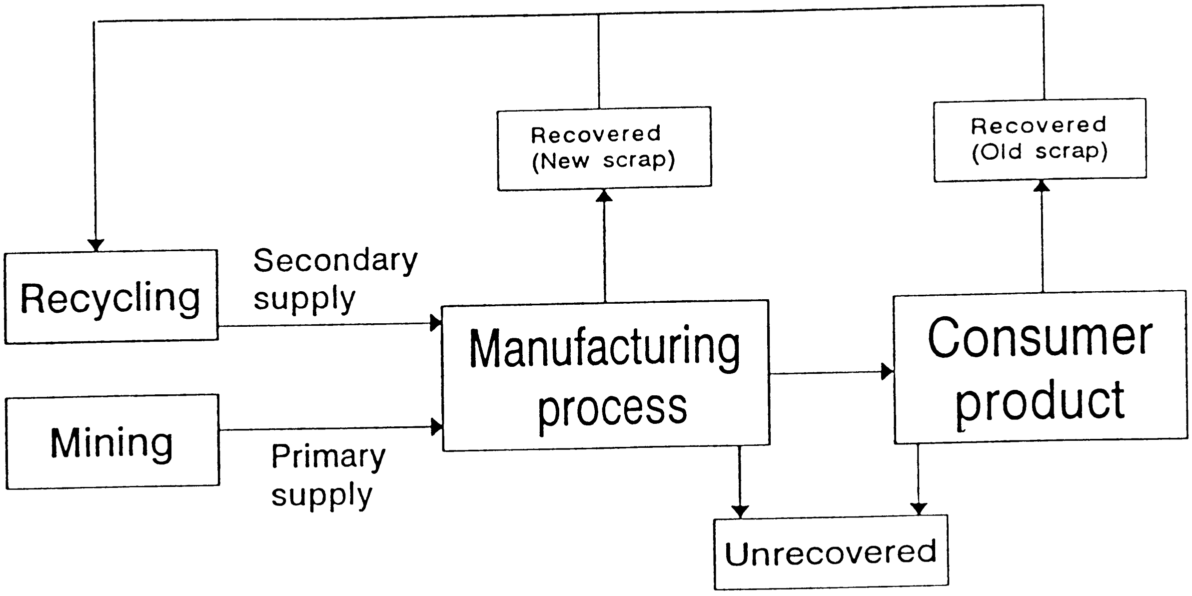
(Metric tons)

	1992	1993
KIND OF SCRAP		
New scrap:		
Zinc-base	106,751	108,269
Copper-base	[r]126,995	137,327
Magnesium-base	[r]47	33
Total	[r]233,793	245,629
Old scrap:		
Zinc-base	107,755	90,983
Copper-base	[r]23,954	17,303
Aluminum-base	[r]557	873
Magnesium-base	[r]47	44
Total	[r]132,313	109,203
Grand total	[r]366,106	354,832
FORM OF RECOVERY		
Metal:		
Slab zinc	127,623	141,472
Zinc dust	20,962	16,506
Other[1]	8,880	10,860
Total	157,465	168,838
In zinc-base alloys	W	W
In brass and bronze	[r]130,367	115,822
In other metal alloys	W	W
In chemical products:		
Zinc oxide (lead free)	37,717	35,997
Zinc sulfate	26,374	18,659
Zinc chloride	6,332	4,235
Miscellaneous	[r]7,851	11,281
Total	[r]208,641	185,994
Grand total	[r]366,106	354,832

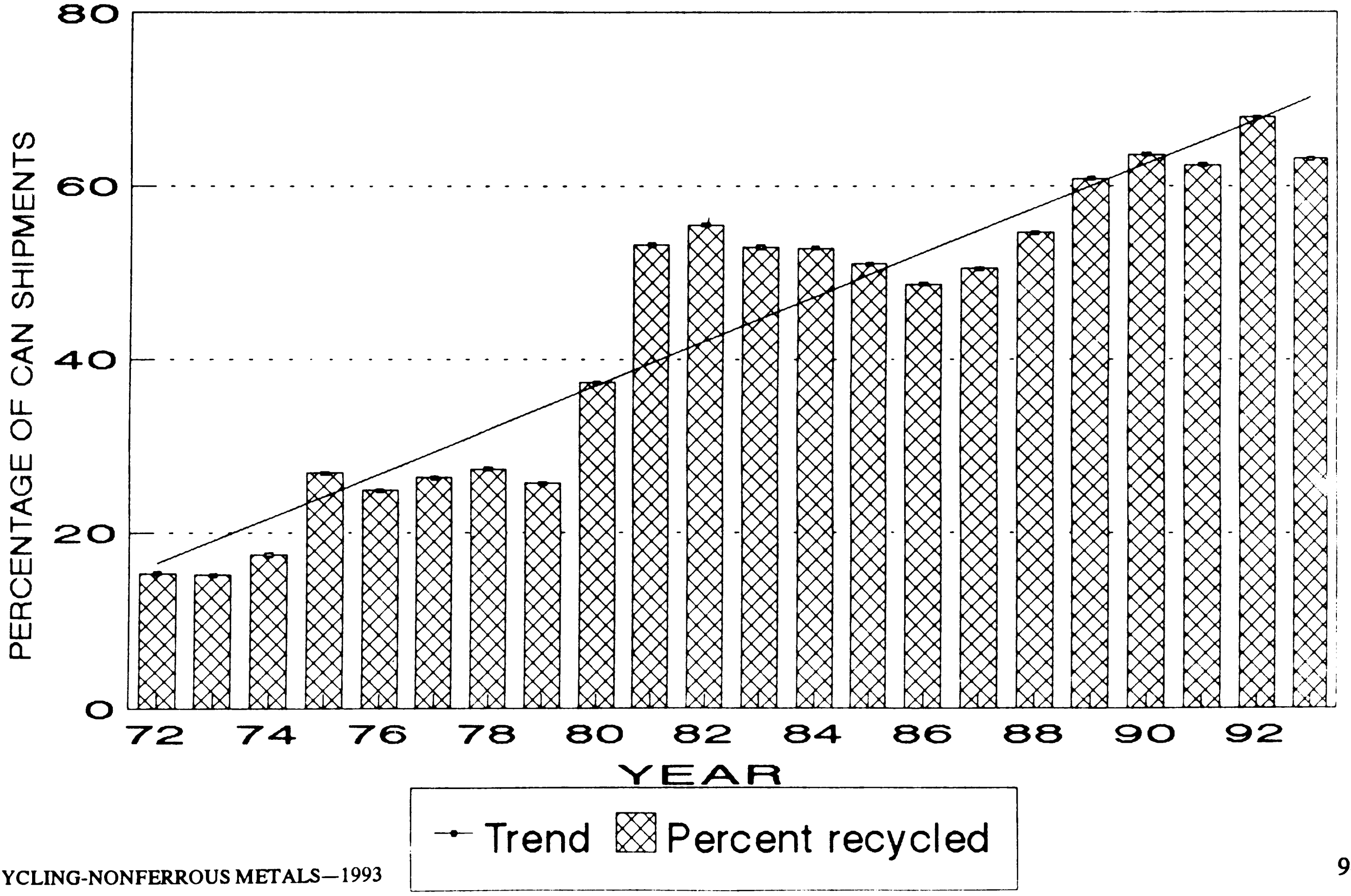
[r] Revised. W Withheld to avoid disclosing company proprietary data, included in "Miscellaneous."

[1] Includes electrogalvanizing anodes and zinc content of slab made from remelt die-cast slab.

FIGURE 1
GENERAL RECYCLING MATERIAL FLOW INDUSTRY STRUCTURE



FIUGRE 2
U.S. ALUMINUM CAN RECYCLING



SALT

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 15 years of U.S. Bureau of Mines experience, has been the commodity specialist for salt since 1980. Domestic survey data were prepared by Christopher Lindsay, supervisory statistical assistant; and international data tables were prepared by Harold Willis, international data analyst.

Salt is the most important mineral feedstock used by the chemical industry. Sodium chloride, commonly known as salt, is a universal commodity that is known and used by virtually every person in the world. It is an important compound that has a multitude of applications with approximately 14,000 different reported uses. Most individuals usually only associate salt with highway deicing and food processing; however, the largest end-use of salt is as feedstock for chlorine and caustic soda manufacture. These two important inorganic chemicals have a multitude of consumer-related end-use products, such as polyvinyl chloride (PVC) plastic made from chlorine and pulping chemicals manufactured from caustic soda.

Beginning with the 1992 Annual Report, all data are reported in metric units to comply with Public Law 100-418 of August 23, 1988. This Federal law required all Federal agencies to use the metric system of measurement by the end of fiscal year 1992. Although the use of the metric measurement standards was authorized by law since 1866 (Act of July 28, 1866; 14 Statute 339) and the United States was an original signatory party to the 1875 Treaty of the Meter (20 Statute 709), the United States has been the only industrially developed nation that has not universally converted to the metric system from the English system of measurements. Therefore, all data in this report are in metric tons unless otherwise noted. For comparison, 1 metric ton is equal to 2,204.6 pounds whereas 1 short ton is equal to 2,000 pounds. To convert metric tons to short tons, multiply the metric ton figure by 1.10231. To convert short tons into metric tons, divide by 1.10231.

As foreign trade of salt with the United States increases and foreign participation in U.S. salt companies continues, such as with the U.S. subsidiaries of Akzo Salt and Basic Chemicals International of the Netherlands and Sifto Canada of Canada, communicating information with an international standard of measurement becomes more important.

DOMESTIC DATA COVERAGE

Domestic production data for salt are developed by the U.S. Bureau of Mines (USBM) from an annual voluntary survey of U.S. salt-producing sites and of company operations. Of the 27 companies to which a survey request was sent, 25 responded, representing 80% of the total production shown in this report. Data for the two nonresponding companies, North American Salt Co. and Dow Chemical Co., were estimated on the basis of their prior responses to previous annual surveys, the 1993 production estimate survey, or brine production capabilities for chloralkali manufacture based on chlorine production capacities.

BACKGROUND

Salt has been an important commodity throughout history. Its presence has determined the location of cities, migration of populations, and routes of trade caravans. One of the earliest accounts of using salt in political-economic societies was traced to 2200 B.C. in China where Emperor Hsia Yu decreed that Shandong Province would supply the court with salt. The Phoenicians (1200 B.C. to 300 B.C.) were one of the first maritime civilizations to trade salt. Salt became an important universal medium of exchange. The English word "salary" is derived from the Latin term "Salarium argentum," which were the salt rations that Roman soldiers were partially paid for their services. Aside from its use as a medium of monetary exchange, salt also has been used to signify hospitality. The custom of presenting newlyweds wine, bread, and salt shows salt as a lifegiving and sustaining substance. In many areas of the world, it is still the custom for the host to offer bread and salt upon entering the home. The custom is also practiced "out of this world"—it has been a tradition that all former U.S.S.R.-staffed spaceflights carry aloft bread and salt and leave them behind on the orbiting space station as presents for the next visiting crew.

The first production of salt in the United States was in 1614 by the Virginia colonists who evaporated seawater. The practice of extracting salt from subsurface brine was first employed in the United States at Onondaga, NY, in 1788. The first salt "mine" in the United States was dug in 1799 at Saltville, VA. A 1.8-meter-wide by 61-meter-deep (6-foot-wide by 200-foot-deep) shaft was dug to the top of the salt formation before ground water flooded the workings. The saline water in the shaft provided the feedstock to iron kettles, in which the water was evaporated and the salt recovered. In 1862, the first commercial rock salt mine in North America began operating at Avery Island, LA. Solution mining of salt began in about 1882 and consisted of drilling a small diameter well down to a salt bed, pumping freshwater down to dissolve the salt, and pumping the resultant brine to the surface for subsequent evaporation. In 1887, the vacuum pan was adopted for salt production, which incorporated a vacuum during evaporation to allow the water to boil from the brine at a lower temperature. This technological achievement reduced fuel consumption below that of direct-heated units.

Definitions, Grades, and Specifications

Technically, salt is a generic term that describes compounds formed by the partial or complete replacement of the hydronium ion of an acid by a metal or metallic radical. Water and salts are the end products from the chemical reaction between acids and bases. Through time, however, "salt" has become synonymous with sodium chloride (common salt) and will be considered synonymous throughout this chapter.

Naturally occurring sodium chloride is mineralogically known as halite. Pure salt contains 39.3% sodium and 60.7% chlorine by weight. Halite deposits usually contain between 1% and 4% impurities, mainly gypsum, shale, dolomite, and quartz. Rock salt is halite that is mined underground by conventional room-and-pillar techniques.

Evaporated salt is the term applied to fine crystals of salt obtained by evaporating brines, either natural or manufactured from solution mining, in large, vacuum-enclosed or open steam-heated kettles. Solar evaporated salt is the product harvested from shallow ponds after the brine has been exposed to solar and wind evaporation.

The physical characteristics of salt vary with the type of production process. Salt specifications from vacuum pan operations are the same because the process is similar throughout the country. Rock salt, however, can vary in color and composition with locality, and these characteristics influence the specifications of the final product. Some impurities must be removed by chemical treatment or filtration to meet specifications for certain end uses.

There are various standards issued by different organizations that apply to salt. These standards may vary, depending on the intended end use. For example, salt for human consumption requires different specifications than those of salt for deicing highways.

Uses and Products for Trade and Industry

Salt for human consumption is packaged in different sized containers for several specialized purposes. Table salt may contain 0.01% potassium iodide as an additive that provides a source of iodine that is essential to the oxidation processes in the body. Kosher salt, seasalt, condiment salt, and salt tablets are special varieties of salt.

Water conditioning and animal feedstock salt are made into 22.7-kilogram (50-pound) pressed blocks. Sulfur, iodine, trace elements, and vitamins are occasionally added to salt blocks to provide missing nutrients not found naturally in the diet of certain livestock. Salt is also compressed into pellets and used for water conditioning.

There are reportedly about 14,000 different direct and indirect uses of salt. The USBM annually surveys 8 major categories comprising 29 separate end uses.

Chemical.—The greatest quantity of salt used in the chemical industry is by the chloralkali sector. Traditionally, the chloralkali sector included salt consumed for chlorine, coproduct sodium hydroxide (also known as caustic soda and lye), and synthetic soda ash. Since 1986, when the last synthetic soda ash plant closed because of high production costs and competition with less expensive natural soda ash, no synthetic soda ash has been manufactured in the United States. Aside from a few economic deposits of natural soda ash, several countries in the world continue to use salt for synthetic soda ash production.

Salt is used as the primary raw material in chlorine manufacture because it is an inexpensive and widely available source of chlorine ions. For sodium hydroxide production, salt is the main source of the sodium ions. About 98% of the domestic chlorine and sodium hydroxide produced is obtained from the electrolysis of salt brine feedstock using three different cell technologies. The types of cells and percent chlorine manufactured by them are diaphragm, 78%; mercury, 14%; and membrane, 6%.

According to the Chlorine Institute, there were 26 chlorine companies operating 49 plants. Of these, 16 were diaphragm cell plants, 12 mercury cell plants, 6 membrane cell plants, 5 diaphragm and mercury cell plants, 3 diaphragm and mercury cell plants, 3 magnesium cell plants, 1 sodium cell plant, 1 hydrochloric acid electrolysis plant, and 1 diaphragm and magnesium cell plant.

It takes about 1.75 short tons of salt to make 1.0 short ton of chlorine and 1.1 short tons of coproduct caustic soda. The electrolytic process ionizes the sodium chloride compound and selectively allows the ions to migrate through special membranes. Chlorine gas forms at the anode while sodium ions bond with water molecules at the cathode to form sodium hydroxide with hydrogen gas evolving.

Chlorine and caustic soda are considered to be the first generation of products made from salt. These two chemicals are further used to manufacture other materials, which are considered second generation products from salt.

Salt is also used as a feedstock by chemical establishments that make sodium chlorate (by the electrolysis of an acidified salt brine using hydrochloric acid adjusted to a pH of 6.5), metallic sodium (by the electrolysis of a molten salt mixture containing 33.2% sodium chloride and 66.8% calcium chloride, which is added to reduce the melting temperature of salt), and other downstream chemical operations. In powdered soaps and detergents, salt is used as a bulking agent and as a coagulant for colloidal dispersion after saponification. In pharmaceuticals, salt is a chemical reagent and is used as the electrolyte in saline solutions. It is also used as a cofeedstock with sulfuric acid to produce sodium sulfate and hydrochloric acid. This subsector is relatively small, representing only 10% of domestic salt sales for the entire chemical sector and only 5% of total domestic salt consumption.

Food Processing.—Every person uses some quantity of salt in their food. The salt is either added to the food by the food processor or by the consumer through free choice. Salt is added to food as a flavor enhancer, preservative, binder, fermentation control additive, texture aid, and color developer. This major category is subdivided into six applications, in descending order of salt consumption: meat packers, canning, other food processing, baking, dairy, and grain mill products.

In meatpacking, salt is added to processed meats to promote the color development in bacon, ham, and other processed meat products. As a preservative, salt inhibits the growth of bacteria, which would lead to spoilage of the product. Early pioneers used to store their perishables in salt barrels for protection and preservation. Salt acts as a binder in sausages to form a binding gel comprised of meat, fat, and moisture. Salt also acts as a flavor enhancer and a tenderizer. In canning, salt is primarily added as a flavor enhancer and preservative. It also is used as a dehydrating agent, tenderizer, enzyme inhibitor, and as a carrier for other ingredients.

In the "other food processing" category, salt is used mainly as a seasoning agent. Other food processing includes miscellaneous establishments that make food for human consumption (i.e., potato chips, pretzels) and domestic pet consumption (i.e., dog and cat food). In baking, salt is added to control the rate of fermentation in bread dough. It also is used to strengthen the gluten (the elastic protein-water complex in certain doughs) and as a flavor enhancer, such as a topping on baked goods. In the dairy industry, salt is added to cheese as a fermentation control agent and as a color and texture control agent. The dairy subsector includes companies that manufacture creamery butter, natural and processed cheese, condensed and evaporated milk, ice cream, frozen desserts, and specialty dairy products. The final food processing category is grain mill products, which consists of milling flour and rice, and manufacturing cereal breakfast food and blended or prepared flour.

General Industrial.—The industrial uses of salt are diverse. They include, in descending order of salt usage, oil and gas exploration; metal processing; other industrial; pulp and paper; textiles and dyeing; tanning and leather treatment; and rubber manufacture.

In oil and gas exploration, salt is an important component of drilling fluids in well drilling. It is used to flocculate and to increase the density of the drilling fluid to overcome high down-well gas pressures. Whenever drilling activities encounter salt formations, salt is added to the drilling fluid to saturate the solution and minimize the dissolution within the salt strata. Salt is also used to increase the set rate of concrete in cemented casings. In metal processing, salt is used in concentrating uranium ore into uranium oxide (yellow cake). It is also used in processing aluminum, beryllium, copper, steel, and vanadium.

In the pulp and paper industry, salt is used to bleach wood pulp. It also is used to make sodium chlorate, which is added along with sulfuric acid and water to manufacture chlorine dioxide—an excellent oxygen-base bleaching chemical. Although the chlorine dioxide process originated in Germany after World War I, it is becoming more popular because of environmental pressures to reduce or eliminate chlorinated bleaching compounds. In textiles and dyeing, salt is used as a brine rinse to separate organic contaminants, to promote "salting out" of dyestuff precipitates, and to blend with concentrated dyes to standardize them. One of its main roles is to provide the positive ion charge to promote the absorption of negatively charged ions of dyes. In tanning and leather treatment, salt is added to animal hides to inhibit microbial activity on the underside of the hides and to replace some of the moisture in the hides. In rubber manufacture, salt is used to make neoprene rubber, white rubber, and buna rubber. Salt brine and sulfuric acid are used to coagulate an emulsified latex made from chlorinated butadiene.

Agricultural Industry.—Since prehistoric times, humankind has noticed that animals satisfied their salt hunger by locating salt springs, salt licks, or playa lake salt crusts. Barnyard and grazing livestock need supplementary salt rations to maintain proper nutrition. Veterinarians advocate adding loose salt in commercially mixed feeds or in block forms sold to farmers and ranchers. Salt also acts as an excellent carrier for trace elements not found in the vegetation consumed by grazing livestock. Sulfur, selenium, and other essential elements are commonly added to salt licks, or salt blocks, for free-choice feeding.

Water Treatment.—Approximately 1.2 trillion liters (325 billion gallons) of water is used daily in the United States for residential and commercial uses. Many areas of the United States have "hard" water, which contains excessive calcium and magnesium ions that contribute to the buildup of a scale or film of alkaline mineral deposits in household and industrial equipment. Commercial and residential water-softening units use salt to remove the ions causing water hardness. The sodium ions captured on a resin bed are exchanged for the calcium and magnesium ions. Periodically, the water-softening units must be recharged because the sodium ions become depleted. Salt is added and dissolved, and the brine replenishes the lost sodium ions.

Ice Control and Road Stabilization.—The second largest end use of salt is for highway deicing. Gabriel Daniel Fahrenheit, the developer of the Fahrenheit temperature scale (° F), discovered that salt mixed with ice (at a temperature below the freezing point) creates a solution with a lower freezing point than water by itself. The brine forms below the surface of the ice and snow and prevents the water from freezing into ice and bonding with the road surface. Therefore, salt causes snow and ice to melt. Salt is an inexpensive, widely available, and effective ice control agent. It does, however, become less effective as the temperature decreases below about -9.4° C to -6.7° C (15° F to 20° F). At lower temperatures, more salt would have to be applied to maintain higher brine concentrations to provide the same degree of melting. Most winter snowstorms and ice storms occur between -3.9° C to 0° C (25° F and 32° F), a range in which salt is most effective.

In highway deicing, salt has been associated with corrosion to motor vehicles, bridge decks, unprotected steel structures, and reinforcement bar and wire used in road construction. Surface runoff, vehicle spraying, and windblown actions also affect roadside vegetation, soil, and local surface and ground water supplies. Although there is evidence of environmental loading of salt during peak usage, the spring rains and thaws usually dilute the concentrations of sodium in the area.

Salt is also added to stabilize the soil and to provide firmness to the foundation on which highways are built. The salt acts to minimize the effects of shifting caused by changes in humidity and traffic load in the subsurface.

Distributors.—A tremendous amount of salt is marketed through various distributors, some of which specialize in certain markets such as agricultural and water-treatment services. In addition to these two categories, distributor sales include grocery wholesalers and/or retailers, institutional wholesalers, U.S. Government resalers, and other wholesalers and retailers.

Other.—The other uses of salt include categories not discussed above.

Geology-Resources

The definitions of reserves and reserve base are published in the U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

The oceans are the world's largest resource of salt. Seawater contains 3.5% dissolved solids by weight with sodium chloride representing the major component, approximately 2.5% by weight. The world's oceans contain about 42 x 10^{15} tons (46 x 10^{15} short tons) of sodium chloride, which is equivalent to 530 million cubic kilometers (4.5 million cubic miles) in volume or a cube measuring 795 kilometers (165 miles) on edge.

Domestic salt resources are found mainly in four large depositional basins, covering an area totaling about 0.2 million square hectacres (0.5 million square miles) in 18 States. These basins are (1) the gulf coast, which covers part of Alabama, Arkansas, Florida, Louisiana, Mississippi, and eastern Texas; (2) the Permian, which is in part of Colorado, Kansas, New Mexico, Oklahoma, and western Texas; (3) the Salina, covering part of Michigan, New York, Ohio, Pennsylvania, and West Virginia; and (4) the Williston, encompassing part of Montana, North and South Dakota, and Wyoming. The gulf coast and Permian basins extend into Mexico; the Salina and Williston both extend into Canada. The identified salt resources of the United States are estimated at 55 x 10^{12} tons (61 x 10^{12} short tons) and are being depleted at the rate of about 35 million tons (39 million short tons) annually. At the present level of production, the United States has enough salt to mine for more than 1.6 million years. Solar evaporation of coastal seawater would extend this rate virtually forever.

Salt can be geologically classified by its occurrence as evaporite deposits and in solutions.

Evaporite Deposits.—Bedded, diapiric flow, and playa salts are the major types of dry salt deposits. Bedded salt deposits were formed by the accumulation of precipitated salts on the 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 914 meters (3,000 feet) in thickness.

Salt domes form when vertical or lateral pressures are applied to stratified salt deposits in which low-density salt will flow plastically through the surrounding rocks of higher density. The salt domes of Romania, the Federal Republic of Germany, and the gulf coast of the United States are examples of diapiric salt flows. The appearance is usually cylindrical with circular or elliptical diameters. A cap rock of anhydrite is common with overlying layers of gypsum and calcite. Oil, gas, and sulfur are associated with many domes and represent large mineral resources. There are 329 proven salt domes in the gulf coastal province and offshore regions of the United States. Louisiana has 183 domes onshore and offshore; Texas, 83; Mississippi, 61; and Alabama, 2.

Playas are flat, vegetation-free floors of an undrained desert basin that may occasionally be covered by water. Postevaporation minerals such as sodium carbonate, sodium sulfate, sodium chloride, borates, nitrates, phosphates, and potash result from the leaching of the rocks surrounding the basin by water flowing into the playa. Searles Lake in California is a classic example of a salt-bearing playa lake.

Salt in Solution.—Ocean, lake, and ground water are the primary aqueous mediums in which salt is dissolved. Seawater contains many dissolved minerals, the major one being sodium chloride. Other dissolved minerals include various calcium, magnesium, potassium and sulfate compounds.

Water tends to accumulate on land in topographic depressions created by tectonic uplifts or subsidences of the Earth's upper crust. As mineralized solutions from upland sources drain into these basins, solar evaporation concentrates the salts to form saline lakes. The Aral Sea in the former U.S.S.R., Great Salt Lake in Utah, and the Dead Sea between Jordan and Israel are examples of this process.

Ground water is composed of mineralized connate and meteoric water found in permeable sedimentary formations. In some areas, sodium chloride-rich brines migrate to the surface through intersecting fractures and joints in the rock strata to form local salt springs. These springs have attracted animals because they are a source of salt. The springs also indicate where buried salt deposits are located. The salt springs at Saltville, VA, are an example of a locality that was developed based on an occurrence of salt springs.

Technology

Exploration.—Exploring for new salt deposits is based on examination of various geochemical and geophysical information. Analysis of the underlying strata by core drilling, oil and water well logs, or other techniques is the basis for establishing the size of the deposit. Usually the most favorable areas for mine development will be 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 6,100 meters (20,000 feet), yet many outcrop at the surface. Most gulf coast salt mining operations are generally less than 300 meters (1,000 feet) below the surface. Working at deeper depths is difficult because of higher temperatures and denser rock.

Solar Evaporation.—Solar evaporation is an effective method of producing solar salt in areas of high evaporation and low precipitation. Along coastal margins in many parts of the world, seawater is collected and allowed to evaporate in specially constructed evaporating ponds. Saline lakewater is also processed using this method. The ponds are separated by levees that isolate the brine during different stages of fractional crystallization.

The initial step concentrates the brine to increase the salinity and allow many calcium, magnesium, and iron compounds to precipitate from solution. The brine is circulated among a network of interconnecting ponds, with salinity increasing with each transfer. The brine is then treated with lime to remove excess calcium sulfate and then pumped to evaporation ponds and then transferred to harvesting ponds to permit the salt to crystallize. After about 85% of the salt is precipitated, the remaining supernatant liquid, called "bitterns," can be drained to adjacent ponds for subsequent extraction of magnesium, potassium, bromine, and sodium compounds. The harvesting pond is flooded again with new brine from the lime pond to repeat the cycle. It takes about 5 years once seawater is first introduced into the system for the completion of the crystallization process. The salt is harvested by special tractors equipped with scrapers and ready for processing.

Solution Mining.—The first reported use of solution mining was about 250 B.C. in China when holes were drilled into deep salt deposits. The brine was brought to the surface by pipes made of bamboo. The brine was evaporated over fires fueled with wood, coal, or natural gas. The basis of current technology began in France about A.D. 858. An injection well is sunk, and pressurized freshwater is introduced to hydraulically fracture the bedded salt. Once communication with the production well is established, the brine is pumped to the surface for treatment.

Roof collapse of the overlying strata and surface subsidence are potential problems associated with solution mining; however, producers have taken precautions to minimize these hazards. One method that was once used was injecting air with the water into the salt caverns. The air formed a protective cover between the water and the top of the cavity that reduced the amount of dissolution of the roof.

Processing.—**Rock Salt.**—About 52% of total rock salt produced and imported is for highway deicing. Crushing and screening to the proper physical size is usually the only processing that road salt undergoes. In many operations, these steps are done underground in the mine to minimize haulage and storage costs. In addition, the extremely fine fraction, which often is unusable, remains underground rather than on the surface, which would represent a waste product to be disposed.

Solar Salt.—After harvesting, the salt crystals are washed with dilute brine to remove residual bitterns and impurities. The salt is transferred to processing facilities where it is washed with saline water, dried for about 8 minutes at approximately 300° F, and screened into fine to coarse sizes, depending on the end use of the salt to be sold. Most operations ship solar salt in bags and in bulk, using barges, truck, and rail transportation.

Mechanical Evaporation.—Salt obtained by dehydrating brine using heat alone or in combination with a vacuum is vacuum pan salt. The vacuum pan process conserves energy by utilizing multiple-effect evaporators connected to vacuum pumps. A saturated salt solution will boil at a higher temperature than pure water. When a vacuum is applied, the brine boils at a lower temperature, enabling the superheated vapor that is generated to act as the heating medium for the next evaporator.

The grainer or open pan process uses open, rectangular pans with steam-heated immersion coils to evaporate the water in the brine. Rotating rakes scrape the salt precipitate into a sump or up a ramp, depending on the method, and onto conveyors for debrining and drying treatment. The final product is usually flake shaped rather than the typical cubic form. Flake salt is preferred for production of cheese, butter, and baked goods.

The Alberger process is a modified grainer operation that produces cubic salt with some flake salt. The pans are shallow, circular units with external heating units, rather than heating coils. The open pan process cannot be operated successfully in regions with high humidities because the evaporation rate is too slow and more energy is required to evaporate the brine.

Desalination.—The conversion of saline water into freshwater has important municipal, industrial, and agricultural applications. Aside from obtaining pure water, desalination also produces byproduct salt. There are four processes presently employed in water desalinization and each has different cost and energy factors. The processes are distillation, membrane, freezing, and ion exchange. Some salt from these processes is used by the chemical industry. In some regions, salt is returned to the saline water source. Seawater typically contains 3.5% to 4.5% salt, or 35,000 to 45,000 parts per million. The standard for drinking water in the United States is 500 parts per million.

Byproducts and Coproducts

Salt is a coproduct from various seawater and saline lake operations. Depending on the cost of recovery and processing, certain magnesium, potassium, and bromine compounds can be produced from the bitterns. Subterranean brines also contain borax, calcium chloride, sodium carbonate, and sodium sulfate in addition to those aforementioned. Certain potash operations in the world also produce salt as a coproduct. When discharged to tailing ponds as a byproduct of potash mining, salt is often harvested and sold by second parties.

Economic Factors

Energy and labor costs are important factors that affect production costs, and ultimately the selling price, for all types of salt. After the salt is produced, shipping costs become very important when attempting to sell to a customer that is in proximity to other salt producers. Industry sources indicate that within the United States, a 485-kilometer (300-mile) radius is an effective limit of competition for a producing location before the influence of other competitors is noticed. Some of the major U.S. producers also have foreign subsidiaries that produce salt, which is imported at prices favorable to many consumers because transportation costs are less.

Capital investment and energy costs are important factors that influence the selling price of the type of salt produced. Vacuum pan and open pan processing require more equipment and energy than solution mining, and consequently, the average value of evaporated salt is considerably higher than that of salt in brine.

Prices.—The four types of salt that are produced each have unique production, processing, and packaging factors that determine the selling prices. Generally, salt sold in bulk is less expensive than salt that has been packaged, pelletized, or pressed. Salt in brine is the least expensive salt sold because mining and processing costs are less. Vacuum pan salt is the most expensive because of the higher energy costs involved in processing and the purity of the product. Table 2 lists the historical values of the different types of salt since 1974. The data are compared with 1993 constant dollars to show the effect of inflation and general economic conditions on the values. *(See table 2.)*

Tariffs.—The United States historically imports more salt than it exports. In 1993, U.S. salt imports were more than eight times the level of salt exports. Imports from countries having most-favored-nation (MFN) status enter duty free. However, salt imported from non-MFN countries have a 26% ad valorum tax imposed. The non-MFN countries in 1993 were Afghanistan, Albania, Azerbaijan, Belarus, Cuba, Georgia, Kampuchea, Kazakhstan, Laos, North Korea, Romania, Tajikistan, Turkmenistan, Uzbekistan, and Vietnam.

Operating Factors

Environmental Requirements.—The environmental problems associated with salt mining are few and tend to be localized without major impacts on the environment. A major concern in solution mining is the potential of land subsidence. As the salt is dissolved, some roof collapse may occur, causing sections of the surface to partially or totally fill the cavity. Subsidence is unpredictable, and once the process begins, it must be allowed to finish and reach equilibrium. Another issue pertaining to solution mining is the potential problem of well casing leakage. Any excursion of salt brine could affect ground water supplies, which are protected by various State and Federal water quality regulations. Solar evaporation facilities may substantially disturb coastal marsh areas because of the large extent of the lagoons needed for efficient operation.

Environmental Issues.—The USBM has been actively assessing the environmental issues pertaining to the type and quantity of waste generated in the different steps from mining through postconsumption for many commodities. Some waste that traditionally may have been discarded after mining and processing may be recovered for reuse; other waste in the form of discarded consumer products may be recycled to reclaim various valuable raw materials. Several material flow studies have been completed by the USBM that trace the flow of a commodity from "cradle to grave." A material flow study on salt was conducted by this author.

Salt was selected as a commodity to study because it had a couple of associated environmental issues, such as the environmental effects from deicing salt and salt used in water treatment. In addition, there were issues pertaining to some of the downstream uses, such as in PVC manufacture, that uses salt as feedstock. Cumulative historical data through 1993 on salt consumption for highway deicing indicates that 271 million tons (299 million short tons) has been applied to the Nation's roads since 1940, when salt usage for this purpose first became significant. Although there are several site specific studies that have been done to measure the concentration of salt in the soil and ground water from deicing runoff, there is no indication of any serious and permanent ill effects from the use of more than one-quarter billion tons of salt in the 50 years that salt has been used.

After analyzing all the categories that salt is used in, it is estimated that about three-fourths of the domestic salt consumed is released to the environment and unrecovered while about one-fourth is discharged to landfills, incinerated, or recycled as consumer products derived from salt, such as PVC plastic containers. For further information about the study, please refer to USBM Information Circular IC-9343, "The Material Flow of Salt."

Employment.—According to the Bureau of Labor Statistics, 1,977 people were employed in the domestic rock salt industry in 1993. Of the 13 rock salt facilities surveyed, 880 personnel worked 1.86 million hours underground, 337 people worked 710,026 hours on surface duties, 552 people worked 1,009,156 hours in the mills, and 208 people worked 456,809 hours in the office. Employment data for solar salt, vacuum pan salt, and salt in brine were incomplete or not surveyed by the Bureau of Labor Statistics.

Transportation.—The locations of the salt supplies often are not in proximity of the consumers location, and transportation can become an important cost. Pumping salt brine through pipelines is an economic means of transportation, but cannot be used for dry salt. Large bulk shipments of dry salt in ocean freighters or river barges are low in cost, but are restricted in points of origin and consumption. River and lake movement of salt in winter is often severely curtained because of frozen waterways. As salt is packaged, handled, and shipped in smaller units, the costs are increased and are reflected in higher selling prices.

Oceanborne imports of salt have been increasing in some areas of the United States because they are less expensive with respect to transportation costs than what could be purchased from many domestic suppliers using rail transportation. Salt continued to be one of the most heavily traded chemical industry ores in the world, representing about 66% of world seaborne mineral trade according to a study done in 1989.

ANNUAL REVIEW

Issues

In April 1992, the International Joint Commission on Great Lakes Water Quality recommended that Canada and the United States should begin considering the phasing out of all chlorine and chlorine-base compounds as industrial feedstocks. Representatives of the Commission contend that toxic pollution of the Great Lakes is causing serious long-term biological harm to human, aquatic life, and other wildlife. The debate between environmental groups and the chemical industry continued in 1993. Because most of the salt used for chloralkali manufacture is captive salt brine made by the chemical industry and not dry salt mined, the chlorine issue does not directly affect the majority of the domestic salt industry. However, it does affect some foreign suppliers of dry salt that export to the United States and sell to domestic chlorine and caustic soda producers, such as those in the Pacific Northwest and the Atlantic seaboard.

In response to the discussion, the chlorine industry contracted a formal study of the impact of a chlorine ban on the economies of Canada and the United States.[1] The major findings were that using substitutes for chlorine-based products and processes would cost an additional $91 billion annually to U.S. consumers and $11 billion annually to Canadian consumers. The investments required to construct plants to manufacture chlorine substitutes would cost $67 billion and take 10 to 20 years to accomplish, during which time consumers would pay higher prices for the services and products being eliminated. About 45% of all U.S. industries are direct consumers of chlorine and its coproducts, and all industries are indirect consumers. If chlorine production were terminated, many of the 1.4 million jobs in both nations would be lost, representing $33 billion in lost wages. Finally, a chlorine ban would severely disrupt certain major and economically important markets as the affected industries were forced to substitute less efficient and more costly technologies.

In a related action, the U.S. Environmental Protection Agency in November proposed strict "cluster rule" regulations for the pulp industry that would combine air and water requirements for the first time rather than adressing each one separately. The rule would virtually eliminate all river and other water discharges of dioxin and reduce airborne emissions by 70%. The environmental groups were critical of the proposal because it excluded chlorine dioxide, an oxygen-base bleaching chemical, from being removed.[2]

In August, a proposed amendment to the Clean Water Act was introduced that would ban chlorine as a bleaching agent in pulp and paper manufacture.[3] The proposal, known as the Chlorine Zero Dischage Act of 1993, would require a total phaseout within 5 years of water discharges of any organochloride compounds, byproducts, or metabolites from chlorine or any chlorinated oxidyzing agents used by the pulp producers. The issue would be discussed in the 1994 legislative calandar by the U.S. Congress. An Executive order was signed late in 1993 regarding the purchase and use of recycled paper and products by Federal agencies. Although there was no provision to use chlorine-free paper, paper brightness specifications were revised that currently prevented the use of paper made from processes that minimize emission of harmful byproducts, including chlorinated compounds.[4]

Production

U.S. salt production increased more than 10% in 1993 compared with that of the previous year. The increase, primarily in rock salt production for highway deicing, was mainly attributed to adverse winter conditions that continued into early 1994. According to the USBM survey for 1993, 27 companies operated 67 salt-producing plants in 14 States. Nine of the companies and 12 of the plants produced more than 1 million tons each and accounted for 91% and 59%, respectively, of the U.S. total. Several companies and plants produced more than one type of salt. In 1993, 11 companies (15 operations) produced solar-evaporated salt; 5 companies (17 operations), vacuum pan salt; 10 companies (14 operations), rock salt; and 14 companies (29 operations), salt brine. *(See tables 1, 3, 4, and 5.)*

The five leading States in terms of total salt sold or used were Louisiana, 32%; Texas, 21%; New York, 15%; and Kansas, 6%. Although Louisiana, New York, and Ohio were major rock salt-producing States, a substantial amount of salt was produced in Alabama, Kansas, Louisiana, New York, Ohio, Texas, Utah, and West Virginia as brine for the chemical industry. *(See table 6.)*

U.S. salt production accounted for about 20% of total world production. Production and trade of salt increased compared with that of the previous year. World production of all types of salt decreased slightly. The depressed market for chlorine and environmental problems associated with emissions of chlorinated compounds may affect the short-term status of the world chloralkali industry, which is the largest single consumer of salt.

Cargill Inc. sold about 4,047 hectares (10,000 acres, or nearly 16 square miles) of its property along the northern part of San Francisco Bay in California. The property, appraised at $35 million but sold to the Shell Oil Spill Litigation Settlement Trustee Committee for $10 million, includes about 85% of Cargill's solar salt facility at Napa that ceased production in 1990 because its sole customer, Dow Chemical, terminated chlorine production at its Pittsburgh, CA, site. The land is made up of tidal wetlands, salt ponds, and mud flats and will be used as a wildlife habitat for various fish and birds.

Formosa Plastics Corp. came on-stream in late 1993 with its 570,000-ton-per-year chlorine facility at Point Comfort, TX.[5] The plant will use membrane cell technology and is expected to be fully operational by April 1994. The three chloralkali plants of LCP Chemicals, which was owned by the Hanlin Group that filed chapter 11 proceedings, was sold to HoltraChem Manufacturing. Allied Signal Corp., which sold some of the operations to LCP in 1979, was a minority investor. The purchase involved the plants at Acme, NC; Orrington, ME; and Brunswick, GA, which had a combined capacity of 210,000 tons, as well as the lease and possible future purchase of terminals in Linden, NJ; Syracuse, NY; and Moundsville, WV.[6]

Consumption and Uses

More than 43.6 million tons of domestic and imported salt was consumed in the United States in 1993, based on the annual survey of the U.S. salt producers. The reported percent distribution of salt by major end use was chemicals, 44%; ice control, 25%; distributors, 11%; food and agricultural, 8%; industrial, 6%; primary water treatment, 1%; and other combined with exports, 5%. Distributors represent a substantial share of salt sales by the salt industry; however, all the salt ultimately is resold to many end users. Some customers have specific uses. For a more complete analysis of end-use markets, specific sectors of distribution in table 7 can be combined, such as agricultural and water conditioning with agricultural and water conditioning distribution, respectively.

The chemical industry consumes nearly one-half of the salt produced, primarily salt brine. Although most salt brine is captively produced by chemical producers, many chloralkali manufacturers now purchase brine from independent brine supply companies. In certain cases, brine is captively produced by one chemical company, and any excess brine is sold to neighboring competitors. According to a survey of domestic salt-based chlorine facilities, about 48% of the salt used to manufacture chlorine was captive and 31% was purchased brine. Purchased solar or rock salt comprised 12% and imported rock, solar, and vacuum pan salt comprised 9%. *(See tables 7 and 8.)*

Using Bureau of the Census data, the chlorine and caustic soda industry consumed about 19.1 million tons (21 million short tons) of salt for feedstock, based on the industry average ratio of 1.75 tons of salt required to produce 1 ton of chlorine and 1.1 tons of coproduct sodium hydroxide. Reported consumption of total domestic and imported salt for chlorine manufacture was 17.5 million tons (19.3 million short tons), as noted in table 7. The difference between the calculated and reported quantities was the amount of salt unreported to the USBM from imports or captive brine production of chloralkali producers. Production of chlorine gas and liquid sodium hydroxide, as reported by the Bureau of the Census and The Chlorine Institute, is shown in table 9. *(See table 9.)*

There are approximately 18 domestic companies that operate 37 chlorine-producing plants that used only salt as feedstock. Estimates were made on the chlorine production capacity for individual plants. Based on these estimates and using Bureau of the Census chlorine production data, the U.S. salt-based chlorine industry operated at 92% of capacity. According to The Chlorine Institute, the industry operated at an average of 92% of nominal capacity and 96% of effective capacity in 1993. Because these capacities include chlorine produced from nonsalt sources; i.e., from the electrolysis of magnesium chloride and the oxidation of hydrochloric acid, these data may differ from other reported chlorine capacity utilization information.

Stocks

Total yearend stocks reported by producers were about 2 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. Rock salt inventories were declining by yearend because of the severe winter in the domestic snow belt.

Markets and Prices

Price quotations are not synonymous with average values reported to the USBM. The quotations do not necessarily represent prices at which transactions actually occurred, nor do they represent bid and asked prices. They are quoted here to serve only as a reference to yearend price levels. Yearend prices were quoted in Chemical Marketing Reporter, as shown in table 10. *(See tables 10 and 11.)*

Foreign Trade

Under the Harmonized Tariff Schedule nomenclature, imports only have one category known as "Salt (including table and denatuted salt) and pure sodium chloride, whether or not in aqueous solution, seawater." The same classificaiton also applies to exports. The trade tables in this report list the previous and current identification codes for salt.

Based on Bureau of Census statistics, the United States in 1993 exported 688,000 tons (758,000 short tons), a decrease of 31% compared with that of the previous year. Salt was shipped to 67 countries through 31 U.S. customs districts, of which the Cleveland, OH, district exported the most. The majority of exports, 73%, was to Canada. The Journal of Commerce's Port Import/Export Reporting Service (PIERS) reported that six domestic salt-producing companies exported 94% of the 378,791 tons (417,545 short tons) exported in 1993. The companies were Akzo Salt Inc., Cargill Salt Co., North American Salt Co. and its subsidiary Sifto Canada, United Salt Co., and Western Salt Co.

The United States imported from 28 countries 5.87 million tons (6.47 million short tons) in 1993, or about 8.5 times more than the quantity of salt that it exported. Although this would indicate that the United States is import reliant on salt to meet its salt requirements, the majority of imported salt was brought into the country by foreign subsidiaries of major U.S. salt producers. Generally, imported salt can be purchased and delivered to many customers at costs lower than the comparable domestic product because production costs are lower abroad and currency exchange rates are more favorable.

The PIERS service reported that 5.26 million tons (5.80 million short tons) was imported; however, PIERS data include only ocean freight and does not include salt shipped by rail or truck over the U.S. land borders with Canada and Mexico. Therefore, Census data and PIERS data often are dissimilar. Using PIERS data, Akzo Salt Co., Cargill Inc., Morton International, and North American Salt Co. imported 62% of the total imports. Five companies that manufacture chlorine, which was the single largest domestic salt market, consumed 16% of total imports, which were primarily solar salt. These companies were ACI Chemicals, Atochem North America, Georgia Pacific Corp., Occidental Chemical Corp., and Weyerhaeuser Co. Three salt distributors, Atlantic Salt Co., Eastern Minerals, and Granite State Minerals, imported 13% of the total salt. The salt producers, salt distributors, and chloralkali producers imported 91% of total PIERS imports; the remainder was to many small direct buyers. Tables 12 through 15 list the import and export statistics reported by the Bureau of Census for 1992 and 1993. *(See tables 12, 13, 14, and 15.)*

World Review

Table 16 lists world salt production statistics for 101 countries based on reported and estimated information. The unification of the two Germany's and the dissolution of the former U.S.S.R. and Yugoslavia in 1992 have modified the list of nations surveyed. World production increased 3% in 1993 compared with that of the previous year. The majority of the increase was in China and the United States. China has been increasing its synthetic soda ash output for domestic glass production, thereby contributing to higher quantities of salt produced. In the United States, all four types of salt showed increases in 1993. *(See table 16.)*

Industry Structure.—The United States remains the world's leading salt-producing nation, representing about one-fifth of total world production. The structure of the U.S. industry has changed throughout the years. In 1970, there were 50 companies operating 95 plants in the United States. Market competition, energy and labor costs, less expensive imports, and an excess of production capacity resulting in the downsizing of the industry through mergers and acquisitions reduced the size of the industry to 27 companies and 67 plants by 1993.

Most countries possess some form of salt production capability with production levels set to meet their own domestic demand requirements with additional quantities available for export. Many developing nations tend to develop their agricultural resources first to feed their population. Development of easily extractable mineral resources follows with salt being one of the first commodities to be mined. Some countries, such as the United States, import a substantial amount of salt to meet total demand requirements because of economic factors.

Capacity.—Each type of salt produced in the world has unique mining, processing, and marketing characteristics that determine the criteria for deriving rated capacities. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought into production within a short period of time with minimum capital expenditure. Capacity data were derived from industry sources, published reports, and estimates based on production trends.

Rock.—Because the majority of rock salt was used for deicing, the operating rate of rock salt facilities fluctuated with the demand for deicing salt, again dependent on the severity of winter weather conditions. During periods of strong demand, production levels often achieve, or exceed in certain situations, the rated capacities. Full mine capacity generally is a function of the hoisting capabilities of the mines. Assuming that the workweek is 5 days (250 workdays per year), two working shifts and one maintenance shift per day, and at least one short-term planned turnaround for the mine and mill per year, the production capacities for domestic rock salt operations in 1993 was 16 million tons (17 million short tons).

Solar.—Solar salt, also known as marine and sea salt, is obtained from the solar evaporation of seawater, of landlocked bodies of saline water, and of discharged brines. Because evaporation rates must exceed the precipitation rates, the climatic conditions and geographic locations of solar evaporation facilities are critical to the successful production and harvesting of solar salt. Therefore, rated capacities generally are based on the historical evaporation patterns within a region and vary depending on the location and the surface areas of the evaporation ponds. Only unpredictable seasonal precipitation and market conditions usually affect the production, and market conditions usually affect the production rates of the facilities. In 1993, total domestic solar salt production capacity was 3.95 million tons (4.35 million short tons).

Vacuum Pan.—The mechanical evaporation of salt by the vacuum pan process is dependent on the number and size of the vacuum crystallizers operating in series. Rated capacities are usually easier to establish because of the proven design performance of the equipment. The total production capacity of the domestic vacuum pan salt producers in 1993 was 4.30 million tons (4.74 million short tons).

Brine.—Brine capacities are difficult to derive because they are based on the variabilities of the injection rate of the solvent and the solubility rates of the underground salt bodies. Both determine the quantity of brine produced. In addition, production levels are dependent on the demand for the products that the brine is being used to manufacture. Therefore, brine production capacity is assumed to be equal to the quantity of brine produced annually. Although data cannot be published for individual companies, the aggregate domestic brine production capacity in 1993 was 18.04 million tons (19.88 million short tons), which was the total quantity of salt brine produced.

OUTLOOK

The outlook for salt for the near future is optimistic. The drawdown of rock salt inventories late in 1993 will cause producers to increase production during early 1994 to meet the demand for deicing salt. Any additional supplies required would have to be imported. Sales of solar salt and rock salt from domestic or import sources for chloralkali manufacture may be in jeopardy, pending the outcome of any proposed legislation to reduce or eliminate the use of chlorine. Despite the adverse publicity regarding chlorine in the environment, chlorine production should be strong since about 18% of total chlorine output is exported as derivatives, such as ethylene dichloride, vinyl chloride monomer, and PVC. In addition, domestic demand for these commodities is estimated to grow at 5% per year for the next few years despite the decline in the use of chlorine in pulp bleaching.

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[1] Can We Afford To Ban Chlorine? Charles River Associates, Sept. 1993, 4 pp.

[2] The Washington Post. EPA Seeks Strict Paper-Industry Rules Aimed at Cutting Dioxin, Air Pollution. V. 222, No. 87, Nov. 2, 1993, p. A24.

[3] Chemical Week. Chlorine Ban Proposed. V. 153, No. 6, p. 38.

[4] ———. Recycling Order Omits Chlorine Ban. V. 153, No. 15, p. 6.

[5] ———. Formosa Worries Chlor-alkali Players. V. 152, No. 25, p. 15.

[6] ———. Holtrachem Acquires LCP Chlor-alkali Units With Allied Signal's Help. V. 153, No. 15, p. 16.

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TABLE 1

SALIENT SALT STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Production[1]	35,632	36,794	36,316	36,016	39,694
Sold or used by producers[1]	35,250	36,916	35,902	34,784	38,665
Value	$776,846	$826,659	$801,507	$802,563	$892,979
Exports	1,422	2,266	1,777	992	688
Value	$20,211	$32,944	$29,875	$32,193	$34,806
Imports for consumption	5,519	5,969	6,188	5,394	5,868
Value	$74,474	$88,419	$87,380	$87,714	$99,963
Consumption, apparent[2]	39,347	40,619	40,313	39,186	43,845
World: Production	[r]191,660	[r]182,445	[r]188,265	[r]181,270	[e]186,190

[e] Estimated. [r] Revised.

[1] Excludes Puerto Rico.

[2] Sold or used plus imports minus exports.

TABLE 2

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
WORLD PRODUCTION										
Production:										
United States	42,114	37,839	39,736	38,938	38,898	42,018	37,633	35,289	34,169	29,913
Rest of world•	124,115	123,828	120,931	118,102	129,350	131,351	131,245	136,127	130,096	128,935
Total•[1]	166,229	161,667	160,667	157,040	168,248	173,369	168,878	171,415	164,265	158,847
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY										
Components of U.S. supply:										
Domestic sources	42,114	37,839	39,736	38,938	38,898	42,018	37,633	35,289	34,169	29,913
Sold or used[2]	42,217	37,222	40,089	39,383	38,890	41,543	36,607	35,296	34,377	31,364
Imports	3,046	2,917	3,948	4,109	4,881	4,785	4,775	3,918	4,945	5,440
Industry stocks, Jan. 1[3]	—	—	—	—	—	—	—	—	—	—
Total U.S. supply[1]	45,263	40,138	44,037	43,491	43,771	46,328	41,381	39,214	39,322	36,804
Distribution of U.S. supply:										
Industry stocks, Dec. 31[3]	—	—	—	—	—	—	—	—	—	—
Exports	473	1,208	914	914	704	632	754	949	908	469
Industrial demand[1]	44,790	38,930	43,124	42,577	43,067	45,696	40,627	38,265	38,414	36,335
U.S. DEMAND PATTERN[4]										
Agriculture	1,799	1,689	1,746	1,656	1,679	1,739	1,664	1,622	1,421	1,456
Alkalies and chlorine	25,945	21,912	23,560	22,780	22,236	24,460	22,447	20,613	17,373	18,361
Deicing	8,265	8,020	9,247	9,449	9,698	10,104	6,782	7,491	9,833	6,250
Food products	2,694	2,480	2,509	2,500	2,554	2,292	2,148	1,999	2,134	2,079
Metal production	229	240	310	318	314	323	247	267	267	220
Other chemicals	1,573	926	1,051	1,018	1,051	1,109	925	1,028	785	864
Paper products	150	156	193	201	200	176	209	224	190	249
Petroleum	220	237	283	327	409	499	643	759	939	833
Textiles and dyeing	186	163	185	178	165	171	161	200	150	155
Water treatment	933	821	653	737	807	869	785	913	731	721
Other[5]	3,019	2,952	3,316	3,284	3,179	3,201	2,971	3,406	3,587	3,673
Undistributed[6]	(223)	(667)	71	128	774	755	1,646	(255)	1,005	1,475
Total U.S. primary demand[1]	44,790	38,930	43,124	42,577	43,067	45,696	40,627	38,265	38,414	36,335
VALUE[7]										
Average annual value (dollars per ton):										
Salt in brine short tons	3.69	3.91	3.80	3.91	4.24	4.51	6.50	5.91	6.21	5.22
Constant 1993 dollars	10.21	9.87	9.02	8.69	8.73	8.55	11.26	9.30	9.20	7.43
Salt in brine metric tons	4.07	4.31	4.19	4.31	4.67	4.97	7.17	6.51	6.85	5.75
Constant 1993 dollars	11.26	10.88	9.95	9.58	9.62	9.42	12.42	10.25	10.15	8.19
Rock salt short tons	7.14	8.94	7.82	8.94	10.10	10.00	14.65	13.76	13.89	13.43
Constant 1993 dollars	19.75	22.57	18.57	19.86	20.80	18.96	25.38	21.66	20.59	19.13
Rock salt metric tons	7.87	9.85	8.62	9.85	11.13	11.02	16.15	15.17	15.31	14.80
Constant 1993 dollars	21.77	24.87	20.47	21.88	22.92	20.90	27.98	23.88	22.69	21.08
Solar salt short tons	9.30	14.21	14.36	14.21	14.67	12.16	15.65	18.35	17.89	21.47
Constant 1993 dollars	25.73	35.87	34.10	31.57	30.22	23.06	27.11	28.89	26.51	30.58
Solar salt metric tons	10.25	15.66	15.83	15.66	16.17	13.40	17.25	20.23	19.72	23.67
Constant 1993 dollars	28.35	39.53	37.59	34.79	33.31	25.41	29.88	31.84	29.23	33.71
Vacuum pan salt short tons	34.50	43.01	50.73	52.01	58.86	61.64	76.44	79.68	86.72	87.39
Constant 1993 dollars	95.43	108.57	120.47	115.56	121.23	116.88	132.41	125.43	128.53	124.47
Vacuum pan salt metric tons	38.03	47.41	55.92	57.33	64.88	67.95	84.26	87.83	95.59	96.33
Constant 1993 dollars	105.20	119.68	132.80	127.38	133.63	128.85	145.96	138.26	141.67	137.20

See footnotes at end of table.

TABLE 2—Continued

U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

		1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WORLD PRODUCTION											
Production:											
United States		35,544	35,577	33,822	33,514	35,534	35,632	36,794	36,316	36,016	39,694
Rest of world[e]		137,055	137,359	140,913	145,210	150,008	[r]156,028	[r]145,651	[r]151,949	[r]145,254	146,496
Total[e] [1]		172,599	172,936	174,735	178,725	185,542	[r]191,660	[r]182,445	[r]188,265	[r]181,270	[e]186,190
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Components of U.S. supply:											
Domestic sources		35,544	35,577	33,822	33,514	35,534	35,632	36,794	36,316	36,016	39,694
Sold or used[2]		35,584	36,348	33,260	33,106	35,326	35,250	36,916	35,902	34,784	38,665
Imports		6,845	5,631	6,046	5,185	4,966	5,519	5,969	6,188	5,394	5,868
Industry stocks, Jan. 1[3]		—	—	—	—	—	—	—	—	—	—
Total U.S. supply[1]		42,429	41,979	39,307	38,291	40,292	40,769	42,885	42,090	40,178	44,533
Distribution of U.S. supply:											
Industry stocks, Dec. 31[3]		—	—	—	—	—	—	—	—	—	—
Exports		744	820	1,057	491	802	1,422	2,266	1,777	992	688
Industrial demand[1]		41,685	41,159	38,250	37,801	39,490	39,347	40,619	40,313	39,186	43,845
U.S. DEMAND PATTERN[4]											
Agriculture		1,562	1,559	1,498	1,592	1,657	1,746	2,105	2,005	1,984	2,704
Alkalies and chlorine		18,273	18,539	17,221	16,289	18,115	17,037	17,402	18,940	[r]16,884	16,339
Deicing		9,726	10,142	9,563	8,961	10,092	10,397	10,253	9,360	7,814	10,805
Food products		1,973	1,913	1,969	2,112	2,075	2,154	2,282	2,162	2,164	2,372
Metal production		296	347	276	282	339	363	314	293	217	230
Other chemicals		1,141	697	742	689	695	1,068	1,856	1,073	1,655	1,796
Paper products		306	282	279	351	341	338	257	237	230	115
Petroleum		789	875	569	542	743	653	719	554	1,208	1,240
Textiles and dyeing		173	169	205	215	208	212	206	232	271	313
Water treatment		1,767	1,307	1,409	1,320	1,373	1,349	1,468	1,321	1,335	1,004
Other[5]		3,799	3,068	2,779	3,696	3,452	4,423	4,017	4,381	[r]5,889	5,517
Undistributed[6]		1,880	2,261	1,741	1,752	399	(393)	(259)	(246)	[r](465)	1,410
Total U.S. primary demand[1]		41,685	41,159	38,250	37,801	39,490	39,347	40,619	40,313	39,186	43,845
VALUES[7]											
Average annual value (dollars per ton):											
Salt in brine	short tons	5.05	6.14	5.15	4.93	3.58	5.67	4.86	4.94	3.95	4.74
Constant 1993 dollars		6.89	8.08	6.60	6.12	4.28	6.49	5.33	5.21	4.05	4.74
Salt in brine	metric tons	5.57	6.77	5.68	5.43	3.95	6.25	5.36	5.45	4.35	5.22
Constant 1993 dollars		7.60	8.91	7.28	6.74	4.72	7.15	5.88	5.75	4.46	5.22
Rock salt	short tons	13.78	15.15	14.51	14.34	14.46	16.38	16.80	17.46	17.81	18.84
Constant 1993 dollars		18.81	19.93	18.60	17.81	17.29	18.75	18.42	18.42	18.27	18.84
Rock salt	metric tons	15.19	16.70	15.99	15.81	15.94	18.06	18.52	19.25	19.63	20.27
Constant 1993 dollars		20.73	21.97	20.49	19.64	19.05	20.67	20.30	20.31	20.13	20.27
Solar salt	short tons	19.67	23.10	23.76	25.40	26.59	27.88	31.60	25.20	29.54	24.85
Constant 1993 dollars		26.85	30.39	30.45	31.55	31.79	31.91	34.64	26.59	30.30	24.85
Solar salt	metric tons	21.68	25.46	26.19	28.00	29.31	30.73	34.83	27.78	32.56	26.13
Constant 1993 dollars		29.59	33.50	33.57	34.78	35.04	35.18	38.18	29.31	33.39	26.13

See footnotes at end of table.

TABLE 2—Continued
U.S. SALT SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
	VALUES[7]—Continued									
Average annual value (dollars per ton)—Continued:										
Vacuum pan salt short tons	92.78	92.66	91.27	94.21	97.71	92.73	100.32	104.10	102.09	103.13
Constant 1993 dollars	126.63	121.91	116.98	117.01	116.80	106.15	109.97	109.85	104.70	103.13
Vacuum pan salt metric tons	102.27	102.14	100.61	103.85	107.71	102.22	110.58	114.75	[r]113.20	111.99
Constant 1993 dollars	139.58	134.38	128.96	128.98	128.75	117.01	121.22	121.09	116.10	111.99

[e]Estimated. [r]Revised.

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

[2] Represents that amount sold or used captively within the industry, from the quantity produced and any sold from inventory. Accurate data on beginning and yearend inventories of salt are unavailable and often are underreported because of additional storage underground at mines, warehouses, terminals, etc. However, about 2.5 million tons is estimated to be stored annually nationwide.

[3] The total quantities of salt in inventory are underreported and are excluded in determining the supply-demand balance relationship for salt. However, the difference between production and sold or used is assumed to be because of changes in inventory.

[4] Includes imports for consumption.

[5] Includes salt used in rubber, tanning, other industrial, institutional wholesalers and/or retailers, U.S. Government resale, other wholesalers. Some exports for consumption in overseas territories administered by the United States, and other various minor uses are included.

[6] Represents the difference between the quantity reported to the U.S. Bureau of Mines and total U.S. primary demand. The amount of discrepancy is attributed to variances in inventory and import statistics.

[7] Values are based on the average of all salt producers' valuations reported for bulk, f.o.b. plant, and includes all processing costs, depreciation of equipment, taxes, and profit.

Source: U.S. Bureau of Mines.

TABLE 3
SALT PRODUCTION IN THE UNITED STATES

(Thousand metric tons)

	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1989	3,606	2,849	12,682	16,496	35,632
1990	3,662	2,985	12,772	17,374	36,794
1991	3,654	2,813	11,188	18,660	36,316
1992	3,811	3,221	11,411	17,574	36,016
1993	3,864	3,541	14,253	18,036	39,694

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

TABLE 4

SALT PRODUCED IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand metric tons)

Product form	Vacuum pans and open pans	Solar	Rock	Brine	Total[1]
1992					
Bulk	727	1,874	10,942	17,574	31,117
Compressed pellets	962	233	XX	XX	1,195
Packaged	1,825	986	428	XX	3,240
Pressed blocks	298	127	40	XX	464
Total[1]	3,811	3,221	11,411	17,574	36,016
1993					
Bulk	726	2,105	13,736	18,036	34,603
Compressed pellets	1,016	288	XX	XX	1,305
Packaged	1,829	1,003	424	XX	3,256
Pressed blocks	292	145	93	XX	531
Total[1]	3,864	3,541	14,253	18,036	39,694

XX Not applicable.

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

TABLE 5

SALT SOLD OR USED[1] IN THE UNITED STATES, BY TYPE AND PRODUCT FORM

(Thousand metric tons and thousand dollars)

Product form	Vacuum pans and open pans		Solar		Rock		Brine		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1992										
Bulk	696	34,710	1,500	24,787	10,369	181,644	17,571	76,428	30,136	317,569
Compressed pellets	954	119,124	153	11,869	NA	XX	XX	XX	1,107	130,993
Packaged:										
Less-than-5-pound units	99	NA	—	NA	—	NA	XX	XX	99	XX
More-than-5-pound units	r1,715	NA	787	NA	503	NA	XX	XX	r3,005	XX
Total[2]	r1,813	238,217	787	42,798	503	31,835	XX	XX	r3,103	312,850
Pressed blocks:										
For livestock	r87	NA	73	NA	r26	NA	XX	XX	r185	XX
For water treatment	r213	NA	26	NA	r12	NA	XX	XX	r252	XX
Total[2]	r300	29,452	99	8,122	38	3,577	XX	XX	r437	41,151
Grand total[2]	3,763	421,503	2,539	87,576	10,910	217,056	17,571	76,428	34,784	802,563
1993										
Bulk	662	32,845	1,891	29,443	12,769	235,030	18,030	94,159	33,352	391,450
Compressed pellets	967	124,839	288	14,204	NA	XX	XX	XX	1,254	139,044
Packaged:										
Less-than-5-pound units	82	NA	1	NA	—	NA	XX	XX	83	XX
More-than-5-pound units	1,852	NA	1,057	NA	547	NA	XX	XX	3,456	XX
Total[2]	1,934	241,221	1,059	40,983	547	35,036	XX	XX	3,539	317,239
Pressed blocks:										
For livestock	108	NA	115	NA	69	NA	XX	XX	291	XX
For water treatment	180	NA	31	NA	16	NA	XX	XX	228	XX
Total[2]	288	28,897	146	8,055	85	8,295	XX	XX	519	45,246
Grand total[2]	3,850	427,803	3,384	92,684	13,401	278,333	18,030	94,159	38,665	892,979

rRevised. NA Not available. XX Not applicable.

[1] As reported at salt production locations. The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company. Because data do not include salt imported, purchased, and/or sold from inventory from regional distribution centers, salt sold or used by type may differ from totals shown in tables 7 and 8, which are derived from company reports.

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

TABLE 6

SALT SOLD OR USED[1] BY PRODUCERS IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Kansas[2]	1,852	98,620	2,316	103,019
Louisiana	12,054	112,334	12,374	115,464
New York	4,703	164,729	5,619	191,491
Texas	7,985	76,125	8,253	76,054
Utah	1,368	44,498	2,251	46,759
Other Eastern states[3]	4,977	245,638	6,049	294,509
Other Western states[4]	1,846	60,619	1,801	65,685
Total[5]	34,784	802,563	38,665	892,979
Puerto Rico[e]	45	1,500	45	1,500

[e] Estimated.

[1] The term "sold or used" indicates that some salt, usually salt brine, is not sold but is used for captive purposes by the plant or company.

[2] Quantity and value of brine included with "Other Western States."

[3] Includes Alabama, Michigan, Ohio, and West Virginia.

[4] Includes Arizona, California, Kansas (brine only), Nevada, New Mexico, and Oklahoma.

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

TABLE 7
DISTRIBUTION OF DOMESTIC AND IMPORTED[1] SALT BY PRODUCERS IN THE UNITED STATES, BY END USE AND TYPE

(Thousand metric tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total[2]	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Chemical:											
Chloralkali producers	2812	17	35	25	152	466	421	[r]16,374	16,870	[r]16,884	17,478
Other chemical	28 (excludes 2812, 2899)	318	475	320	559	923	683	94	79	1,655	1,796
Total[2]		335	509	346	711	1,389	1,104	[r]16,468	16,949	[r]18,538	19,273
Food-processing industry:											
Meat packers	201	214	226	64	75	112	129	—	—	389	430
Dairy	202	111	107	6	6	3	3	2	1	122	117
Canning	2091, 203	137	171	43	81	72	69	1	1	252	322
Baking	205	148	139	3	2	10	11	—	—	161	152
Grain mill products	204 (excludes 2047)	86	101	9	17	13	55	—	—	108	173
Other food processing	206-208, 2047, 2099	208	221	44	29	32	31	(3)	(3)	283	281
Total[2]		904	964	168	210	240	298	3	3	1,315	1,475
General industrial:											
Textiles and dyeing	22	197	235	44	46	25	27	5	5	271	313
Metal processing	33, 34, 35, 37	12	10	34	30	171	190	(3)	—	217	230
Rubber	2822,30 (excludes 3079)	1	2	(3)	1	3	6	31	28	34	37
Oil	13, 29	21	24	245	244	75	125	867	847	1,208	1,240
Pulp and paper	26	17	18	158	44	48	45	7	8	230	115
Tanning and/or leather	311	11	10	21	31	35	30	—	—	67	71
Other industrial	9621	111	53	122	268	344	328	5	3	581	652
Total[2]		369	352	623	665	701	751	915	891	2,609	2,659
Agricultural:											
Feed retailers and/or dealers- mixers	434	230	221	337	437	454	514	(3)	(3)	1,020	1,172
Feed manufacturers	2048	64	67	89	106	239	307	(3)	(3)	392	480
Direct-buying end user	02	5	8	6	22	8	177	—	—	19	207
Total[2]		298	297	432	565	701	997	(3)	(3)	1,431	1,859
Water treatment:											
Government (Federal, State, local)	2899	15	17	110	119	201	107	5	3	331	246
Commercial or other	2899	8	14	53	63	36	97	7	1	104	175
Total[2]		23	31	162	181	238	203	13	4	435	419
Ice control and/or stabilization:											
Government (Federal, State, local)	9621	4	1	157	407	7,278	9,941	1	10	7,440	10,359
Commercial or other	5159	5	2	37	38	331	403	—	1	374	444
Total[2]		9	4	194	445	7,609	10,344	1	12	7,814	10,805
Distributors:											
Agricultural distribution	5159	282	328	113	233	158	284	—	(3)	553	845
Grocery wholesalers and/or retailers	514, 54	537	506	237	288	75	103	—	—	849	897
Institutional wholesalers and end users	58, 70	32	80	17	29	16	30	1	(3)	66	139
Water-conditioning distribution	7399	229	127	521	396	145	62	5	—	899	585

See footnotes at end of table.

TABLE 7—Continued
DISTRIBUTION OF DOMESTIC AND IMPORTED[1] SALT BY PRODUCERS IN THE UNITED STATES, BY END USE AND TYPE

(Thousand metric tons)

End use	Standard industrial classification	Vacuum pans and open pans		Solar		Rock		Salt in brine		Grand total[2]	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Distributors—Continued:											
U.S. Government resale	9199	5	1	5	10	2	19	—	—	12	30
Other wholesalers and/or retailers	5251	809	651	438	705	454	915	(3)	(3)	1,701	2,271
Total[2]		1,894	1,692	1,331	1,660	850	1,413	5	(3)	4,081	4,765
Other n.e.s.[4]		273	277	186	264	2,838	1,665	165	148	3,462	2,354
Grand total[2]		4,104	4,127	3,442	4,702	14,567	16,775	[r]17,571	18,006	[r]39,683	43,610

[r] Revised.

[1] The quantity of imports included in the total for each type of salt is the amount reported by the U.S. salt industry, not the quantity reported by the Bureau of the Census that appears in tables 1, 2, 14, and 15.

[2] Data may not add to totals shown because of independent rounding. Because data include salt imported, produced, and/or sold from inventory from regional distribution centers, salt sold or used by type may differ from totals shown in tables 1, 2, 5, and 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.

[3] Less than 1/2 unit.

[4] Includes exports.

TABLE 8
DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand metric tons)

Destination	1992				1993			
	Evaporated		Rock	Total[2]	Evaporated		Rock	Total[2]
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Alabama	55	1	137	193	58	1	84	143
Alaska	1	10	(3)	11	(3)	5	—	5
Arizona	8	85	2	95	9	104	60	173
Arkansas	34	2	57	93	43	3	72	118
California	161	679	2	842	141	812	2	955
Colorado	15	147	24	187	12	196	48	256
Connecticut	9	9	151	169	12	8	219	239
Delaware	3	10	3	15	3	38	16	57
District of Columbia	1	1	7	9	1	1	19	21
Florida	68	114	37	220	67	134	27	228
Georgia	158	34	66	259	85	35	68	188
Hawaii	2	3	—	5	2	3	1	6
Idaho	7	53	2	62	6	85	(3)	91
Illinois	324	119	1,296	1,739	340	204	1,462	2,006
Indiana	185	65	591	841	195	91	622	908
Iowa	153	78	309	541	185	109	481	775

See footnotes at end of table.

TABLE 8—Continued

DISTRIBUTION OF DOMESTIC AND IMPORTED EVAPORATED AND ROCK SALT[1] IN THE UNITED STATES, BY DESTINATION

(Thousand metric tons)

Destination	1992				1993			
	Evaporated		Rock	Total[2]	Evaporated		Rock	Total[2]
	Vacuum pans and open pans	Solar			Vacuum pans and open pans	Solar		
Kansas	83	30	236	348	79	64	434	577
Kentucky	57	2	93	152	60	5	145	210
Louisiana	43	2	1,442	1,486	39	1	973	1,013
Maine	33	20	175	228	8	19	258	285
Maryland	68	80	195	343	77	173	139	389
Massachusetts	32	6	279	318	26	8	673	707
Michigan	230	19	1,259	1,509	240	26	1,325	1,591
Minnesota	132	171	376	679	132	258	354	744
Mississippi	22	(3)	141	162	20	(3)	140	160
Missouri	138	31	262	431	166	48	458	672
Montana	2	44	5	51	1	64	3	68
Nebraska	84	24	208	317	73	30	245	348
Nevada	2	239	W	240	2	408	W	410
New Hampshire	5	4	200	209	4	4	214	222
New Jersey	118	102	193	413	125	145	338	608
New Mexico	7	64	1	72	7	48	—	55
New York	190	52	2,067	2,308	144	52	2,546	2,742
North Carolina	279	51	46	376	264	42	81	387
North Dakota	8	22	9	39	11	36	18	65
Ohio	347	30	1,442	1,819	349	33	1,573	1,955
Oklahoma	29	16	52	97	31	16	52	99
Oregon	15	45	1	61	12	56	1	69
Pennsylvania	194	103	728	1,025	180	132	1,064	1,376
Rhode Island	7	7	35	50	10	7	50	67
South Carolina	47	10	9	66	43	8	12	63
South Dakota	32	77	32	141	32	60	48	140
Tennessee	73	1	271	345	75	2	271	348
Texas	164	117	298	580	176	139	320	635
Utah	5	206	W	211	6	367	W	373
Vermont	6	1	227	234	5	1	179	185
Virginia	86	32	46	164	100	49	160	309
Washington	20	240	(3)	260	23	329	(3)	352
West Virginia	13	3	148	163	13	3	128	144
Wisconsin	221	93	1,016	1,330	227	124	977	1,328
Wyoming	(3)	27	1	28	(3)	26	2	28
Other[4]	127	64	389	581	208	88	413	709
Total[2] [5]	4,104	3,442	14,567	22,114	4,127	4,702	16,775	25,604

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

[1] Each salt type includes domestic and imported quantities. Brine is excluded because brine usually is not shipped out of State.

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

[3] Less than 1/2 unit.

[4] Includes shipments to overseas areas administered by the United States, Puerto Rico, exports, some shipments to unspecified destinations, and shipments to States indicated by symbol W.

[5] Because data include salt imported, purchased and/or sold from inventory from regional distribution centers, evaporated and rock salt distributed by State may differ from totals shown in tables 1, 2, and 5, which are derived from plant reports at salt production locations. Data may differ from totals shown in table 7 because of changes in inventory and/or incomplete data reporting.

TABLE 9

CHLORINE AND SODIUM HYDROXIDE PRODUCTION IN THE UNITED STATES

(Metric tons)

	Bureau of the Census		The Chlorine Institute	
	Chlorine gas, 100%	Sodium hydroxide liquid, 100%	Chlorine gas, 100%	Sodium hydroxide liquid, 100%
1989	[r]10,353,653	[r]10,404,177	10,803,494	11,345,994
1990	[r]10,713,293	[r]10,913,269	10,747,326	11,302,760
1991	[r]10,498,158	[r]10,916,271	10,423,461	11,023,463
1992[r]	10,665,980	11,111,676	10,574,504	11,188,850
1993	10,911,577	11,661,126	10,871,189	11,451,426

[r]Revised.

Sources: Bureau of the Census and The Chlorine Institute.

TABLE 10

SALT YEAREND PRICES

	1992	1993
Salt, evaporated, common:		
80-pound bags, carlots or truckloads:		
North, works, 80 pounds	$4.02	$4.02
Bulk, same basis, per ton	$60.00-61.20	$60.00-61.20
Salt, chemical grade, same basis:		
North, works, 80 pounds	4.30	4.30
Salt, rock, medium, coarse:		
Same basis, 80 pounds	2.70	2.70
Bulk, same basis, per ton	18.00-25.00	18.00-25.00
Sodium chloride, U.S.P.:		
Granular bags, per pound	.29	.29

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials, v. 242, No. 26, Dec. 28, 1992, p. 29; and v. 245, No. 1, Jan. 3, 1994, p. 30.

TABLE 11
AVERAGE VALUES[1] [2] OF SALT, BY PRODUCT FORM AND TYPE

(Dollars per metric ton)

Product form	Vacuum pans and open pans	Solar	Rock	Brine
1992				
Bulk	49.88	16.53	17.52	4.35
Compressed pellets	124.83	77.42	XX	XX
Packaged	[r]131.37	54.35	[r]63.15	XX
Average[3]	[r]113.20	32.56	19.63	4.35
Pressed blocks	[r]98.22	[r]82.51	[r]93.40	XX
1993				
Bulk	49.62	15.56	18.40	5.22
Compressed pellets	129.16	49.36	XX	XX
Packaged	124.73	38.71	64.07	XX
Average[3]	111.99	26.13	20.27	5.22
Pressed blocks	100.38	55.12	97.54	XX

[r] Revised. XX Not applicable.

[1] Net selling value, f.o.b. plant, excluding container costs.

[2] Average values calculated using unrounded totals.

[3] Salt value data previously reported were an aggregate value per ton of bulk, compressed pellets, and packaged salt. For time series continuity, an average of these three types of product forms is presented, which is based on the aggregated values and quantities of the product form for each type of salt shown in table 5.

TABLE 12
U.S. EXPORTS OF SALT, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Argentina	(1)	19	(1)	30
Australia	(1)	41	2	87
Bahamas, The	2	162	2	138
Bahrain	1	318	1	299
Belize	(1)	12	(1)	9
Brazil	(1)	10	(1)	15
Canada	718	19,562	499	20,424
Chile	(1)	6	1	29
Costa Rica	(1)	21	1	28
Dominican Republic	(1)	69	(1)	87
El Salvador	1	99	5	440
France	(1)	36	(1)	56
Germany	2	28	2	69
Guatemala	3	240	1	96
Honduras	(1)	34	3	181
Hong Kong	(1)	4	(1)	65
Ireland	(1)	6	(1)	26
Jamaica	6	158	2	154
Japan	35	913	11	644
Korea, Republic of	84	2,173	32	2,075
Mexico	110	4,487	66	3,856
Netherlands	(1)	36	(1)	7
Netherlands Antilles	(1)	91	(1)	65
Panama	1	107	2	187
Saudi Arabia	13	1,865	29	3,377
Taiwan	1	89	8	705
Trinidad and Tobago	(1)	6	(1)	5
United Arab Emirates	(1)	149	1	282
United Kingdom	8	831	1	131
Venezuela	(1)	3	1	24
Other	8	618	16	1,215
Total[2]	992	32,193	688	34,806

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13

U.S. EXPORTS OF SALT, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1992		1993	
	Quantity	Value	Quantity	Value
Anchorage, AK	(1)	3	27	410
Baltimore, MD	5	1,167	10	1,424
Boston, MA	1	25	—	—
Buffalo, NY	64	2,190	12	1,575
Charleston, SC	—	—	(1)	7
Chicago, IL	65	940	(1)	13
Cleveland, OH	327	5,858	276	6,576
Columbia-Snake, OR	1	81	(1)	77
Detroit, MI	46	2,836	63	3,660
Duluth, MN	(1)	24	(1)	24
El Paso, TX	28	1,258	1	126
Great Falls, MT	13	479	2	223
Houston, TX	1	246	11	903
Laredo, TX	80	2,893	61	2,518
Los Angeles, CA	5	426	36	2,176
Miami, FL	4	422	5	360
Mobile, AL	(1)	48	1	135
New Orleans, LA	13	792	15	1,939
New York, NY	6	905	4	285
Nogales, AZ	(1)	23	1	65
Norfolk, VA	4	67	7	1,426
Ogdensburg, NY	41	801	4	454
Pembina, ND	2	147	1	207
Philadelphia, PA	(1)	41	(1)	37
St. Albans, VT	(1)	9	—	—
St. Louis, MO	(1)	17	(1)	56
San Diego, CA	3	322	1	259
San Francisco, CA	35	980	28	1,210
San Juan, PR	1	34	(1)	26
Savannah, GA	4	781	7	1,132
Seattle, WA	89	2,199	13	1,013
Tampa, FL	(1)	62	(1)	33
Other[2]	154	6,115	100	6,454
Total[3]	992	32,193	688	34,806

[1] Less than 1/2 unit.

[2] Unknown, but assumed to be rail and/or truck shipments to Canada through various points of entry.

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

Source: Bureau of the Census.

TABLE 14

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

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Bahamas, The	534	7,589	807	11,334
Bermuda	—	—	19	298
Brazil	36	420	106	1,200
Canada	2,505	42,798	3,102	53,021
Chile	203	3,226	192	4,183
France	154	572	3	599
Germany	3	739	3	536
Italy	24	311	1	70
Korea, Republic of	57	346	3	564
Mexico	1,416	21,008	1,340	20,938
Netherlands	325	7,616	176	4,137
Netherlands Antilles	124	2,345	93	1,709
Spain	9	23	16	531
United Kingdom	([1])	112	2	113
Other	3	609	4	728
Total[2]	5,394	87,714	5,868	99,963

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF SALT, BY CUSTOMS DISTRICT

(Thousand metric tons and thousand dollars)

Customs district	1992		1993	
	Quantity	Value	Quantity	Value
Anchorage, AK	16	599	—	—
Baltimore, MD	287	4,873	344	6,613
Boston, MA	168	2,977	295	5,825
Buffalo, NY	117	1,428	4	363
Charleston, SC	347	6,291	94	1,965
Chicago, IL	111	2,300	575	9,471
Cleveland, OH	176	3,246	127	2,410
Columbia-Snake, OR	437	5,553	363	4,208
Dallas-Fort Worth, TX	1	88	—	—
Detroit, MI	804	13,804	873	15,781
Duluth, MN	210	2,872	175	2,467
El Paso, TX	—	—	(1)	3
Great Falls, MT	—	—	(1)	17
Honolulu, HI	(1)	3	(1)	30
Houston, TX	(1)	48	(1)	23
Los Angeles, CA	93	1,445	119	2,081
Miami, FL	12	65	(1)	43
Milwaukee, WI	603	10,299	748	13,701
Minneapolis, MN	(1)	9	20	334
New Orleans, LA	161	2,200	176	2,444
New York, NY	339	3,357	235	5,378
Norfolk, VA	44	640	19	288
Ogdensburg, NY	1	80	49	915
Pembina, ND	12	293	12	379
Philadelphia, PA	112	1,713	329	4,723
Portland, ME	286	5,348	356	5,164
Providence, RI	52	659	70	782
St. Albans, VT	(1)	43	(1)	12
St. Louis, MO	(1)	2	(1)	26
San Diego, CA	(1)	72	(1)	46
San Francisco, CA	2	44	(1)	42
San Juan, PR	7	411	16	595
Savannah, GA	220	3,979	83	1,390
Seattle, WA	507	8,090	454	6,935
Tampa, FL	181	2,666	209	3,085
Washington, DC	—	—	(1)	3
Wilmington, NC	86	2,216	120	2,418
Total[2]	5,394	87,714	5,868	99,963

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 16
SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Afghanistan (rock salt)[e]	10	10	12	12	13
Albania[e]	80	[3]85	[r]55	[r]5	10
Algeria	229	222	211	[e]210	210
Angola[e]	70	70	70	70	70
Argentina:					
Rock salt[e]	1	1	1	1	1
Other salt	1,185	[r]595	[r]678	[r]937	1,000
Armenia	—	—	—	[e]100	50
Australia (brine salt and marine salt)	7,069	7,227	7,791	[e]8,000	9,000
Austria:					
Brine salt	647	674	[r]698	[r]662	650
Rock salt	1	1	1	[e]1	1
Azerbaijan	—	—	—	[e]50	40
Bahamas, The	858	828	1,096	[r]809	850
Bangladesh (marine salt)[4]	415	350	[e]300	[e]320	340
Belarus	—	—	—	[e]360	300
Benin (marine salt)[e]	(5)	(5)	(5)	(5)	(5)
Bolivia	(5)	(5)	(5)	[e](5)	(5)
Bosnia and Herzegovina	—	—	—	[r][e]70	50
Botswana[6]	—	—	3	[r]54	200
Brazil:					
Marine salt	2,355	4,170	3,703	[e]3,700	3,700
Rock salt	1,298	1,033	4,510	[e]4,500	4,500
Bulgaria	[r]93	[r]93	[r][e]90	[r][e]90	80
Burkina Faso[e]	7	7	7	7	7
Burma[e][7]	[3]262	260	260	260	260
Cambodia[e]	40	40	40	40	40
Canada	[r]11,021	[r]11,261	11,993	[r]11,171	11,169
Cape Verde[e]	3	4	4	4	4
Chile	904	1,834	1,676	[r]1,672	1,400
China[e]	28,000	20,000	24,100	[r]28,100	29,530
Colombia:					
Marine salt	470	478	482	[r]317	317
Rock salt	190	209	219	[r]230	230
Costa Rica (marine salt)[e]	30	40	50	50	45
Croatia	—	—	—	[r][e]15	15
Cuba[e]	[3]206	200	200	185	185
Czech Republic[8]	—	—	—	—	180
Czechoslovakia[9]	344	227	207	[e]200	—
Denmark (sales)	552	522	[r]550	[r]528	525
Dominican Republic (rock salt)	30	11	[r][e]11	[e]12	12
Egypt (marine salt)	1,162	989	891	[e]890	890
El Salvador (marine salt)	5	8	15	[r][e]20	20
Ethiopia:[e][4]					
Marine salt	100	100	85	[r]100	100
Rock salt	10	10	[r]8	10	10

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
France:					
Brine salt	[r]1,138	[r]1,155	[e]1,000	[r]1,651	1,600
Marine salt	[r]1,914	1,298	[e]1,200	[r]1,156	1,200
Rock salt[e]	910	790	800	[r] [3]103	100
Salt in solution	[r]4,305	3,362	[e]3,500	[r]3,206	3,200
Germany:					
Marine salt:					
Eastern states	[r]60	[r]45	—	—	—
Western states	941	785	—	—	—
Total	[r]1,001	[r]830	[r]789	[r]815	807
Rock salt and other:					
Eastern states	[r]5,131	[r]4,081	—	—	—
Western states	10,997	10,808	—	—	—
Total	[r]16,128	[r]14,889	[r]14,190	[r]12,280	11,800
Ghana[e]	50	50	50	50	50
Greece	148	150	[e]150	[e]125	100
Guatemala	63	[r]181	[e]100	[e]100	100
Honduras[e]	30	30	30	30	30
Iceland[e]	3	3	3	[3]4	5
India:[e]					
Marine salt	9,600	9,500	9,500	9,500	9,500
Rock salt	3	3	3	3	2
Indonesia[e]	600	600	610	630	650
Iran[10]	990	848	901	[r]1,108	1,200
Iraq[e]	300	250	120	250	300
Israel	475	426	1,115	1,100	1,100
Italy:					
Brine salt and rock salt	3,501	[r]3,752	[r]3,504	[r]3,211	3,200
Marine salt, crude[e] [11]	[r]685	[r]680	450	500	500
Jamaica	16	12	15	[e]14	14
Japan	1,367	1,377	1,380	[r]1,405	1,400
Jordan	57	55	57	[r]56	56
Kenya (crude salt)	103	102	[e]102	[e]102	102
Korea, North[e]	570	580	580	590	590
Korea, Republic of	830	617	696	[r]772	750
Kuwait	32	[e]30	—	[r] [e]15	30
Laos (rock salt)[e]	[3]8	8	8	8	8
Lebanon[e]	3	3	3	3	3
Leeward and Windward Islands[e]	5	5	5	1	1
Libya[e]	12	12	12	12	12
Madagascar[e]	30	30	30	30	30
Mali[e]	[3]5	5	5	5	5
Malta (marine salt)[e]	([5])	([5])	([5])	([5])	([5])
Martinique[e]	200	200	200	200	200
Mauritania[e]	6	6	6	6	6
Mauritius[e]	6	6	6	6	6
Mexico	[r]6,703	7,135	[r]7,533	[r]7,395	7,240

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Mongolia[e]	16	17	17	17	18
Morocco (rock salt)	89	125	109	[r]165	164
Mozambique (marine salt)[e]	40	40	40	40	40
Namibia (marine salt)	142	157	141	[r]115	130
Nepal[12]	7	7	7	[e]7	7
Netherlands	3,756	3,653	3,417	[r]3,628	3,500
Netherlands Antilles[e]	350	350	350	350	300
New Zealand[e]	76	80	80	80	80
Nicaragua (marine salt)[e]	15	15	15	15	15
Niger	3	3	[e]3	[e]3	3
Pakistan:[4]					
Marine salt	250	14	12	[r]10	15
Rock salt	721	763	769	[r]853	950
Panama (marine salt)[e]	[r]18	[r]22	[r]18	20	20
Peru[e]	200	200	200	[r][3]238	238
Philippines (marine salt)	489	490	493	[r]496	500
Poland:					
Rock salt	995	556	[r]556	[r]582	600
Other salt	3,675	3,499	[r]3,284	[r]3,305	3,400
Portugal:					
Marine salt[e]	150	125	125	125	125
Rock salt	584	523	[r]525	[e]525	530
Romania:					
Rock salt[e]	[r]2,000	[r]2,000	[r]1,000	[r][3]900	900
Other salt	[r]3,038	[r]2,262	[r][e]3,000	[r]1,590	1,500
Russia	—	—	—	[r][e]4,000	3,500
Senegal[e]	97	92	102	[r]110	110
Serbia and Montenegro	—	—	—	[r]47	45
Sierra Leone[e]	200	200	200	200	200
Slovakia[8]	—	—	—	—	70
Slovenia	—	—	—	[e]8	8
Somalia[e]	2	2	1	1	1
South Africa, Republic of	692	728	665	702	660
Spain:					
Marine salt and other evaporated salt[e]	594	858	[e]900	[e]900	900
Rock salt	2,496	2,519	[e]2,500	[r][e]2,870	2,800
Sri Lanka	150	53	53	[r]122	130
Sudan	91	68	[e]75	[e]75	75
Switzerland	243	254	[e]250	[r]276	300
Syria	138	127	[e]127	[e]127	127
Taiwan (marine salt)	170	83	195	[r]26	184
Tanzania	20	39	64	[e]64	64
Thailand:					
Rock salt	15	119	125	[r]213	200
Other[e]	165	100	100	100	100
Tunisia (marine salt)	480	402	441	[r]460	460
Turkey	1,739	[r]1,889	1,440	[r]1,418	1,425

See footnotes at end of table.

TABLE 16—Continued

SALT: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Uganda[e]	5	5	5	5	5
U.S.S.R.[13]	15,000	14,700	[e]14,000	—	—
Ukraine	—	—	—	[e]4,400	4,000
United Kingdom:					
Brine salt[14]	1,344	1,341	1,319	[r] [e]1,200	1,200
Rock salt	[r]1,148	1,102	1,635	[r] [e]1,500	1,500
Other salt[14]	4,228	3,991	3,874	[r]3,401	3,500
United States including Puerto Rico:					
United States:					
Brine	16,509	17,724	18,640	17,571	[3]18,030
Rock salt	12,645	13,055	11,064	10,911	[3]13,401
Solar salt	2,498	2,484	2,575	2,539	[3]3,384
Vacuum pan salt	3,599	3,655	3,623	3,763	[3]3,850
Puerto Rico[e]	41	41	41	[3]45	45
Venezuela	365	439	430	[r]318	350
Vietnam[e]	320	340	350	350	350
Yemen[e]	230	[3]220	[r]250	[r]280	280
Yugoslavia:[15]					
Brine salt	184	204	[e]220	—	—
Marine salt	60	71	[e]70	—	—
Rock salt	134	100	[e]100	—	—
Total	[r]191,660	[r]182,445	[r]188,265	[r]181,270	186,190

[e] Estimated. [r] Revised.

[1] Table includes data available through June 20, 1994.

[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] From natural soda ash production.

[7] Brine salt production as reported by the Burmese Government in metric tons, was as follows: 1989—60,229; 1990—49,670; 1991—46,835; 1992—46,509 (revised); 1993—58,500 (estimated).

[8] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[9] Dissolved Dec. 31, 1992.

[10] Year begining Mar. 21 of that stated.

[11] Does not include production from Sardinia and Sicily, estimated at 200,000 metric tons annually.

[12] Year ending July 15 of that stated.

[13] Dissolved in Dec. 1991.

[14] Data captioned "Brine salt" for the United Kingdom are the quantities of salt obtained from the evaporation of brines; that captioned "Other salt" are the salt content of brines used for purposes other than production of salt.

[15] Dissolved in Apr. 1992.

CONSTRUCTION SAND AND GRAVEL

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years of industry experience, has been the construction sand and gravel commodity specialist with the U.S. Bureau of Mines since 1979. Domestic survey data were prepared by the construction sand and gravel survey staff of the Branch of Data Collection and Coordination.

Construction sand and gravel is one of the most accessible natural resources and a major basic raw material used mostly by the construction industry. Despite the relative low value of its basic products, the construction sand and gravel industry is a major contributor to and an indicator of the economic well-being of the Nation.

Beginning with this issue, the statistical information included in the Annual Report for Construction Sand and Gravel is published in metric units in compliance with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418). The information that was published in prior years in short tons was converted to metric tons in this issue of the Annual Report. During 1994, only the totals in each table are published in dual units: metric tons and short tons.

A total of 869 million metric tons [958 million short tons (Mst)] of construction sand and gravel was estimated to have been produced in the United States in 1993, a 4.2% increase compared with the total production of 1992. This tonnage represents the highest production level since the record production of 1978, indicating a significant increase in the demand for construction aggregates in the United States in 1993. *(See table 1.)*

Foreign trade of construction sand and gravel remained relatively small. Exports of construction sand and gravel decreased 20.4% tc 1.1 million metric tons (1.2 Mst), while value decreased 13.2% to $15.6 million. Imports of construction sand and gravel remained unchanged at 1.3 million metric tons (1.5 Mst), while the value decreased slightly to $15.4 million. Domestic apparent consumption of construction sand and gravel was 869 million metric tons (958 Mst).

The major issues of concern to the construction sand and gravel industry continue to be the implementation of the Clean Air Act Amendments of 1990 and their complex legal and technical provisions; the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, section 404, dealing with "wetlands" and the associated "no net loss of wetlands" policy; the Storm Water Pollution Prevention Program; the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standards regulating the use of products containing more than 0.1% crystalline silica; and the provisions of the Federal Endangered Species Act.

DOMESTIC DATA COVERAGE

Domestic production data for construction sand and gravel are developed by the U.S. Bureau of Mines (USBM) from voluntary surveys of U.S. producers. Full surveys of construction sand and gravel producers are conducted for even-numbered years only. For odd-numbered years, only annual estimates for each State are generated based on information provided by the quarterly sample survey of construction sand and gravel and crushed stone producers. This survey provides production estimates by quarters for each State and the nine geographic regions. The sample surveys canvass most of the large companies in each State, accounting for up to 80% of most States' total tonnage. The results of this survey are published each quarter in a separate publication, the Quarterly Mineral Industry Survey.

BACKGROUND

Sand and gravel is a granular, unconsolidated, and usually rounded agglomeration of particles of rocks and minerals, resulting primarily from the natural disintegration and abrasion of rocks through weathering or erosion. Sand and gravel, as one of the most accessible natural resources, has been used since the earliest days of civilization, mostly as a construction material. At the beginning of the 20th century, U.S. production of construction 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 U.S.-Canadian and U.S.-Mexican borders.

Most sand and gravel is used for construction purposes, mainly as aggregate in concrete; as road base material in the construction and repair of highways, railways, and runways; and as aggregate in asphaltic concrete for paving highways, streets, etc. Construction sand and gravel has one of the lowest average per ton values of all mineral commodities. The constant dollar price has changed relatively little over the past 20 years. Increased operating costs have been partially offset by automation and other means of increasing operating efficiency.

Although construction sand and gravel resources are widespread and in adequate supply nationally, local shortages exist. Land use conflicts and environmental problems associated with rapid urban expansion are major factors contributing to these shortages. In addition, in some geographic areas with sufficient resources, some shortages occur because the proportions of various size fractions of sand or gravel may not meet size specifications of the construction industry. Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future. This will permit increased use of less accessible and lower quality deposits and will keep prices at competitive levels.

Definitions, Grades, and Specifications

Sand is defined throughout the industry and by the American Society for Testing and Materials (ASTM) as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a No. 4-mesh (4.75-millimeter) U.S. standard sieve and are retained on a No. 200-mesh (75-micrometer) 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-millimeter)-square openings and are retained on a No. 4-mesh U.S. standard sieve.

Sand and gravel is made up of varying amounts of different rock types and is, therefore, of varying chemical composition. Silica is the major constituent of most commercial sands, and lesser amounts of feldspar, mica, iron oxides, and heavy minerals are common. Most applications of sand and gravel have specifications for size, physical characteristics, and chemical composition. A compilation of 42 ASTM Specifications and Test Methods, including the latest revisions and updates pertaining to aggregates, concrete, and admixtures, was reprinted by the National Aggregates Association.[1]

Specifications for sand and gravel used in roadbuilding and concrete construction are often rigid regarding particle size gradation and shape and include physical as well as some chemical properties. However, these specifications can differ in detail from State to State or even from city to city within the State. Soil conditions, climate, and peculiarities in different deposits may necessitate adjustments of requirements of sand and gravel mixtures and chemical composition.

Specifications are written by commercial users; Government agencies, including Federal; State, county, and city construction and highway departments; and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Uses and Products for Trade and Industry

Concrete is made by mixing properly sized aggregate, portland cement, and water into a slurry. Chemical action between the cement and the water results in the crystallization of hydrous calcium aluminum silicates, which causes the mass to bind and harden. Round particles in the aggregate are desirable because they improve the workability of the concrete as it is poured. If broken material is used and angular or flattish fragments exceed about 15% of the total volume, workability can be maintained only by increasing the amount of sand and water, thus reducing strength, or by adding more cement, thus increasing the cost of the concrete.

Sized and broken sand and gravel is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than do rounded surfaces and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than do rounded particles and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long-duration stresses.

Industry Structure

Because of the low unit value, construction sand and gravel is produced near the point of use; therefore, the industry is concentrated in or nearby large, 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 populations and largest production of sand and gravel.

Construction sand and gravel is produced in virtually all countries, but relatively few of them publish official statistics on sand and gravel and even fewer regularly survey their industries.

On the basis of tonnage, the construction sand and gravel industry is the second largest nonfuel mineral industry in the United States. In 1992, the last year when a full survey was conducted, there were 4,213 companies producing construction sand and gravel from 5,999 operations with 8,424 pits. The individual operations range in size from those producing millions of tons annually to those reporting less than 25,000 tons per year. Most operations are small, turning out one product or a limited number of products, but most of the tonnage comes from large operations. For example, the 18 operations reporting more than 2 million tons each in 1992 represented only 0.2% of the total number of operations but produced 6.7% of the total tonnage, while 81 operations reporting between 1 and 2 million tons each, representing only 1.4% of the total number of operations, produced 12.2% of the total tonnage. In 1992, most of the construction sand and gravel was produced by operations reporting between 200,000 and 1,000,000 tons each—1,191 operations, or 20% of the total, produced 52.1% of the total tonnage.

The leading companies producing construction sand and gravel, in descending order of tonnage, based on the 1992 survey, were CalMat Co. of Los Angeles, CA; Beazer U.S.A. Inc./Hanson PLC of Walnut Creek, CA; CSR America, Inc., of Atlanta, GA; APAC Inc., of Atlanta, GA, a subsidiary of Ashland Oil of Russell, KY; and Western Mobile, Inc., of Ft. Collins, CO, a subsidiary of Redland PLC of Groby, Leicester, United Kingdom. The top 5 companies operated 203 pits and produced 10.1% of the U.S. total. Three of these five companies are subsidiaries of foreign companies.

Many producers are in the sand and gravel business exclusively, but others are diversified in various degrees in the production of other mineral raw materials, intermediate construction products such as ready-mixed concrete and concrete blocks, final manufactured products, or construction of buildings, roads, and other structures. At the same time, construction companies are entering more into the sand and gravel business to integrate their operations.

Geology-Resources

The processes of formation and deposition impart to sands and gravels the physical characteristics that largely determine the commercial value for a particular use and influence the manner of development. The principal types, based on origin, are stream, glacial, residual, marine, and lake. Windblown deposits are of minor importance. Much of the commercial production is from stream deposits, many of which are deficient in the fines required by present-day grading specifications for concrete aggregates. Stream deposits usually exhibit stratification and often large-size gradation. The beds vary in thickness and sometimes have interspersed lenses of clay or fine sand. The degree of roundness and the particle size varies with the hardness and distance transported. Glacial deposits have the least sorting of all transported deposits, while marine and lake deposits exhibit the best sorting with coarse and fine particles, often well segregated. Residual deposits are found overlying the parent rock and are unstratified mixtures of pebbles, boulders, sand, and clay. They often contain much soft material that prohibits commercial production. Marine or offshore deposits could become more important as inland deposits become depleted or environmentally less desirable to extract. A comprehensive report showing geologic occurrences of potential sources of sand and gravel and crushed stone of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.[2]

On the basis of geologic evidence, world reserves are sufficient to meet demands, although not necessarily at precisely the locations where needed. Reserves, which are measurable amounts of sand and gravel that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The total sand and gravel resources of the United States are very large. However, the geographic distribution and/or quality of the reserve base often does not match market patterns or requirements.

Technology

Major technological developments that have been instrumental in maintaining adequate production at relatively stable real costs include use of larger operating units, more efficient portable and semiportable plants, unitized plants for versatility of plant capacity, new prospecting methods utilizing aerial and geophysical surveying methods, and greatly increased rehabilitation and resale of mined areas. Use of mined-out pits as lake beds and as sanitary landfill areas has been successful at numerous localities. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations. Along with the use of improved equipment, these 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 improve productivity and minimize environmental conflicts.

Exploration.—Sand and gravel deposits, like any mineral deposit, must be explored and evaluated before development. Preliminary examination can establish the extent and nature of the deposits. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information on the quantity of material available, the degree of uniformity throughout the deposit, and, especially, variations in particle size, both vertically and horizontally. Also, the nature and amount of waste materials and the economic feasibility of their removal must be studied.

Geophysical methods are of value in preliminary surveys. Detailed exploration may be achieved by a systematic arrangement of test pits, trenches, boreholes, or other procedures designed to obtain a cross-section of the deposit in conjunction with sampling and testing. Advances in interpretation of aerial photographs and increased application of geophysical techniques have made evaluation of sand and gravel deposits more quantitative. For underwater exploration, mining devices such as dredges and draglines are used. Pilot runs are necessary to determine if required specifications can be met consistently and economically.

Much of the sand and gravel that is being mined in stream, floodplain, alluvial fan, riverbeds and terrain, and glacial deposits is good quality material with nearly equal amounts of gravel and sand and small amounts of unusable material. As these deposits become depleted in future years, less desirable and more expensive sources will have to be developed where mining, reserves, ratio of sand to gravel, quality of material, waste factors, and environmental factors such as waste disposal will present more problems.

Exploration and planning will become more important in assessing deposits, particularly hillslope deposits of older sand and gravel. Grading to meet required slope and setback requirements at hillslope sites may necessitate leaving large tonnages of material unmined. Many millions of tons of material is available, but it may not be of proper quality or ratio of sand to gravel. More deposits of marginal quality will have to be developed to provide for future demand.

Mining.—Sand and gravel generally occur in the same deposit, but the relative proportions of each vary greatly within most deposits. Consequently, the control problem of producing aggregate to rigid specifications involves combinations of many types of equipment like screens, washers, classifiers, crushers, and grinding mills. The two basic sand and gravel mining methods are open pit excavation and dredging. Open pit excavation and processing has four major steps: (1) site clearing—removing trees and vegetation, stripping overburden and topsoil, and transporting, redepositing, or stockpiling it at or off the site; (2) mining—removing the sand and gravel from the deposit; (3) processing—screening, washing, crushing, blending, and stockpiling the mined material to conform to standards and specifications; and (4) reclamation of the extraction area. Processing may or may not take place at the mining site. Mining equipment ranges from small, simple units such as tractor-mounted high-loaders and dump trucks to more sophisticated systems involving large power shovels, draglines, bucket wheel excavators, and belt conveyors. Increasingly, mining systems are being designed to provide for more efficient and economical land reclamation.

Mining with a dredge usually involves mounting the equipment on boats or barges. Suction or bucket-type dredges are used most commonly to harvest sand and gravel from the bottom of a body of water. The sand and gravel is processed either on board or transported to land for processing.

Processing.—Although small amounts of unprocessed bank-run sand and gravel are used for fill, most of the U.S. production is processed in some way. Present methods include washing with water during the screening process, in some cases followed by crushing of the larger particles in cone or gyratory crushers. Secondary crushing may be done by roll crushers. Sizing is done in most plants by horizontal or sloped single or multideck vibratory screens. If necessary, heavy-media separation or jigging is used to remove heavy, unusable materials. Sand for use in construction is freed from clay by log washers or rotary scrubbers. The scrubbing is followed by classification, use of separatory cones or hydroseparators to remove water, and fine screening for grading. Rodmilling is often required for production of small-sized fractions of sand. Transfer of processed sand and gravel from the processing plant to stockpiles or bins is accomplished by flexible combinations of conveyor belts, bucket elevators, and screw conveyors.

Permanent installations are built when large deposits are to be operated for many years. Portable and semiportable units are used in many pits that have an intermediate working life. Several such units can be tied together to obtain large initial production capacity or to add capacity as needed. Mobile screening plants can be quickly moved from one deposit to another without undue interruption or loss of production.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Local scarcity or high cost of construction aggregates in some areas as well as waste disposal problems are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement and also because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.[3] The amount of asphalt roads recycled is significantly larger than that of concrete roads, mainly because asphalt can be rejuvenated with oil additives and used in pavements, significantly reducing the cost of the finished road. Experience has shown that about 35% of crushed asphalt pavement can be recycled into new asphalt mixtures. Proper testing under engineering supervision in all construction projects using recycled materials as aggregates should be performed to ensure that the technical specifications are met.

Byproducts and Coproducts

Small amounts of gold and silver are recovered as a byproduct or coproduct of sand and gravel extraction, particularly in highly sorted deposits.

Economic Factors

Construction sand and gravel is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets. Production costs vary widely depending on geographic location, the nature of the deposit, and the number and type of products produced. Constant dollar unit values have been quite steady during the past 20 years. As a result of rising costs of labor, energy, and mining and processing equipment, the average unit price of construction sand and gravel increased from $1.1 per ton, f.o.b. plant, in 1970 to $3.63 in 1992. However, the unit price in constant 1982 dollars fluctuated between $2.64 and $2.71 per ton for the same period. Increased productivity achieved through increased use of automation and more efficient equipment was mainly responsible for maintaining the prices at this level. Constant dollar prices are expected to rise in the future because of decreased deposit quality and more stringent environmental and land use regulations.

Accessibility is a problem for the construction sand and gravel industry. The high-volume 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, or parks and 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 longerlived, can afford greater capital investment for higher efficiency, and often are where competing land use pressures are less severe. The topographically rugged stone-bearing areas are usually less desirable for construction purposes than sand-and-gravel-bearing areas, which are generally flatter.

A 5% depletion allowance based on gross income is allowed for construction sand and gravel. There are no import tariffs.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a sand and gravel company owns or leases land within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines or regulations of the appropriate governmental agency must also be approved. Environmental concerns such as noise, dust, beautification, and storage of wastes must be accounted for in a manner satisfactory to the governmental entity involved. Wastewater discharge requirements must be planned for and met. If the deposit to be worked is on a river or land controlled by a river or water or flood control agency, whether municipal, State, or Federal, that agency's requirement must also be satisfied.

In most States, permits for sand and gravel operations require an Environmental Impact Report or Environmental Impact Statement (EIS). A reclamation plan and a use permit application may also be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Issues.—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, 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. Rail and water transportation combined account for about 10% to 20% of total construction sand and gravel shipments.

ANNUAL REVIEW

A total of 869 million metric tons (958 million short tons) of construction sand and gravel was estimated to have been produced in the United States in 1993, a 4.2% increase compared with the total production of 1992. This tonnage represents the highest production level since the record production of 1978, indicating a significant increase in the demand for construction aggregates in the United States in 1993. *(See table 3.)*

During the year, production of construction sand and gravel increased every quarter, compared with the same period of 1992, with the largest increases occurring in the third and fourth quarters of 1993.

Legislation

The Department of Transportation and Related Agencies Appropriation Act of 1994 (Public Law 103-122) was signed by the President on October 27, 1993. The act appropriates $20.6 billion for new highway spending, a $2 billion increase from the fiscal year 1993 total. The act also includes a $2.2 billion appropriation in grants for airport construction and provision for a 1-year delay in the imposition of the "crumb rubber" use in highway construction as required by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991.

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the crushed stone industry. There is a significant amount of uncertainty regarding the process of designating some lands as wetlands and whether the current exemptions to the Clean Water Act, section 404, permit program will be maintained in the future. On August 24, 1993, the administration's wetlands policy was announced. The new policy endorses an interim goal of "no overall net loss" of wetlands and a long-term goal of increasing wetlands quantity and quality; provides for administrative appeals of permitting process decisions; establishes deadlines for the Army Corps of Engineers' decisions on permit applications, generally within 90 days; mandates the use of the 1987 Wetlands Delineation Manual by the Army Corps of Engineers, Environmental Protection Agency (EPA), Soil Conservation Service, and Fish and Wildlife Service to identify wetlands; encourages the development of wetland mitigation banks; and promotes the long-term restoration of wetlands through voluntary, nonregulatory programs.

Several bills were reintroduced in the 103d U.S. Congress to replace the current section 404 of the Federal Water Pollution Control Act. These proposed bills plan to provide a concise and structured program for the delineation of wetlands based on their functions and values and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The complex legal and technical provisions of the comprehensive amendments to the Clean Air Act of 1990 and implementation of regulations for these provisions continues to constitute another major area of concern to the crushed stone industry. One major emphasis of the amendments is the expanded authority given to EPA and the States to enforce the new law and to assess increased penalties. EPA is now authorized to issue administrative orders with penalties of up to $200,000 for noncompliance, and its field inspectors can issue citations for minor violations with penalties of up to $5,000 per day for each violation. The law also includes provisions for new Federal permits to be issued by the State agencies that include source-specific emission limitations and related monitoring, recordkeeping, and reporting requirements. Complying with the new provisions of the Clean Air Act, amendments will constitute a major challenge to all crushed stone producers.

Another issue of concern to the construction aggregates industries is the classification of crystalline silica as a probable human carcinogen by the International Agency for Research on Cancer, an agency of the World Health Organization. OSHA-regulated sites that receive and/or use products containing more than 0.1% crystalline silica must comply with OSHA's Hazard Communication Standards. Both the classification of crystalline silica as a probable human carcinogen and the requirement to quantitatively analyze for crystalline silica at the 0.1% level are controversial.

Production

The production estimates indicate that in 1993 the U.S. production of construction sand and gravel was 869 million metric tons (958 million short tons), a 4.2% increase compared with the total production of 1992. Of the four major geographic regions, the West again led the Nation in the production of construction sand and gravel with 314 million tons, or 36.1% of the U.S. total, followed by the Midwest with 274 million tons, or 31.5% of the total, and the South with 188 million tons, or 21.6%. Compared with 1992, production by major geographic regions increased in the South, 9.4%; in the West, 4.5%; and in the Midwest, 2.4%; while decreasing in the Northeast by 1.9%. *(See table 2 and figure 1.)* Of the nine geographic regions, the East North Central led the Nation with 181 million tons, or 20.9% of the U.S. total. Next was the Pacific with 164 million tons, or 18.9% of the total, and the Mountain with 150 million tons, or 17.2% of the total. Compared with 1992, production increased in all regions except New England, West North Central, and Pacific. The largest increases were recorded in the Mountain region, 13.3%; the East South Central region, 10.7%; and the West South Central region, 9.5%. *(See table 2.)*

The estimated production by quarters for 1993 indicated that most of the construction sand and gravel in the United States was produced in the third quarter, followed by the second quarter and the fourth quarter. Estimated production by each quarter of 1993 was also available for most of the States. *(See table 5.)*

Construction sand and gravel was produced in every State, and the 1993 production estimates indicate that the 10 leading States, in descending order of tonnage, were California, Texas, Ohio, Michigan, Washington, Arizona, New York, Illinois, Minnesota, and Colorado. Their combined production represented 50.5% of the national total. *(See table 4.)*

Compared with 1992, production increased in 34 States, including 8 of the top 10 States. The major increases, in percentage, occurred in Mississippi, 39.8%; New York, 22.3%; and Arizona, 14%. Production decreased in 15 States, with the major decreases, in percentage, occurring in Maine, 27.6%; Minnesota, 10.6%; and California, 6%.

Limited information about the production of construction sand and gravel in foreign countries may be found in the USBM "Minerals Yearbook, Area Reports: International." For nonreporting countries, estimates of sand and gravel and crushed stone outputs can be based on indirect sources of information such as the level of cement consumption.

In the second half of 1993, Beazer USA, Inc./Hanson Industries of Walnut Creek, CA, a subsidiary of Hanson PLC of London, United Kingdom, reorganized its U.S. operations to provide more local operational and financial control and to capitalize on the company's more recognizable names in regional markets. Beazer Northeast became General Materials & Construction Co. of Easton, PA; Beazer Southeast became Benchmark Materials Co. of Research Triangle Park, NC; Beazer Northwest became Kaiser Materials Corp. of Pleasanton, CA; and Beazer Southwest became Southwest Construction Materials and Services Co. of Long Beach, CA. Gifford-Hill & Co. of Dallas, TX, and Spectrum Construction Co. of Virginia Beach, VA, also part of the Beazer Group, will retain their original names.

On November 12, 1993, Martin Marietta Corp. announced that its construction materials division, Martin Marietta Aggregates, will become a separate company, Martin Marietta Materials Inc., in Raleigh, NC. The new company that was incorporated in North Carolina will be a wholly owned subsidiary of Martin Marietta Corp. On December 8, 1993, a registration statement was filed with the Security and Exchange Commission for an underwritten public offering of about 19% of the company's common stocks.

In December 1993, Lafarge Corp. of Reston, VA, announced the restructuring of its North American operations by consolidating 11 cement and construction materials regional operating units into six units. Effective January 1, 1994, Lafarge's new North American organization will include three regional centers for construction materials: Western, based in Calgary, Alberta, Canada; Eastern, based in Toronto, Ontario, Canada; and the United States, based in Canfield, Ohio; and three regional offices for cement's group in Calgary, Alberta, Canada; Montreal, Quebec, Canada; and the United States in Southfield, MI.

Consumption and Uses

Sand and gravel reported by producers to the USBM 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 USBM, 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.

Of the 834 million metric tons (919 Mst) of construction sand and gravel produced in 1992, the last year when a complete survey of producers was conducted by the USBM, 213 Mmt (235 Mst) or 25.6% of the total was for unspecified uses. Of the remaining 588 Mmt (648 Mst) 41% was used as concrete aggregates; 29.9% for road base and coverings and road stabilization; 14.9% as asphaltic concrete aggregates and other bituminous mixtures; 13.7% as construction fill; 1.9% for concrete products such as blocks, bricks, pipes, etc.; 1.5% for plaster and gunite sands; and the remainder for snow and ice control, railroad blast, roofing granules, filtration, and other miscellaneous uses.

To provide a more accurate estimation of the consumption patterns for construction sand and gravel, "Unspecified uses—actual and estimated" are not included in the above percentages. The "Unspecified uses" represent quantities reported by some producers only as their total production without a breakdown by uses and estimated quantities for nonreporting companies. It is recommended that in any marketing or use pattern analysis the quantities included in "Unspecified uses" be distributed among the reported uses by applying the above percentages.

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. For 1993, only production estimates were generated for construction sand and gravel, and therefore no information by end uses is available for this year.

Prices

Prices in this chapter are f.o.b. plant, usually at the first point of sale or captive use. This value does not include transportation from the plant or yard to the consumer. It does, however, include all costs of mining, processing, in-plant transportation, overhead costs, and profit. Compared with that of 1992, when the last full annual survey was conducted, the estimated 1993 average unit prices increased only 1.2% to $4.06 per metric ton ($3.63 per short ton).

As a result of rising costs of labor, energy, and mining and processing equipment, the average unit value of construction sand and gravel increased from $1.22 per metric ton, f.o.b. plant, in 1970, to $4.06 in 1993. However, the unit price in constant 1987 dollars declined from $5.48 in 1970 to $2.89 in

1993.

Foreign Trade

The widespread distribution of domestic sand and gravel deposits and the high cost of transportation limits foreign trade mostly to local transactions across international boundaries. U.S. imports and exports are small, representing less than 1% of the domestic consumption.

Exports.—Exports of construction sand decreased 31.4% to 597,000 metric tons, compared with 1992 totals, while value decreased 15.9% to $10.6 million. Canada was the major destination, receiving 61.3% of the total, followed by Mexico with 28.8%. Exports of construction gravel declined 2.9% to 534,000 metric tons, compared with 1992, while value declined 6.9% to $5 million. Canada was the major destination with 88.6% of the total, followed by Mexico with 3.6%. *(See table 6.)*

Imports.—Imports of construction sand and gravel remained at the 1992 level in terms of quantity, 1.3 Mmt, as well as value, $15.4 million. Canada continued to be the major source of imported construction sand and gravel with 73.1% of the total, followed by the Bahamas with 15%. *(See table 7.)*

Current Research

The Center for Aggregates Research (CAR), established by the National Aggregates Association and the National Stone Association and managed through the Aggregates Foundation for Technology, Research, and Education, is the first organization dedicated wholly to aggregates research. A technical advisory committee overviewing the center's activity identified six priority areas of research that include fine aggregates properties and their influence on end products; uses for fines resulting from the processing of aggregates; performance-related tests for aggregates; proper use of aggregates in asphaltic concrete to minimize rutting; prevention of alkali-silica and alkali-carbonate reactivity of aggregates in portland cement concrete; and nature and effects of coatings on aggregates. CAR will concentrate its efforts into these areas.

The University of Texas at Austin and Texas A&M University, the two institutions operated jointly by CAR, already have considerable research in progress related to aggregates. Some of the projects under way are:

- Evaluation of the performance of pavements made with different coarse aggregates including those with different thermal coefficients and the development of design procedures;
- Evaluation of the effectiveness of large stone mixtures in resisting plastic deformation—rutting—in asphalt pavements and recommended design procedures and quality assurance testing and constructability;
- Study of the alkali-silica reaction in concrete containing fly ash. The objectives of the study are to identify the most relevant components of fly ash, portland cement, and aggregates affecting the alkali-silica reaction and to determine the type and amount of a given component to be used in producing high-quality concrete.
- Study of surface friction of seal coat pavements to identify the best methods for determining aggregates properties and characteristics that will accurately predict surface friction performance of seal coats.
- Potential engineering and environmental uses of quarry fines.[4]

The ISTEA of 1991 authorized about $108 million for Strategic Highway Research Program (SHRP) implementation and Long Term Pavement Performance (LTPP) projects. With the completion of SHRP's 5-year research program, the Federal Highway Administration (FHWA) was assigned the responsibility of implementing the research results, products, and techniques through FHWA's Technology Applications program. A series of implementation actions is also being undertaken by the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB). AASHTO's Subcommittee on Materials amended its procedures to accept new product standards on a provisional basis for a maximum of 4 years, during which time hands-on testing will be conducted. At the end of 2 years, the product standards can be balloted for acceptance as regular standards, or the provisional status can be extended for an additional 2 years. The Subcommittee on Materials is also developing information about the specific resources needed to implement SHRP products. TRB has created the TRB/SHRP committee, which will provide industry, highway agencies, and research specialists with a continuing forum to coordinate activities related to implementation of SHRP products and continuation of the LTPP program.

Technology

A new mobile conveyor system designed to load or unload bulk commodity railcars was introduced by Granite Rock Co. of Watsonville, CA, at the Rock by Rail Third Conference held in April 1993 in League City, TX. TransloadXpress conveyor system was engineered by Granite Rock Co. to provide a cost-effective, efficient, and fast method of loading and unloading railcars. TransloadXpress can convey bulk materials at rates of up to 800 tons/hour and can unload rail-to-truck systems at rates averaging 300 tons/hour. TransloadXpress can unload materials into waiting trucks for short hauls to the job site or can convey materials directly into portable ready-mix concrete and asphalt plants. TransloadXpress helps the aggregates producer take advantage of the economies of scale offered by rail shipments and also provides significant environmental advantages. According to a study conducted by the Department of Energy, rail delivers more than eight times the energy efficiency of trucking when measured by the required BTU's per ton-mile of transportation.[5]

A comprehensive review of the available microcomputer software for use in the aggregate-producing industry was published by Rock Products magazine. The review includes software for mine planning, geographic information systems, plant design, mining cost analysis, blasting design, scale management, financial modeling, and accounting. Available information on environmental and occupational health and safety standards, State and Federal regulatory requirements, and legal and engineering codes and standards affecting the aggregates industry is also included in the review.[6]

Quarry blasting usually requires considerably greater control than most mining or public works rock blasting. Maximizing the breakage of rock during primary blasting reduces significantly the need for secondary breakage of oversize rock and therefore reduces the energy consumption required to produce the final product. Efficient and cost-effective blasting requires proper selection of blasthole pattern, explosive selection, delay timing, and initiation sequence, as well as a thorough understanding of the impact the blasting will have on nearby structures. A comprehensive review of the technology, including blasting fragmentation, drilling accuracy, explosive performance, ground vibration, blast size and delay timing, and how the technology can be used to reduce blasting costs, was published by Quarry Management magazine and was reprinted by Rock Products magazine.[7]

OUTLOOK

The demand for construction sand and gravel in 1994 is expected to be about 900 million metric tons (992 Mst), a 3.6% increase from that of 1993. Gradual increases in demand for construction aggregates are anticipated, based on increased volume of work on the infrastructure occurring as a result of the funding provided by ISTEA of 1991. The law authorized $151 billion to be spent in the next 6 years on transportation projects, of which $119.5 billion is for highway work and $32.5 billion for mass transit. It is estimated that the demand for construction sand and gravel will reach 930 Mmt (1,025 Mst) in 1995. The projected increases will be influenced by construction activity in the public as well as the private construction sector.

The value of public construction work as part of the gross domestic 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 significantly 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, especially in and near metropolitan areas, mainly because more aggregates are transported from distant sources.

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TABLE 1
SALIENT U.S. CONSTRUCTION SAND AND GRAVEL STATISTICS

		1989	1990	1991	1992	1993
Sold or used by producers:						
Quantity[1]	thousand metric tons	814,017	828,713	707,876	[r]834,000	[e]868,700
Quantity	thousand short tons[2]	[e]897,300	913,500	[e]780,300	919,300	957,600
Value[1]	thousand dollars	[e]$3,249,100	$3,267,500	[e]$2,805,500	$3,341,300	[e]$3,530,100
Exports	value, thousand dollars	$13,591	$11,880	$19,044	$17,963	$15,594
Imports	do.	$6,618	$22,912	$16,638	$15,463	$15,445

[e]Estimated. [r]Revised.

[1] Hawaii and Puerto Rico excluded from all sand and gravel statistics.

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 2
CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1992				1993[e]			
	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	33,681	4.0	$154,535	4.6	31,400	3.6	$150,100	4.2
Middle Atlantic	60,971	7.3	305,015	9.1	61,500	7.0	325,500	9.2
Midwest:								
East North Central	171,394	20.5	617,290	18.4	181,300	20.8	683,100	19.4
West North Central	95,851	11.4	291,705	8.7	92,400	10.6	287,900	8.2
South:								
South Atlantic	64,103	7.6	265,299	7.9	69,600	8.0	295,000	8.4
East South Central	35,956	4.3	145,651	4.3	39,800	4.5	160,300	4.5
West South Central	71,755	8.6	278,891	8.3	78,600	9.0	314,700	8.9
West:								
Mountain	132,104	15.8	[r]506,919	15.1	149,700	17.2	562,400	15.9
Pacific	168,115	20.1	[r]732,638	21.9	163,900	18.9	751,100	21.3
Total[1]	[r]834,000	100	3,341,300	100	868,700	100	3,530,100	100
Total[2] [3]	919,300	XX	3,341,300	XX	957,600	XX	3,530,100	XX

[e]Estimated. [r]Revised. XX Not applicable.

[1] Data may not add to totals shown because of independent rounding, and differences between projected totals by States and by regions.

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3] Total shown in thousand short tons and thousand dollars.

TABLE 3

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY GEOGRAPHIC REGION AND QUARTER[1]

(Thousand short tons and thousand dollars)

Geographic region	Quantity (thousand metric tons)				Total	Value (thousands)	Number of companies[2]
	1st quarter	2d quarter	3d quarter	4th quarter			
Northeast:							
New England	4,000	9,600	11,700	9,300	34,600	$150,100	25
Middle Atlantic	7,300	19,800	23,500	17,100	67,800	325,500	31
Midwest:							
East North Central	20,000	55,400	68,800	55,700	199,900	683,100	51
West North Central	10,300	[r]27,900	[r]34,200	29,400	101,800	287,900	42
South:							
South Atlantic	15,200	21,400	21,200	18,900	76,700	295,000	49
East South Central	7,500	12,500	12,700	11,300	43,900	160,300	22
West South Central	17,400	23,000	25,100	21,200	86,600	314,700	19
West:							
Mountain	28,300	43,800	48,900	44,100	165,000	562,400	32
Pacific[3]	31,800	44,800	47,600	42,000	166,200	751,100	26
Total[4]	141,700	258,000	293,700	249,100	[5]957,600	[5]3,530,100	XX
Total[6] [7]	128,600	234,100	266,400	226,000	[5]868,700	[5]3,530,100	XX

[r]Revised. XX Not applicable.

[1] As revised from data published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1993 Mineral Industry Survey."

[2] Number of companies reporting for the quarterly survey.

[3] Does not include Alaska and Hawaii.

[4] Data may not add to totals shown because of independent rounding and differences between projected totals by States and by regions.

[5] Includes Alaska.

[6] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[7] Total shown in thousand metric tons and thousand dollars.

TABLE 4

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1992			1993[e]		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value
Alabama	11,153	42,038	$3.77	10,300	39,100	$3.80
Alaska	13,613	43,335	3.18	13,100	42,600	3.25
Arizona	30,701	123,517	4.02	35,000	138,300	3.95
Arkansas	9,896	39,627	4.00	10,100	40,900	4.05
California	102,410	522,108	5.10	96,300	475,700	4.94
Colorado	26,721	105,281	3.94	29,000	117,500	4.05
Connecticut	5,466	30,107	5.51	6,400	34,900	5.45
Delaware	2,257	8,574	3.80	2,500	10,300	4.12
Florida	21,107	66,141	3.13	22,800	73,100	3.21
Georgia	4,409	15,581	3.53	4,600	16,600	3.61
Idaho	13,522	40,728	3.01	13,600	44,900	3.30
Illinois	32,382	123,720	3.82	34,500	137,300	3.98
Indiana	26,183	95,889	3.66	27,000	102,600	3.80
Iowa	15,263	58,382	3.82	16,600	64,700	3.90
Kansas	10,867	27,289	2.51	11,900	30,700	2.58
Kentucky	6,710	24,412	3.64	7,700	29,900	3.88

See footnote at end of table.

TABLE 4—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1992			1993[e]		
	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value	Quantity (thousand metric tons)	Value (thousand dollars)	Unit value
Louisiana	11,470	48,698	$4.25	11,900	51,500	$4.33
Maine	6,081	26,932	4.43	4,400	18,900	4.30
Maryland	10,875	69,297	6.37	11,200	72,200	6.45
Massachusetts	10,916	48,671	4.46	10,800	51,300	4.75
Michigan	43,539	143,107	3.29	45,000	157,500	3.50
Minnesota	34,114	98,673	2.89	30,500	85,400	2.80
Mississippi	10,403	44,124	4.24	14,500	57,300	3.95
Missouri	8,186	26,457	3.23	6,400	19,800	3.09
Montana	10,078	31,375	3.11	10,000	32,000	3.20
Nebraska	11,980	38,108	3.18	12,900	41,900	3.25
Nevada	22,020	93,585	4.25	24,900	107,600	4.32
New Hampshire	5,839	25,570	4.38	4,800	20,700	4.31
New Jersey	14,892	79,993	5.37	14,700	80,100	5.45
New Mexico	10,170	46,176	4.54	11,100	51,100	4.60
New York	28,538	130,379	4.57	34,900	161,500	4.63
North Carolina	9,283	42,717	4.60	11,100	53,800	4.85
North Dakota	7,929	20,609	2.60	7,700	20,400	2.65
Ohio	42,874	177,508	4.14	46,400	202,900	4.37
Oklahoma	8,985	24,204	2.69	9,700	27,300	2.81
Oregon	14,958	69,536	4.65	15,800	74,800	4.73
Pennsylvania	17,540	94,643	5.40	16,100	83,900	5.21
Rhode Island	2,227	11,964	5.37	2,500	13,900	5.56
South Carolina	6,256	19,923	3.18	6,800	21,800	3.21
South Dakota	7,511	22,187	2.95	8,300	25,000	3.01
Tennessee	7,691	35,077	4.56	7,200	34,000	4.72
Texas	41,404	166,362	4.02	47,100	195,000	4.14
Utah	16,037	54,819	3.42	16,000	56,000	3.50
Vermont	3,152	11,291	3.58	3,000	10,400	3.47
Virginia	8,659	37,336	4.31	9,000	40,500	4.50
Washington	37,134	140,994	3.80	40,200	158,000	3.93
West Virginia	1,256	5,730	4.56	1,400	6,700	4.79
Wisconsin	26,415	77,066	2.92	27,600	82,800	3.00
Wyoming	2,855	11,438	4.01	3,400	15,000	4.41
Total[1]	[r]834,000	3,341,300	4.01	868,700	3,530,100	4.06
Total[2] [3]	919,300	3,341,300	3.63	957,600	3,530,100	3.69

[e]Estimated. [r]Revised.

[1] Data may not add to totals shown because of independent rounding and differences between projected totals by States.

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3] Total shown in thousand short tons and thousand dollars.

TABLE 5

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE AND QUARTER[1]

State	Quantity (thousand short tons)					Value (thousands)	Number of companies[3]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[2]		
Alabama	2,400	3,300	2,900	2,700	11,300	$39,100	9
Alaska[4]	—	—	—	—	14,500	42,600	—
Arizona	7,000	9,900	11,400	10,800	38,600	138,300	9
Arkansas	2,100	2,800	3,300	2,900	11,100	40,900	4
California	20,600	28,800	30,500	26,200	106,100	475,700	12
Colorado	4,800	9,800	10,400	7,800	32,000	117,500	8
Connecticut	700	1,800	2,300	2,300	7,100	34,900	6
Delaware	400	1,000	800	600	2,800	10,300	5
Florida	5,900	6,700	6,600	6,500	25,200	73,100	9
Georgia	1,100	1,400	1,400	1,200	5,100	16,600	8
Idaho	1,000	3,800	6,800	3,400	15,000	44,900	4
Illinois	3,100	10,700	13,000	11,200	38,000	137,300	8
Indiana	3,600	8,400	10,200	7,600	29,800	102,600	12
Iowa	1,400	5,000	6,500	5,400	18,300	64,700	7
Kansas	1,700	3,800	4,100	3,500	13,100	30,700	8
Kentucky	1,200	2,500	2,600	2,200	8,500	29,900	5
Louisiana	2,700	3,800	3,700	3,500	13,200	51,500	5
Maine	300	1,300	1,600	1,600	4,800	18,900	4
Maryland	2,100	3,200	3,500	3,500	12,300	72,200	8
Massachusetts	1,900	3,100	4,000	2,900	11,900	51,300	6
Michigan	4,500	13,900	18,200	14,100	49,700	157,500	10
Minnesota	4,100	8,000	12,300	9,200	33,600	85,400	13
Mississippi	2,900	4,100	4,600	4,400	16,000	57,300	6
Missouri	800	2,100	1,700	2,500	7,100	19,800	6
Montana[4]	—	—	—	—	11,000	32,000	—
Nebraska	900	4,800	5,100	3,900	14,200	41,900	6
Nevada	6,100	6,900	7,000	7,500	27,500	107,600	5
New Hampshire	600	1,700	1,800	1,200	5,300	20,700	5
New Jersey	2,500	4,500	4,900	4,300	16,200	80,100	5
New Mexico	2,100	3,300	3,500	3,300	12,200	51,100	3
New York	3,900	10,900	14,200	10,100	38,500	161,500	11
North Carolina	2,800	3,600	3,100	2,700	12,200	53,800	4
North Dakota[4]	—	—	—	—	8,500	20,400	—
Ohio	5,700	14,200	17,400	13,800	51,100	202,900	16
Oklahoma	1,900	2,900	3,300	2,600	10,700	27,300	7
Oregon	2,300	3,500	5,500	6,100	17,400	74,800	4
Pennsylvania	1,600	5,400	6,400	4,300	17,700	83,900	15
Rhode Island[4]	—	—	—	—	2,800	13,900	—
South Carolina	1,500	1,900	2,000	2,100	7,500	21,800	7
South Dakota	400	2,400	3,700	2,600	9,100	25,000	5
Tennessee	1,200	2,400	2,400	1,900	7,900	34,000	6
Texas	11,000	13,700	15,200	12,200	51,900	195,000	10
Utah[4]	—	—	—	—	17,600	56,000	2
Vermont	300	900	1,300	800	3,300	10,400	4

See footnotes at end of table.

TABLE 5—Continued

CONSTRUCTION SAND AND GRAVEL SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE AND QUARTER[1]

State	Quantity (thousand short tons)					Value (thousands)	Number of companies[3]
	1st quarter	2d quarter	3d quarter	4th quarter	Total[2]		
Virginia	1,900	2,900	2,900	2,200	9,900	$40,500	7
Washington	8,900	12,600	12,100	10,700	44,300	158,000	10
West Virginia	200	500	500	300	1,500	6,700	4
Wisconsin	3,000	8,100	10,000	9,300	30,400	82,800	13
Wyoming	600	1,200	1,200	800	3,800	15,000	3
Total	XX	XX	XX	XX	957,600	3,530,100	XX
Total[5] [6]	XX	XX	XX	XX	868,700	3,530,100	XX

XX Not applicable.

[1] As revised from data published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1993 Mineral Industry Survey."

[2] Data may not add to totals shown because of independent rounding and differences between projected totals by States.

[3] Number of companies reporting for the quarterly survey.

[4] Due to a low number of reporting companies, no production estimates by quarters were generated.

[5] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[6] Total shown in thousand metric tons and thousand dollars.

TABLE 6

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1993, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country or territory	Sand		Gravel	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bahamas, The	3	46	1	9
British Virgin Islands	(2)	12	3	39
Canada	366	2,955	473	2,181
Guadeloupe	—	—	4	54
Mexico	172	1,979	19	1,749
Netherlands Antilles	(2)	12	1	12
Other[3]	5	213	15	279
Total[4]	545	5,218	516	4,325
South America:				
Argentina	8	953	(2)	3
Chile	1	93	—	—
Peru	1	71	—	—
Venezuela	7	1,412	(2)	10
Other	(2)	71	(2)	12
Total[4]	16	2,601	(2)	24
Europe:				
Belgium	5	467	(2)	6
Germany	3	231	(2)	32
United Kingdom	(2)	64	1	59
Other[3]	3	500	1	27
Total[4]	12	1,261	2	124

See footnotes at end of table.

TABLE 6—Continued

U.S. EXPORTS OF CONSTRUCTION SAND AND GRAVEL IN 1993, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country or territory	Sand		Gravel	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
Asia:				
Japan	1	432	5	270
Hong Kong	1	31	(2)	8
Singapore	1	208	—	—
Taiwan	2	87	10	119
Other[6]	1	272	(2)	17
Total[4]	7	1,030	15	413
Oceania:				
Australia	1	38	(2)	34
Other	(2)	7	(2)	22
Total[4]	1	41	(2)	56
Middle East:				
United Arab Emirates	5	137	(2)	23
Other	—	—	(2)	29
Total[4]	5	137	1	53
Africa:				
British Indian Ocean	7	95	—	—
St. Helena	2	132	—	—
Other	(2)	81	—	—
Total[4]	10	307	—	—
Grand total[4]	597	10,599	534	4,995
Grand total[7] [8]	658	10,599	589	4,995

[1] Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

[2] Less than 1/2 unit.

[3] Includes Antigua and Barbuda, Martinique, Montserrat, Panama, Trinidad and Tobago, Turks and Caicos Islands, and others.

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

[5] Includes Ireland, Italy, Sweden, and others.

[6] Includes China, Indonesia, Thailand, and others.

[7] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[8] Total shown in thousand short tons and thousand dollars.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF CONSTRUCTION SAND AND GRAVEL, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country or territory	1992		1993	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Antigua and Barbuda	43	912	39	455
Australia	13	909	12	852
Bahamas, The	196	411	197	549
Barbados	26	223	8	72
British Virgin Islands	3	93	2	55
Canada	940	7,018	962	7,608
Dominica	6	59	9	71
Germany	3	2,174	3	2,144
Japan	17	818	38	888
Mexico	41	1,038	8	592
Netherlands Antilles	4	35	5	58
Norway	5	299	4	201
Sweden	(2)	52	1	147
United Kingdom	2	485	1	546
Other[3]	13	939	28	1,206
Total[4]	1,311	15,463	1,316	15,445
Total[5] [6]	1,445	15,463	1,451	15,445

[1] Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.

[2] Less than 1/2 unit.

[3] Includes Austria, Bangladesh, Belgium, Brazil, China, Denmark, France, Hong Kong, India, Indonesia, Israel, Italy, Luxembourg, Malaysia, Mali, Papua New Guinea, the Philippines, Singapore, Tanzania, the former U.S.S.R., and the United Arab Emirates.

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

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

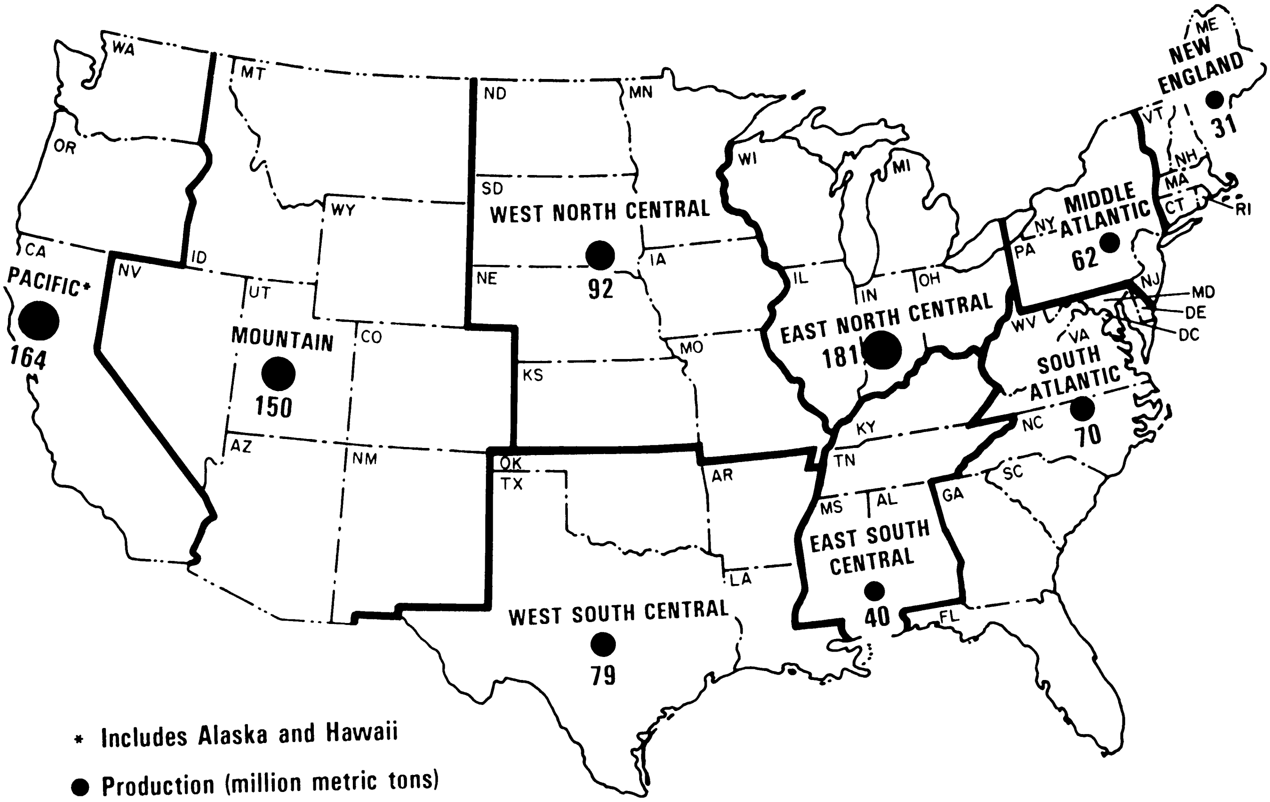
[6] Total shown in thousand short tons and thousand dollars.

Source: Bureau of the Census.

FIGURE 1

PRODUCTION OF CONSTRUCTION SAND AND GRAVEL IN THE UNITED STATES IN 1993, BY GEOGRAPHIC REGION

(Million metric tons)



INDUSTRIAL SAND AND GRAVEL

By Wallace P. Bolen

Mr. Bolen, a physical scientist, has been the commodity specialist for industrial sand and gravel since October 1988. Domestic survey data were prepared by Christopher Lindsay, supervisory statistical assistant; and the international production table was prepared by Jeremy Tidwell, international data coordinator.

Probably no other nonmetallic mineral has more diversified uses than silica (industrial) sand, mainly because of its common occurrence around the world and its distinctive physical characteristics, including hardness, resistance to high temperature and chemical action, and relatively low price. Silica sand is the major component of common glasses, foundry molding and cores, abrasive blast sand, and hydraulic fracturing sand (frac sand). Industrial sand and gravel is also important in ceramics, chemicals, and fillers for rubber and plastics, and also is utilized in golf courses, as a flux in smelting and chemical production, as filter media, and in many other uses.

Complying with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418), this issue of the Annual Report for Industrial Sand and Gravel, the U.S. Bureau of Mines (USBM) will publish most data in metric units, mainly the metric ton. To help ease the transition, this report will contain two total lines, one in metric units and one in English units.

DOMESTIC DATA COVERAGE

The annual survey form was updated in 1992 and used for the collection of data for this 1993 report. After consulting with U.S. producers of industrial sand and gravel, the following new end-use categories were created: whole grain filler/building products; ground fillers; filtration: water (municipal, county, local, etc.); filtration: swimming pool, other; petroleum industry: hydraulic fracturing; petroleum industry: well packing and cementing; recreational: golf course; recreational: baseball, volleyball, play sand, beaches, etc.; and nonmetallurgical flux. The aim of the changes was to produce meaningful end-use categories that more accurately and fully cover the disposition of industrial sand and gravel. Comments or questions on these changes should be directed to the author (see the table of contents page).

Production of industrial sand and gravel in 1993 increased to 26.2 million metric tons, about 4% more than 1992's production. Production increased in response to greater demand for foundry sand, frac sand, specialty glass sand, and for silica used in ceramics production.

Exports of silica sand and gravel increased nearly 31% in quantity but remained virtually unchanged in value compared with that of 1992. Imports of industrial sand and gravel plummeted in quantity (73%) while the associated value remained about $2.5 million. Domestic apparent consumption of industrial sand and gravel in 1993 was 24.5 million tons, an increase of about 2% compared to that of 1992.

Domestic production data for industrial sand and gravel were developed by the USBM from voluntary surveys of U.S. producers. Of the 160 industrial sand and gravel operations surveyed, 133 (83%) reported to the USBM. Their combined production represented about 93% 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. *(See table 1.)*

BACKGROUND

One of the first industries to use silica sand was the glass industry. At least 4,000 years ago, long before iron was smelted, glassmaking was already a known craft. Although the place and date of the first manufactured glass are not known, the oldest known specimens of glass are from Babylon (ca. 2600 B.C.) and from Egypt (ca. 2500 B.C.), where the industry was well established by about 1500 B.C. Many varieties of glass were known during Roman times. Little is known of the glassmaking methods used in Europe from the fall of Rome until the 10th century, when stained glass was produced in Venice. After this, Venice remained the leader in fine glassware for the next four or five centuries. In the 17th century, a process for casting glass was invented in France, and later, England began to make flint glass, marking the beginning of modern glass technology.

Glassmaking was apparently the first industry to be transplanted from Europe to North America, first to Mexico and later to the British colonies. The first manufacturing establishment in what is now the United States was a glass factory at Jamestown, VA, built in 1608. The 1885 edition of "Mineral Resources of the United States," the predecessor of today's USBM "Minerals Yearbook," reported a total of 288,000 tons of silica sand produced in 1884 in the United States, under "Glass Materials." In 1993, a total of 24.5 million tons of silica sand was produced in the United States for a variety of uses, of which 10.3 million tons was for glassmaking. Today, glass has become an invaluable product with a multitude of forms and applications.

Metals casting was probably the second industry that used silica sand. Today, the casting industry provides vital components for most modern manufacturing industries. The number of industries using silica sand is growing constantly, as are the products made by using silica sand.

Another early use for silica sand was water filtration. According to an article presented at the Industrial Minerals Forum in London, November 1992, the earliest accounts of water filtration appeared in Greek and Roman writings about 2000 BC. However, early filtration was done at individual households and it was not until 1829 when the first sand filters were employed in a public system.[1]

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 (4.75-millimeter) U.S. standard sieve, are retained on a No. 200 mesh (75-micron) 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 sand, foundry sand, abrasive blasting sand, and hydraulic fracturing sand. Almost invariably, these sands, in addition to being high in silica, consist mostly of quartz grains.

Products for Trade and Industry

Silica sand had a wide range of uses in a significant number of industries, the most important being glass and foundry. Other uses were metallurgical and as abrasives, as fillers, for filtration, and for hydraulic fracturing of rock formations to improve recovery in oil wells.

Glass sand was used as a main constituent for manufacturing glass containers, flat glass, safety glass, pressed and blown glass, fiberglass, and a wide variety of specialty glasses such as optical glass and industrial glass.

Glass sand had to meet rigid specifications with respect to purity and silica content, depending on the kind of glass being manufactured. Only a very small amount of iron oxide and chromium compounds could be tolerated, and a high percentage of aluminum, calcium, or magnesium oxides was undesirable. The standards of the American Ceramic Society for glass sand indicated that all grains should pass through a No. 20 mesh screen, between 40% and 60% should be retained on a No. 60 screen, between 10% and 20% on a No. 80 screen, and not more than 5% should pass a No. 100 screen. Sand for first-quality optical glass should contain 99.8% SiO_2 and a maximum of 0.1% aluminum oxide (Al_2O_3) and 0.02% iron oxide (Fe_2O_3). Third-quality flint glass could contain only 95% SiO_2 and as high as 4% Al_2O_3. Only in the low-quality amber glass was the content of Fe_2O_3 permitted to reach 1%.

Most glass manufacturers established their own specifications for the physical size and chemical purity of the raw materials that have to be met by the suppliers of glass sand. Recently, glass manufacturers showed an increased interest in finer glass sands because processing of smaller particles required lower temperatures and, therefore, reduced the consumption of energy.

Foundry sands included molding sand and core sand that were used for casting iron-, aluminum-, and copper-base alloys. Required properties included cohesiveness sufficient to hold together the mold or core when moist, which is achieved by a bonding agent; refractoriness to withstand the high temperature of the molten metal; strength to resist the weight of the metal; permeability to release vapors and gases generated during cooling of the metal; and proper texture and composition to produce a smooth casting that will not react with the metal. Most metals were cast in "green sand," which is a mixture of silica and clay, although to a lesser extent, resins or oils also were 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.[2]

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.[3]

Quartz sands, on the Knoop scale at 820, are quite hard and are one of the oldest abrasives known. Abrasive sands were quartz sands used in stone sawing, glass grinding, metal polishing, and sand blasting. No rigid specifications existed for these sands, but sound, clean, hard, and closely sized sand grains were required. Purity and grain-shape specifications varied with the type of abrasive action and the requirements of the final product. Traditionally, 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.[4]

Ground sand or silica flour has found wide industrial application as a filler in paint, plastics, rubber, ceramics, and a variety of other products. Mainly because of the diversity of its uses, no standard specifications exist for the silica flour used in most of these applications except grain size and chemical composition. Silica was used in various plastics such as acrylonitrile-butadiene-styrene polymer, polyolefins, polystyrene, polyvinylchloride (PVC), thermoplastic polyester, polyurethane, and epoxy, which is the largest consuming resin. The silica thickens liquid systems, works as a flatting and thixtopic agent, and helps to avoid plateout in PVC.

As a filler and extender in paint formations, ground silica renders paint more resistant to chemical attack because of its acid resistance. The paint's scrubbing and wear resistance, tint retention, durability, and flowability also are enhanced by silica. Additionally, whole grain silica sand was used as a filler in many products that may be categorized as "building products," including, but not limited to, stucco, no-skid floors, and grouts.

Silicon carbide, which was used as an abrasive, for refractory uses, and in specialty ceramics, was produced by the reaction of silica sand (60%) and coke (40%) at elevated temperatures up to 2,400° C. Metallurgical sand was used as a fluxing agent for basic oxides in various smelting operations and as a source of silicon in ferrosilicon manufacture. The ferrosilicon was a steel alloying additive.

Filter sand was used extensively in filtering water for municipalities, industry, swimming pools, and in sewage treatment plants. Traditional sand filters for public water purification use the "slow sand filtration" design, which contains fine sand, 0.3-millimeter grain size, in a bed that ranges from 0.6 to 1.0 meter in thickness. Slow filtration rates require many beds of sand. A representative-size bed would cover about 0.4 hectare, which is about the size of a soccer (European football) field. The sand used was typically subangular, brown, or yellow quartz, with little advantage being given to highly rounded pure quartz. Besides slow sand filtration, "rapid filters" are also employed. Rapid filters use salts to precipitate aluminum or ferric hydroxides, and these filters are backwashed daily to remove materials that are clogging the sand.[5]

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, and in manufacturing pottery. Industrial sand was used also for chemical production, golf courses (both in traps and in green construction), and in a growing variety of building products. Industrial gravel was used as the source material in the production of silicon and ferrosilicon and as a flux for the production of copper, nickel, and elemental phosphorus. Some gravel was used as filtration media, mainly in municipal water-treatment facilities.

Industry Structure

In 1993, 85 U.S. companies with 153 active operations produced silica sand and gravel. The individual industrial sand and gravel operations ranged in size from those producing well over 1 million tons annually to those reporting less than 10,000 tons per year. Most of the production came from large operations that were mostly owned or operated by a small number of companies. In the past 10 to 15 years, there was a gradual trend toward larger operations, mostly because small plants were becoming less economical. The viability of small operations was dependent on demand in local markets, mining conditions, and the degree of processing required to supply the final product.

Beyond the move toward larger operations, the industry also has developed into two groups: one, the larger national or regional companies that produce many grades of silica, and the other, which consists mainly of smaller and local companies that produce industrial sand and gravel for limited uses and often include construction sand and gravel. Because companies that traditionally produced only construction sand and gravel may sometimes produce sand for industrial uses, the number of companies producing industrial sand and gravel could change by upward of 10% annually.

Geology-Resources

U.S. resources of industrial sand and gravel were expected to be sufficient to meet domestic demand in the foreseeable future, although their geographic distribution and quality often did not match market requirements. The availability of these reserves was controlled to a significant degree by land use and/or environmental constraints. Reserves of industrial sand and gravel owned or controlled by domestic producers were estimated to total about 3 to 4 billion tons.

Although silica reserve data for the rest of the world were not available, it could be assumed, on the basis of geologic evidence, that world reserves were sufficient to meet demand, even if not always at the locations where needed.

Industrial sand or silica sand was produced in the United States from a variety of geological formations ranging in age from late Precambrian to mid-Tertiary. About 70 stratigraphic units were known as having an economic potential for this industry. Lithologically, these deposits ranged from quartzites, sandstones with different degrees of cementation, quartz conglomerates, chert deposits, and quartz pegmatites to terrace sands and gravels, and dune sands. Most of the high-quality industrial sand was produced from a few geological formations in the Eastern United States. Oriskany sandstone, or more precisely the Ridgeley formation of Early Devonian age, was one important source of silica sand. It extended from New York State to southern Virginia and eastern Ohio, but was being mined only in central Pennsylvania, northwestern Maryland, and northern West Virginia, where the formation was thick enough to be of commercial value. It was a hard, white orthoquartzite with medium to fine, angular and subangular, and well-sorted grains. The St. Peter sandstone of Middle Ordovician age, extending from Wisconsin and Minnesota through Iowa, Illinois, and east-central Missouri, was another major source of industrial sand. The best known center of production of silica sand from this formation was the Ottawa district of La Salle county, IL, where it was known as "Ottawa sand," and to a lesser degree in southern Wisconsin and east-central Missouri. It was a soft and poorly cemented high-purity orthoquartzite with coarse, rounded grains. The weak cement holding the silica grains together was mostly a light-colored clay.

In addition to the two formations just mentioned, the most important sources of industrial sand in the United States, numerous other deposits were being mined for silica sand in different parts of the country. Included are the Jordan sandstone of Upper Cambrian age in Minnesota and Wisconsin, a primary source of hydraulic fracturing sand; the Raritan formation of Upper Cretaceous age in central New Jersey and the Cohansey sand of probable Miocene age in southern New Jersey; and the Tuscarora quartzite of Lower Silurian age in Pennsylvania and Virginia used for the manufacture of refractory bricks. Other deposits are the Sylvania sandstone of Devonian age in the Detroit area; the Oil Creek and McLish formations of Lower Ordovician age in Oklahoma, a southwestward extension of the St. Peter sandstone; and the Hickory sandstone of Cambrian age in central Texas that produced mostly hydraulic fracturing sand.

In the West, the most important sources of industrial sand were the Ione formation of Eocene age in northern California, the Silverado (Paleocene) and Tejon (Eocene) formations in southern California, and the Eureka quartzite of Middle Ordovician age in central California.

Approximately two-thirds of the U.S. industrial sand and gravel was produced east of the Mississippi River, especially in the industrialized areas of the East North Central, South Atlantic, and Middle Atlantic regions. Of the top six producing States that accounted for about 51% of 1993 production, four—Illinois, Michigan, New Jersey, and Wisconsin—were in the East and the other two—California and Texas—were in the West. The concentration of the industrial sand operations in the eastern part of the United States resulted from the existence of high-quality geologic deposits close to the major consuming industries, glass and foundry. In the south and west, demand from the oil and gas industry in the Louisiana, Oklahoma, and Texas area has been the largest factor for the sustained growth of industrial sand operations in Texas. California production remained large owing to demands from local industry, particularly the glass container industry, with the wine industry consuming a large portion, coupled with the distance of California from the traditional production areas in the Midwest.

Technology

Exploration.—A large number of geologic formations with economic potential as a source of industrial sand have been mapped and described in the literature over many years and were, therefore, well known. Consequently, detailed exploration and development work for new industrial sand operations was expected to occur on some of these formations. The qualities of a silica deposit necessary for a viable operation should include proper particle size, chemical composition, degree of cementation, and deposit uniformity. Also, the nature and amount of waste material and the economic feasibility of its removal and possible use or disposal should be studied. The evaluation of the new deposit should also include an environmental impact study as required by most local or State agencies before authorizing a new mining operation.

If the raw material should prove to meet the requirements and adequate reserves are demonstrated, the development stage of the operation could be started. Economic feasibility and marketing studies should be performed by analyzing all factors important for any such mining operations. Included are the availability of power and water supply, mining and processing costs and requirements, and the condition of nearby roads and highways. Other factors include the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population as well as its attitude toward such a project.

Mining.—Most industrial sand was mined from open quarries, but a few underground operations existed, mostly because of an exceptionally thick overburden or environmental limitations. Surface mining methods and equipment varied with the type of the geologic formation, size and configuration of the deposit, production capacity, estimated life of the operation, and location of the deposit with respect to urban centers. The mining methods depended primarily on the degree of cementation of the rock, although most open pit mining operations included site clearing and removal of the overburden; mining of the silica rock or sand; processing of the material, including crushing, screening, and classification; and reclamation of the extraction area. Unconsolidated sands, such as the Cohansey of New Jersey, below the ground water level were dredged. Much of the St. Peter sandstone was first loosened by light blasting and then washed down by hydraulic jets or "monitors" into sumps, from which it was pumped to the processing plants. Harder rock such as the Oriskany sandstone required blasting and primary and secondary crushing before it could be processed.

Processing.—Processing of mined silica sand required specialized operations that varied considerably with the nature of the deposit and the physical and chemical requirements of the desired product. Depending on the degree of cementation, several stages of crushing were necessary to achieve the desired size reduction. Gyratory crushers, jaw crushers, impact mills, or roll crushers were used as primary or secondary crushers, and smooth rolls, media mills, autogenous mills, high-speed hammer mills, or fluid energy jet mills were used for grinding the product down to 50 microns and finer. Some producers employed flotation cells, with a variety of flocculants, to remove unwanted minerals and fines if they were not easily removed through mechanical scrubbing and separation, which most producers installed. Dry or wet screening was used to separate particles of sizes down to about 150 microns, and wet or air classifiers processed particles from 250 microns into the submicron range. Vibratory screens and gyrator screens, in addition to mechanical, hydraulic, or air classifiers, were used, depending on the size distribution required.

Research for the silica mining industry related not only to new methods that increased output and reduced production costs but also to health and safety problems as well as exploration, land management, and reclamation. Significant technological developments instrumental in maintaining adequate production at relatively stable real costs were mostly in the processing plant technology. The use of computerized systems in plant operation and quality control increased; this, along with improved mining and processing equipment, permitted the recovery of salable fractions that were previously considered uneconomical.

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.

Substitutes

Various materials can be substituted for silica, depending on the application, but most products have a hard time competing on a price basis. As a raw, natural material, nothing can compete with silica as a glass forming oxide; however, on a material level, virgin silica competes with recycled glass, often called cullet. Zircon and carbon grains are two sands that compete with silica but the largest competitor will probably be reclaimed or recycled "spent" foundry sand if cost and quality are acceptable. The silica that is suffering the greatest competition is abrasive blasting sand as garnet, olivine, slags, manufactured abrasives (synthetic abrasives), and many others seek to grab market from silica as consumers fear reported silica health hazards. Substitutes for many other uses also exist.

A recent report of a silica substitute comes from National Mineral Products, a division National Refractories & Minerals Corp. of California. It was introducing a dolomite-based replacement for silica sand in stucco mix applications. The group claims that its product is whiter, brighter, and more consistent than silica.[6]

Economic Factors

Silica sand deposits are nonrenewable resources. New mining methods combined with advances in mineral processing that were introduced during the past decade have increased the number of silica deposits that can be commercially developed.

The industrial sand industry was very competitive, largely because silica sand is a relatively abundant mineral, with supply usually exceeding demand. The delivered price of the product, in addition to quality, was a very important element in any major transaction. The producer with an operation closest to the market had a significant advantage over competitors. Combining sophisticated (and therefore expensive) processing equipment backed by technical knowledge and solid sales expertise was important. For this reason, only a small number of large companies were able to compete successfully and succeed in the silica sand business and supply a wide variety of products. Smaller, less efficient operations became uneconomical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continued to increase. The only alternatives they had were to either limit the range of products they supplied to close markets or go out of business.

Prices.—As a result of rapidly rising costs of labor, energy, and mining and processing equipment, 1993 constant dollar prices, per metric ton, all uses, of industrial sand and gravel rose steadily between 1973 to 1983. From 1985 to 1990, 1993 constant dollar prices fluctuated in the 17.88 to 18.86 range, owing to decreased demand and tight competition in some markets. Since 1990, constant dollar prices have fallen from 18.86 to 17.73 as the 1993 constant dollar price dropped to approximately the 1978 adjusted value. Competition, coupled with environmental and recycling policies, could very likely continue to decrease the use of silica in traditional markets. However, specialty markets for silica will probably experience increased consumption, and these higher cost uses will cause the overall constant dollar price to rise through the year 2000.

Costs.—Production costs for silica sand were determined to a large extent by the cost of labor, equipment, energy supply, water availability, and the additional burden of compliance with environmental and safety regulations. Production costs varied widely depending on the nature of the geologic deposit, the geographic location, and the type and number of products produced. Profits were relatively small for most producers, total production costs being close to the f.o.b. selling price per ton.

Tariffs.—There has been no tariff on imported silica sand containing 95% or more SiO_2 and not more than 0.6% iron oxide from most favored nations since January 1, 1987. For all other countries, the tariff for imported silica sand remains $1.94 per long ton.

Depletion Provisions.—The depletion allowance for industrial sand and gravel was 14%.

Operating Factors

Environmental Requirements.—Major environmental considerations that had to be dealt with in mining and processing of industrial sand and gravel were emission of particulate matter into the air, discharge of processing water, and noise abatement. Air pollution constituted a major problem in the processing plants, especially in the drying and packaging stages of finer products such as silica flour, silicosis being the major disease that can be contracted as a result of long-term exposure to silica dust. Because of the high cost of compliance with the environmental regulations designed to reduce this health hazard and possible long-term liabilities associated with it, some companies were no longer producing silica flour or did not plan to produce it in the future. Both wet and dry methods of dust control were used. The most important water pollutant was clay in suspension as a result of washing and screening silica sand. Because of the large quantities of water used to process silica sands and the need of compliance with stringent regulations, the treatment of discharge water by the sand producer was expected to require increasingly sophisticated and expensive processing methods. Significant progress was made in reducing noise pollution, both inside and outside of the operations, including noise and vibration produced by blasting and movement of heavy trucks.

Sand producers had to obtain mining permits from the appropriate governmental agency, which sometimes also required an Environmental Impact Statement (EIS) and a reclamation plan that met its guidelines or regulations. More emphasis was being put by local communities on improving the overall appearance of the operating mines as well as on land reclamation after mining was completed. At the same time, industry and the communities had to recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Many States, counties, and towns had zoning laws that regulated land use.

Most of the active silica sand quarries as well as the known deposits were on private land, which was either owned or leased on a long-term basis by the producers. These deposits contained high-quality silica sand and were in the best locations with respect to markets. Unlike the construction sand and gravel industry, the industrial sand industry was usually not significantly affected by increasing land values near populated areas.

Transportation.—Transportation costs for silica sand were often equal or considerably greater than the cost of the product at the processing plant. Because of the large variety and number of consumers of silica sand, long-distance haulage was not uncommon. In 1993, the largest tonnage, 63% 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 shipped by rail, especially when large volumes were sent long distances. The remaining tonnage was shipped by barge or used at the mine.

ANNUAL REVIEW

Legislation and Government Programs

The National Institute for Occupational Safety and Health (NIOSH) released a draft criteria document for review that recommends drastic reductions in the current permissible exposure limits (PEL's) for respirable coal mine dust and crystalline silica. The draft recommends lowering the current PEL for crystalline silica from 0.1 milligram per cubic meter of air (mg/m^3) to 0.05 mg/m^3. NIOSH's responsibility is to make recommendations, but it usually carries a lot of weight with the regulatory agencies. This recommendation applied mainly in relation to coal mining but NIOSH recommendations may eventually be applied to all mining and occupational activities.[7]

Proposed changes in the Safe Water Act and a crackdown on the use of lead in plumbing pipes are aimed at reducing lead levels in areas with high readings. The plan also could benefit silicate chemicalmakers. The best way to lower lead levels is to keep the lead in the pipes by preventing erosion that occurs when water is very acidic or alkaline. The Environmental Protection Agency has recommended several ways to combat the problem, including increasing the pH of the water above 7 to make the water less corrosive by adding alkaline materials such as silicates. Other recommendations also were made that would benefit silicate chemicalmakers.[8]

The Department of Health and Human Services has ordered a review of research that concludes fiberglass insulation used in 90% of U.S. homes is a possible carcinogen. The review was ordered in July after petitions in June 1992 and June 1993 and industry-sponsored research were submitted.[9]

Issues

Issues that concerned and affected silica miners included land use restrictions, respirable silica studies and control, fiberglass health concerns, and foreign trade. The New Jersey Pinelands Commission (PC) proposed heightened restrictions or elimination of mining in a jurisdictional area covering 400,000 hectares (1 million acres) of land in seven counties. The PC was formed in 1980 and implemented tough mining restrictions but included a grandfather clause on land owned by mining operators who were permitted. It was expected that continuing debate and compromise concerning this issue may free more land to mining.[10] New Jersey was the third largest producing State for industrial sand and gravel in 1993.

Silicosis and lung cancer related to respirable silica continued to attract attention in 1993. In the United Kingdom, the Industrial Injuries Advisory Council (IIAC) released a report suggesting a twofold increase risk of lung cancer where there is evidence for silicosis. Two professors suggested that although there were only 50 to 100 cases of silicosis in the United Kingdom each year, there were 35,000 cases of lung cancer, and silicosis risk was masked by smoking.[11] The Wall Street Journal published an article in March titled, "How Sand on a Beach Came To Be Defined as Human Carcinogen." The lengthy article depicted the problems, confusion, and challenges facing those who work with or seek to regulate crystalline silica.[12]

To respond to concerns over respirable silica, producers, consumers, and handlers of industrial sand and gravel were continually seeking to reduce exposure. Allied Colloids developed a specially designed dust suppressant for use on all mineral stockpiles. The suppressant forms a film on the surface of the mineral stockpile, preventing the creation of windborne dust.[13] In a mechanical control method, Australian-based Speedlock Ducting Pty. Ltd. has produced a ducting system designed for use in any enclosed area where crushing, screening, dry processing, or bulk handling of ore takes place. The system was said to provide an easily installed, cost-effective alternative to conventional welded or riveted systems.[14] Additionally, Entecon Ltd. of the United Kingdom, has extended its range of systems for dust-free opening and emptying of bags. The systems are enclosed totally, avoid product contamination, compact and bag empty bags, and handles paper, plastic, woven, or combination bags.[15]

Trade issues that affected the silica industry included actions on glass, ferrosilicon, and silicon carbide. Flat glass trade with Japan was one focus of contention as U.S. flat glass producers sought to increase the amount of glass exports to Japan via trade talks. Tokyo had promised to help open its domestic glass market to foreign competitors such as Guardian Industries Corp., which was trying to get more glass into Japan. However, little progress had been made. Increased exports would benefit U.S. industrial sand producers.[16] The International Trade Commission (ITC) has announced that it is to continue with its investigation into damage inflicted on U.S. industry by imports of silicon carbide from China.[17] In another trade dispute, the U.S. Department of Commerce found dumping of ferrosilicon from Brazil, but the ITC found no injury from imports of ferrosilicon from Egypt.[18]

Production

The Midwest (East and West North Central regions) continued to lead the Nation in production with about 44% of the 26.2 million tons produced in the United States, followed by the South (South Atlantic, East and West South Central regions) with about 34% and the West (Pacific and Mountain regions) with 12%. *(See table 2 and figure 1.)*

The six leading States in the production of industrial sand and gravel, in descending order of volume, were Illinois, Michigan, New Jersey, California, Wisconsin, and Texas. Their combined production represented 51% of the national total. Among these six States, New Jersey experienced a 33% increase in production, Michigan a 31% increase, and Wisconsin and Texas also had sizable increases. Illinois' output remained about the same while California saw a decrease of 6% in production compared to that of 1992. *(See tables 3, 4, and 5.)*

The USBM canvassed 85 producers of industrial sand and gravel with 153 active operations. About 75% of the industrial sand and gravel was produced by 47 operations, each with an annual production of more than 200,000 tons. The 10 leading producers of industrial sand and gravel were, in descending order of tonnage, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., The Morie Co. Inc., Oglebay Norton Co., Badger Mining Corp., Construction Aggregates Corp., WHIBCO Inc., Nugent Sand Co. Inc., and Simplot Industries Inc. Their combined production, from 63 operations, represented 70% of the U.S. total.

There were no major merger and acquisition activities in 1993 but operations did move in and out of the industrial sand and gravel sector as some companies (re)introduced silica for industrial uses while others removed operations from the industrial sand and gravel sector. Tri-Sands Inc., Trafford, AL, reported the closure of its silica operation in Tishomingo County, MS.

FMC Corp.'s phosphorous chemicals division announced that it was lowering the capacity for elemental phosphorus at its plant at Pocatello, ID. Elemental phosphorus production consumes silica as a flux.

Consumption and Uses

Sand and gravel production reported by producers to the USBM was actually material used by the companies or sold to their customers. Stockpiled material was not reported until consumed or sold. Of the 26.2 million tons of industrial sand and gravel sold or used, 39% was consumed as glassmaking sand and 22% as foundry sand. Other important uses were abrasive sand (6%) and frac sand (6%).

The amount of sand sold for container glass declined in 1993 compared to that in 1992, even as the total number of shipments of glass containers rose 2.7% during the year. This decline amidst an increased production of glass containers was reflective of the increased amount of recycled glass going into glass container production. The share of silica sold for glassmaking as a percentage of all silica sold dropped to its lowest level (39%) since 1985, when glass markets consumed only 35% of silica sold.

Container glass was not only being used to produce more containers but also for producing fiberglass. The fiberglass industry reportedly consumed 272,000 tons of cullet in 1992. In 1993, it was expected that just over 320,000 tons would be used. Contamination of cullet was also a concern for the fiberglass industry as the amount of cullet in the batch continues to rise.[19]

Furthering this trend, Denver-based Schuller International Inc., a manufacturer of Manville-brand fiberglass insulation, announced a multiyear contract with Pure

Tech International Inc., Somerset, NJ, to supply glass cullet. Schuler will initially be receiving 20,000 tons per year of recycled glass. Additionally, Owens-Corning announced it will reopen its Jackson, TN, glass fiber plant facility in April 1994, which was closed in 1987. Capacity was not disclosed.

The blasting market also consumed less silica in 1993 as sales fell 8% from those of 1992. The blasting market suffered, not from increased recycling, although there was some blast sand recycled, but from increased concern about health hazards related to respirable silica. Consumers increasingly are using competing materials such as garnet, slags, and glass beads.

On a more positive note, foundry and frac sand sales were up 12% and 9%, respectively, compared to those of 1992. The domestic automotive industry, the leading consumer of foundry sand, had a good sales year while the oil and gas industry worldwide consumed more frac sand, especially for gas wells. The Texas Railroad Commission (TRC) reported that drilling for gas was up sharply in Texas, up 40% in the first 8 months of 1993 compared to that in 1992. Conversely, the TRC expected 1993 oil production in Texas to reach a 50-year low attributed to many factors, especially foreign imports and low crude prices. Nationally, oil production dropped to its lowest volume in 35 years.

Specialty silicas were produced usually by means of chemical processing of natural silica or as a byproduct of other mineral or chemical processing. Although the USBM did not specifically collect information for specialty silicas, their consumption does affect natural silica sales. Specialty silicas included, but were not limited to, fumed silica, fused silica, precipitated silica, sol-gel silica, and ultrahigh-purity silica. These silicas were used in abrasives, catalyst, electronics, food, health care, optics, paper, plastics, refractories, rubber, specialty coatings, and others. In 1991, specialty silicas sales were $1.6 billion and were expected to grow to $2 billion by the year 2000.[20]

Smaller volume markets, traditional and newly developed, continued to consume significant amounts of silica. These markets include chemical, filler, ceramic, and other categories. A division of Rhone-Poulenc crafted a sodium carbonate-silicate cogranulate, the first of its type. The new builder considerably enhances the efficiency of the detergent formula through the combined action of its two components, sodium carbonate and sodium polysilicate. Should this receive wide acceptance as a detergent, it would positively affect consumption of silica via sodium silicate.[21]

In other related developments, Degussa Corp. brought on-line its Waterford, NY, hydrophobic fumed silica plant. The plant will produce *Aerosil,* Degussa's fumed silica, used in silicone rubber sealants, coatings, printing inks, and other applications. Additionally, PQ Corp. has started a 500,000-pound-per-year facility in Kansas City, KS, for the production of silica catalyst. The material formerly was made in Rahway, NJ, and is used in the production of high-density polyethylene. Both of these actions should stimulate greater silica consumption and production in various regions of the United States.

The production of industrial sand and gravel in the United States has developed in response to market location and vice-versa as industry sometimes located near silica resources. Because silica deposits (or resources) are found throughout the United States, locating a consuming industry specifically to be near a silica source was not always a priority, although certainly a consideration. The auto industry, responding to iron, coal, clays, and silica resources, centered in the Midwest, and thus foundry sands were greatly exploited in Illinois, Indiana, Michigan, and Ohio and other regional States. This resulted in more than 75% of the foundry sand being produced in the Midwestern region in 1993.

The glass industry, somewhat conversely, had to locate plants where they could minimize the shipping distance of finished glass products. Hence, glass plants were more evenly distributed as 43% of glass sand was produced in the South region, 33% in the Midwest, 17% in the West, and 7% in the Northeast in 1993. To varying degrees, all silica production was similarly influenced as markets and consuming industries either forced the silica mining location or were forced to locate near the silica source. *(See table 6 and figure 2.)*

Northeast.—Cumberland County, NJ, continued to be the largest source for the glass and foundry sand markets in the region. Unimin, U.S. Silica, Morie, and WHIBCO Inc., all of which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Morie and Ricci Brothers Sand Co. Inc., both in Cumberland County, NJ, produced a major percentage of the abrasive blast sand in the region.

Midwest.—Unimin's plants in LaSalle and Ogle Counties, IL; LeSueur and Scott Counties, MN; and Columbia County, WI, were among the leaders in producing sand for the blast, foundry, frac, and glass sand markets. Fairmount Minerals, with operations in Berrien and Van Buren Counties, MI, Geauga County, OH, and La Salle County, IL, was a major producer of sand for the blast, foundry, and glass sand markets in the region. U.S. Silica's plant in La Salle County, IL, was a large producer for the glass, foundry, and frac markets and its St. Louis County, MO, operation was a large producer for the glass market. Construction Aggregates Corp., Ottawa County, MI; Nugent Sand Co. Inc., Muskegon County, MI; and Sargent Sand Co., Wexford County, MI; were all large producers for the foundry industry. Badger Mining, Jackson and Green Lake Counties, WI, were major producers for the frac and foundry markets. Manley Brother's of Indiana, LaSalle County, IL, was also a large producer for the blast, foundry, and glass markets. Major producers for the blast sand market included Oglebay Norton Co., Knox and Perry Counties, OH, and Kaw Valley Sand and Gravel Co., Wyandotte County, KS.

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 Izard County, AR; Richmond County, NC; Pontotoc County, OK; Kershaw County, SC; and Frederick County, VA. U.S. Silica's Bullock County, AL; Johnston County, OK; Lexington County, SC; Limestone County, TX; and Morgan County, WV, operations were the major contributors for these markets. Morie's Tuscaloosa County, AL; Marion County, GA; and Carrol County, TN, plants were large producers of foundry and glass sand. Cobb Industrial Corp., Red River Parish, LA; Foster-Dixiana Corp., Lexington County, SC; Huey Stockstill Inc., Pearl River County, MS; Mid-State Sand and Gravel Co., Allen Parish, LA; Pioneer Concrete of Texas Inc., Liberty County, TX; and Specialty Sand Co., Newton County, TX, were large producers of blasting sand. W.R. Bonsal and Co. and B.V. Hedrick Gravel and Sand Co., both in Anson County, NC, produced a large percentage of the industrial gravel used in the production of silicon and ferrosilicon. Oglebay Norton's Texas Mining Co. and Vulcan Materials Co., both in McCulloch County, TX, were the largest producers of frac sand in the region. WHIBCO in Kershaw County, SC, was an important producer of foundry sand. APAC Arkansas Inc., Crawford County, AR; Florida Rock Industries Inc., Putnam County, FL; and Short Mountain Silica Co., Hawkins County, TN, were important producers of glass sand. Oglebay Norton's Texas Mining Co., McCulloch County, TX, was also an important contributor of blast sand in the region.

West.—Corona Industrial Sand Co., Owens-Illinois, Simplot Industries, and Unimin were the four largest producers of glass sand in the region, with major operations in Riverside County, CA; Amador County, CA; Clark County, NV; and Contra Costa County, CA, respectively. Lane Mountain Silica, Stevens County, WA; Lone Star Industries Inc., Monterey County, CA; and P.W. Gillibrand Co., Ventura County, CA, were the major suppliers for the sandblasting industry in the region. Simplot Industries, Clark County, NV, also supplied a large portion of the foundry sand consumed. FMC Corp., Power County, ID; Rhone-Poulenc Basic Chemicals Co., Beaverhead County, ID; and Monsanto Industrial Chemicals Co., Caribou County, ID, each produced industrial gravel for use as a flux in elemental phosphorus production.

Recycling.—Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and airblasting sands, and, increasingly, postconsumer glass and scrap glass (cullet) that substitutes for batch mix (including industrial sand). Most glass recycling was restricted to container glass, with green and amber being consumed at a higher rate than flint because it was more difficult to use in the batch mix. Glass recycling was put at 33% in the United States for 1992, the fifth straight year of growth. This included glass containers used in glasphalt and those that were refilled and represents an increase from the 1991 rate of 31%.[22]

As the level of glass used increases, so does the level of quality required. Contamination of cullet by ceramics and nonmagnetic materials was an increasing concern. Because of the increased use of cullet, restrictions on the iron and chromium levels in glass sands have become stricter and the proportion of refractory particles allowed has been reduced to almost zero. The Fe_2O_3 content of a typical glass silica sand is now as low as 0.015% to 0.02% for flint glass manufacture and 0.1% to 0.15% for colored glass. Additionally, recycling of amber and green glass was substantially greater than flint glass, and therefore lower grade deposits are in less demand.[23]

A new sand recycling technology promises to provide tremendous environmental and economic benefits to the U.S. foundry industry. Developed at Navistar International Transportation Corp., Indianapolis, IN, it is the world's first electric infrared sand reclaimer. The sand reclaimer combines high-intensity infrared heating with "fluidized bed" technology to reclaim all types of foundry sand. The projected benefits of the system at full production scale are substantial and include both environmental and economic factors.[24]

International trends toward increased recycling of glass and foundries sands and innovative ideas on recycling other materials should influence greater recycling of silica products.

Transportation

Of the total industrial sand and gravel produced, 63% was transported by truck from the plant to the site of first sale or use, up from 56% in 1992; 34% was transported by rail, down from 38% in 1992; 3% was transported by waterway; and 1% was not transported. Because most of the producers did not report shipping distances or cost per ton per mile, no transportation cost data were available.

Prices

Compared with that of 1992, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased slightly to $17.33 per metric ton. Average unit values for industrial sand and industrial gravel were $17.78 and $10.90 per ton, respectively. Nationally, ground industrial sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($104.27), followed by silica for well packing and cementing ($72.09), ground silica for molding and core facings, ($57.73), ground silica sand used in ceramics ($51.53), silica for swimming pool filters ($44.40), ground silica used for fiberglass ($41.11), ground silica for scouring cleansers ($36.60), and frac sand ($30.83).

Industrial sand and gravel price changes were greatly mixed because some markets were level, others had small increases or decreases, and still others experienced large increases or decreases. This situation was possible because although the silica was essentially the same, most markets were very independent from each other and price competition was influenced by availability, regulations and health concerns, and competition from other materials. Those end uses that sustained greater prices in 1993, compared to those of 1992, included: blasting, ceramics, fiberglass, fillers, filtration, and frac sand. Silica for container and flat glass, foundry, roofing granules and fillers, and traction experienced a decrease in unit value.

The average value per ton of industrial sand and gravel was highest in the West

($20.31), followed by the South ($17.90), the Northeast ($17.46), and the Midwest ($16.03). Prices can vary greatly for similar grades of silica at different locations in the United States. For example, glass sand average value per ton varied markedly, from $19.87 in the West to $11.53 in the Midwest. Tighter supplies and higher production costs in the West and much greater competition in the Midwest caused the difference in the cost of sand and gravel in these two regions.

Foreign Trade

Exports.—Exports of industrial sand, compared with those of 1992, increased 31% to 1,751,000 tons, while the value remained about the same. Export distribution is as follows: 80% went to Canada, 5% went to Japan, 4% went to Brazil, and the remainder went to numerous other countries throughout the world. This situation, where there was greater tonnages exported but an insignificant change in the associated value, occurred mainly because of two reasons. The distribution of grades that make up the total exports changes from year to year and different grades have different values. Also, the prices may change for the same product in response to increased competition or changes in supply contracts.

Imports.—Compared with those of 1992, imports for consumption of industrial sand dropped 73% to 44,000 tons valued at $2.4 million. Silica imports vary greatly from year to year but are always rather insignificant. Australia supplied 95% of the silica imports for 1993, averaging near $42 per ton. The Australian imports were the relatively low priced silica while higher priced silica came from Belgium, Canada, France, Italy, Japan, Sweden, the United Kingdom, and Venezuela. *(See tables 7 and 8.)*

World Review

World production of industrial sand and gravel, based on information usually provided by foreign Governments, was estimated to be 108 million tons, virtually unchanged from that of 1992. The United States was the leading producer, followed by, in descending order, the Netherlands, Germany, France, and Austria. Most countries in the world had some production and consumption of industrial sand and gravel because of its basic uses in glass and foundries. However, because of variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed, many other countries were believed to have had some type of silica production and consumption. *(See table 9.)*

Current Research and Technology

Reports on advances in glasses, ceramics, fillers, and chemicals that would consume or affect the industrial sand and gravel industry were scattered throughout various journals, magazines, and periodicals. Some have been mentioned earlier in this report and others are briefly highlighted on the following pages.

J.M. Huber Corp. has made what it calls a breakthrough in synthetic precipitated silica technology. The company says that materials using this technology offer advantages in lower rolling resistance and enhanced fuel mileage. The silica would be used in place of carbon black in tires. Huber is calling tires made using such silicas "green" tires to denote their environmentally friendly nature.[25]

Panhandle Eastern Corp. has become the first U.S. natural gas pipeline company to install a fiberglass reinforcement on an in-service gas pipeline. The 12-inch-wide reinforcement wraps consist of glass fibers impregnated with a polymer-based resin that, when treated with a special adhesive and wrapped around the weakened area of a steel pipe, restore the pipe's integrity.[26]

In 1988 and 1990, this report discussed the use of glass to encapsulate radioactive or hazardous waste. The process was still being investigated in 1993 but the outlook was dampened, to some degree, by results from research at Argonne National Laboratory. Its research showed that slow dripping water can change the largely nonreactive borosilicate glass into a form that facilitates the flaking of microscopic mineralized shards. More important, the Department of Energy-funded study shows some of the waterborne flecks bear unexpectedly enriched concentrations of certain interred radionuclides.[27]

Hoechst AG, Frankfurt, Germany, was planning a new plant to produce the novel detergent builder SKS-6 (layered silicic acid). This plant replaces a detergent phosphate plant that was closed on the site in 1992. SKS-6 works as an ion exchanger and reportedly better than zeolites that are currently used. The new product is produced in a two-stage drying process where sodium silicate raw material is transformed first to an amorphous and then to a crystalline product.[28]

Silica is not normally considered a lightweight aggregate but according to a recent article a rather simple process may yield a light weight. Silica and sodium carbonate are dissolved in a digester to produce water glass. The liquid is then converted to dense sandy particles that are then processed in a carousel furnace where they expand 25 times. The product, *Cylafoam*, has been tested by Oak Ridge National Laboratories and yields good thermal properties.[29]

Blasch Precision Ceramics Inc., Schnectady, NY, has developed a new commercial process for producing high-precision fused silica parts. The process can be used to manufacture large or small fused silica parts of complex shape, with fine edges and typical tolerances of ±0.001 inch per linear inch without machining.[30]

OUTLOOK

Demand

The forecast range of total U.S. demand in the year 2000 was expected to be 25 to 30 million tons for industrial sand and gravel. Probable demand was expected to be about 28 million tons. All forecasts were based on previous performances for this commodity within various end uses and contingency factors considered relevant to the future of the commodity.

Glass Sand

Since 1987, annual demand for glass sand has fluctuated between 10 and 11.1

million tons. The amount of sand consumed for container glass has generally 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 on the amount of sand used. However, glass fibers and novel uses for glass may offer new avenues for silica sales for glass.

Forecasts for specialty glasses, particularly fiber optics, were proffered by various groups in 1993. A study by Business Communications Co., Inc., concluded that silica is the most important advanced glass, with a wide spectrum of applications, such as optical fibers, optical devices and lenses, dielectric layers, and antireflective and radiation-resistant coatings. It was projected that overall precursor-derived advanced glasses will account for sales of almost $1.9 billion by the year 2000 as a result of 20% growth annually.[31]

KMI Corp., Newport, RI, forecasted very positive growth for fiber-optic components, including cable, for countries, regions, and worldwide. It predicted world growth at 20% per year through the year 2000. For Mexico and South America, growth was predicted at a whopping 30% per year for the next 6 years, the highest growth rate in the world.[32]

In a different glass market, Certain-Teed Corp., Valley Forge, PA, predicted strong recovery for the fiberglass-reinforced plastics industry because shipments in 1993 were expected to exceed 375,000 tons of fiberglass reinforcements for the first time.[33]

Overall, although demand for specialty glasses is expected to increase, the large tonnage consumers—the container and flat glass segments—will probably experience little total growth. Therefore, demand for glass sand was expected to grow very slowly in quantity until the year 2000. Probable demand for glass sand for the year 2000 was forecast to be 11.5 million tons with a range of 9 to 12.5 million tons.

Foundry Sand

The use of foundry sand was seen to be dependent mainly on automobile production. Another important factor for the future consumption of virgin foundry sand was the recycling of used foundry sand. The level of recycling, though not clear, was thought to be increasing. Other materials or minerals compete with silica as foundry sand but these other "sands" usually suffer a price disadvantage.

Based on foundry activity, competing materials, and recycling, the probable forecast for silica foundry sand consumption in the year 2000 was expected to be 6 million tons and the demand range was expected to be 5 to 7 million tons.

Hydraulic Fracturing Sand

Frac sand was sold in greater volumes in 1993 compared to those of 1992. The Baker-Hughes' cumulative rig count comparing year to year data revealed 1993 consistently ahead of 1992 as the year ended 13.5% ahead of yearend 1992. U.S. production of oil will likely suffer as imports have continued to control a higher percentage of supply but natural gas production has seen steady increases. Based on these factors, demand was expected to grow for this end use during the decade, partially due to strong exports and a growing demand for natural gas. Probable demand for hydraulic fracturing sand for the year 2000 was expected to be 1.9 million tons, with a range of 1.6 to 2.2 million tons.

Other Silica Markets

Because of the many uses of silica it is difficult to forecast silica demand with great precision. Some factors affecting future demand have been discussed but a few additional factors are worth mentioning. Texas and New Mexico are becoming the focal points of a miniboom in the construction of microchip processing plants. Texas Instruments Inc., Motorola Inc., and Advanced Micro Devices, Inc., all have new plants planned for the region. Strong growth in the semiconductor market, approaching 20% worldwide, has spurred the construction of these facilities.[34]

Consumption of sodium silicates for use in detergents and water treatment will grow at a rate of 2.5% annually through 1997, according to Freedonia Group Inc., Cleveland, OH. Developments affecting these uses were discussed earlier in this report. Industrial sand will be the major silica source for the silica, boding well for U.S. producers.[35]

As mentioned in the consumption and uses section, specialty silicas should see good growth this decade. More particularly, TCP Business Research Group, Basel, Switzerland, predicted the U.S. silicon compounds industry will grow at a rate of 5.3% annually through 1997. High average annual growth is expected for silicone elastomers, with liquid, two-component heat-cured silicones that can be injection-molded. Other silicones to see good growth include silicon alloys used in superalloy production and silicones used in household and personal products. Silicates for paper bleaching and water treatment were predicted to grow less quickly.[36]

Adequacy of Supply

Domestic production was expected to continue to meet more than 99% of demand through the year 2000. Imports, mostly from Australia, Canada, and Europe, were expected to remain minor.

The United States was the largest producer and consumer of silica sand among the market economy countries and was self-sufficient in this commodity. Most of it was produced in the eastern part of the United States, where the largest deposits and major markets are. A significant amount of silica sand also was produced in the West and Southwest, mostly in California and Texas.

Because the unit price of silica sand was relatively low, except for a few end uses that required a high degree of processing, the location of silica sand deposits in relation to the market was an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supplied local markets with a limited number of products.

The constant dollar price of domestic

silica sand had fluctuated since 1983 and was expected to continue fluctuating because of strong competition among producers for retention of dwindling markets for traditional uses.

Possible Supply-Demand Changes

Several factors could affect supply-demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand. These substitutes, mainly polymers and ceramics, would likely increase demand for ground silica, which is used as a filler in plastics; for glass fibers, which are used in reinforced plastics; and for silica, either chemically, whole grain, or ground, which is used to manufacture ceramics. Also, increased efforts to reduce waste and increase recycling could hinder glass sand demand. However, with advances in high-tech materials, silica sand may see increased consumption for fiber optics and other silicon and glass compounds. Although developments could cause demand for silica sand to decrease, the total value of production could increase because of the increased unit value of the more specialized sands.

An increase in the price of oil on the international market would stimulate domestic drilling and extraction from new and old oil deposits. This would increase demand for domestic hydraulic fracturing sand.

Concern over the use of silica as an abrasive due to health concerns and the imposition of stricter legislative and regulatory measures concerning silica exposure could decrease demands in many silica markets. Silica sand for use in the abrasive blast industry was being attacked as a health hazard as marketers of competing materials, including garnet, slags, and olivine, pushed the use of their "safer" abrasive medium.

Development of more efficient mining and processing methods are expected to continue. This will enhance development of lower grade silica sand deposits closer to markets but not presently mined. Such developments are expected to increase silica sand reserves.

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TABLE 1
SALIENT U.S. INDUSTRIAL SAND AND GRAVEL STATISTICS[1]

(Thousand metric tons and thousand dollars)

		1989	1990	1991	1992	1993
Sold or used:						
Sand:						
Quantity		25,237	24,454	22,263	[r]23,672	24,521
Value		$395,807	$420,871	$377,578	[r]$414,683	$435,901
Gravel:						
Quantity		1,256	1,315	961	[r]1,523	1,699
Value		$14,388	$15,284	$12,899	[r]$19,791	$18,530
Total industrial:						
Quantity		26,494	25,769	23,224	[r]25,195	26,220
Quantity	thousand short tons[2]	29,205	28,406	25,600	[r]27,773	28,903
Value		$410,200	$436,200	$390,477	[r]$434,474	$454,431
Exports:						
Quantity		1,869	1,048	1,485	1,337	1,751
Quantity	thousand short tons[2]	2,060	1,155	1,637	1,474	1,930
Value		$78,308	$83,826	$106,606	$90,403	$90,990
Imports for consumption:						
Quantity		32	66	83	164	44
Quantity	thousand short tons[2]	35	73	91	181	49
Value		$2,057	$3,148	$932	$2,454	$2,439

[r] Revised.

[1] Puerto Rico excluded from all industrial sand and gravel statistics.

[2] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

TABLE 2
INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION

Geographic region	1992 Quantity (thousand metric tons)	1992 Percent of total	1992 Value (thousands)[r]	1992 Percent of total	1993 Quantity (thousands metric tons)	1993 Percent of total	1993 Value (thousands)	1993 Percent of total
Northeast:								
New England	[r]124	1	$3,738	1	102	([1])	$4,424	1
Middle Atlantic	[r]2,023	8	36,233	9	2,428	9	39,749	9
Midwest:								
East North Central	[r]8,880	[r]35	133,782	[r]31	9,757	37	147,176	32
West North Central	[r]1,727	7	35,029	8	1,767	7	37,567	8
South:								
South Atlantic	[r]3,801	15	70,242	16	3,905	15	71,690	16
East South Central	1,311	5	19,162	4	1,278	5	19,449	4
West South Central	[r]3,641	15	65,238	15	3,747	14	68,669	15
West:								
Mountain	1,558	6	23,701	[r]5	1,226	5	19,500	4
Pacific	[r]2,131	[r]8	47,350	11	2,010	8	46,207	10
Total[2]	[r]25,195	100	434,474	100	26,220	100	454,431	100
Total thousand short tons[3]	[r]27,773	XX	XX	XX	28,903	XX	XX	XX

[r] Revised. XX Not applicable.

[1] Less than 1/2 unit.

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

[3] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

TABLE 3

INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992		1993	
	Quantity	Value	Quantity	Value
Alabama	605	6,768	559	6,802
Arizona	W	W	W	W
Arkansas	[r]806	10,458	642	7,597
California	[r]1,915	[r]42,512	1,797	41,668
Colorado	W	W	W	W
Connecticut	W	W	W	W
Florida	[r]536	[r]6,145	504	5,911
Georgia	533	8,783	491	7,941
Idaho	728	9,214	W	W
Illinois	[r]4,241	[r]57,454	4,224	61,734
Indiana	107	1,278	W	W
Iowa	W	W	W	W
Kansas	W	W	W	W
Louisiana	471	9,267	465	9,359
Maryland	W	W	W	W
Massachusetts	8	151	2	42
Michigan	[r]1,954	[r]22,585	2,567	25,129
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	644	10,931	520	9,389
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	482	W	480	W
New Jersey	1,377	24,727	1,826	28,640
New York	W	W	W	W
North Carolina	1,088	17,533	1,344	18,597
North Dakota	W	W	W	W
Ohio	1,276	26,445	1,360	27,533
Oklahoma	972	19,011	1,208	23,155
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	770	17,316	749	18,964
Tennessee	614	10,665	644	11,736
Texas	[r]1,392	[r]26,501	1,433	28,558
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	[r]1,303	[r]26,020	1,479	31,399
Other	[r]3,379	[r]80,709	3,926	90,278
Total[1]	[r]25,195	[r]434,474	26,220	454,431
Total thousand short tons[2]	[r]27,773	XX	28,903	XX

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

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

[2] One metric ton equals 1,000 kilograms or 2,204.62 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

TABLE 4
INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1993, BY SIZE OF OPERATION

Size range	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total
Less than 25,000	29	19	326	1
25,000 to 49,999	16	10	572	2
50,000 to 99,999	34	22	2,224	8
100,000 to 199,999	27	18	3,299	13
200,000 to 299,999	9	6	2,047	8
300,000 to 399,999	13	8	4,043	15
400,000 to 499,999	9	6	3,670	14
500,000 to 599,999	9	6	4,505	17
600,000 to 699,999	3	2	1,718	7
700,000 and over	4	3	3,815	15
Total	153	100	[1]26,220	100

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

TABLE 5
NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1993, 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	2	—	—	—	1	3
Middle Atlantic	9	—	3	1	3	16
Midwest:						
East North Central	30	1	2	4	4	41
West North Central	7	—	—	—	6	13
South:						
South Atlantic	16	—	—	3	6	25
East South Central	10	—	—	—	3	13
West South Central	10	—	—	2	11	23
West:						
Mountain	8	—	1	—	—	9
Pacific	8	—	—	1	1	10
Total	100	1	6	11	35	153

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1993, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton
Sand:															
Glassmaking:															
Containers	W	W	$16.36	1,747	$17,659	$10.11	1,983	$29,097	$14.67	W	W	$20.40	5,948	$88,113	$14.81
Flat (plate and window)	W	W	15.92	819	8,801	10.75	1,357	20,400	15.03	W	W	17.74	2,477	34,548	13.95
Specialty	208	$4,019	19.35	364	5,783	15.89	429	7,628	17.79	29	$824	28.49	1,029	18,254	17.74
Fiberglass (unground)	W	W	13.81	276	3,877	14.08	75	1,103	14.67	W	W	17.36	500	7,397	14.80
Fiberglass (ground)	—	—	—	29	1,186	40.42	347	14,278	41.17	—	—	—	376	15,464	41.11
Foundry:															
Molding and core	W	W	20.80	4,625	53,701	11.61	898	12,072	13.45	W	W	20.78	5,899	73,530	12.46
Molding and core facing (ground)	W	W	47.81	W	W	57.34	W	W	74.68	W	W	18.74	27	1,565	57.73
Refractory	W	W	7.55	46	501	10.88	W	W	21.97	W	W	22.14	70	921	13.26
Metallurgical:															
Silicon carbide	—	—	—	W	W	14.49	—	—	—	—	—	—	W	W	14.49
Flux for metal smelting	W	W	20.93	W	W	21.35	W	W	7.87	20	189	9.34	28	274	9.62
Abrasives:															
Blasting	146	3,552	24.31	336	8,684	25.85	969	20,835	21.51	141	4,438	31.51	1,592	37,508	23.56
Scouring cleansers (ground)	W	W	30.50	W	W	38.12	W	W	57.60	—	—	—	14	508	36.60
Sawing and sanding	W	W	20.67	—	—	—	W	W	16.53	—	—	—	W	W	19.15
Chemicals (ground and unground)	W	W	18.08	W	W	11.10	185	4,362	23.57	46	961	20.48	531	9,249	17.42

See footnotes at end of table.

TABLE 6—Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1993, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton
Sand—Continued:															
Fillers (ground):															
Rubber, paints, putty, etc.	W	W	187.08	72	5,078	70.96	W	W	151.50	W	W	42.90	122	12,715	104.27
Whole grain fillers/building products	64	1,609	25.21	381	8,202	21.53	213	3,474	16.29	243	5,835	23.99	902	19,120	21.20
Ceramic (ground):															
Pottery, brick, tile, etc.	W	W	41.60	109	5,940	54.63	83	4,101	49.00	W	W	24.16	208	10,718	51.53
Filtration:															
Water (municipal, county, local, etc.)	64	1,405	22.12	93	2,786	29.96	126	2,213	17.62	77	2,644	34.29	360	9,049	25.14
Swimming pool, other	9	220	24.25	W	W	75.16	W	W	63.93	—	—	—	20	888	44.40
Traction (engine)	W	W	11.60	114	1,156	10.14	46	557	12.04	W	W	18.06	214	2,480	11.59
Roofing granules and fillers	W	W	19.07	46	518	11.20	206	2,531	12.29	W	W	16.48	289	3,731	12.89
Hydraulic fracturing	—	—	—	1,365	43,006	31.51	W	W	27.78	W	W	31.22	1,694	52,223	30.83
Well packing and cementing	W	W	50.16	W	W	124.93	6	211	33.23	—	—	—	14	981	72.09
Golf course (greens and traps)	139	2,392	17.21	210	3,212	15.30	232	2,160	9.30	130	2,466	19.01	711	11,130	15.65
Baseball, volley ball, play sand, beaches	95	1,259	13.22	19	276	14.53	54	575	10.56	3	474	174.17	172	2,584	15.02
Other (ground silica)	W	W	46.44	W	W	56.81	16	628	38.34	—	—	—	23	1,005	43.60

See footnotes at end of table.

TABLE 6—Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1993, BY MAJOR END USE

Major use	Northeast			Midwest			South			West			U.S. total[1]		
	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton	Quantity (thousand metric tons)	Value (thousands)	Value per ton
Sand—Continued:															
Filtration—Continued:															
Other (whole grain)	94	2,212	23.38	312	5,656	18.14	561	7,970	14.21	320	6,808	21.22	1,287	22,645	17.59
Total[1] or average	2,304	42,875	18.61	11,242	181,810	16.17	8,176	151,001	18.47	2,799	60,214	21.51	24,521	435,900	17.78
Gravel:															
Silicon, ferrosilicon	—	—	—	118	1,570	13.28	402	5,869	14.60	W	W	10.86	W	W	13.92
Filtration	108	911	8.46	64	1,066	16.45	33	805	24.80	—	—	—	205	2,782	13.58
Nonmetallurgical flux	—	—	—	—	—	—	—	—	—	W	W	13.39	W	W	13.39
Other uses, specified	118	387	3.27	99	295	2.98	320	2,133	6.67	54	542	9.92	592	3,356	5.67
Total[1] or average	226	1,298	5.74	282	2,931	10.39	754	8,807	11.68	436	5,493	12.58	1,699	18,530	10.90
Grand total[1] or average	2,530	44,173	17.46	11,524	184,741	16.03	8,930	159,808	17.90	3,236	65,707	20.31	26,220	454,431	17.33
Grand total thousand short tons[2]	2,789	XX	XX	12,703	XX	XX	9,844	XX	XX	3,567	XX	XX	28,903	XX	XX

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] One metric ton equals 1,000 kilograms or 2,204.62 pounds. To convert metric tons in to short tons, divide metric tons by 0.907185.

TABLE 7

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
North America:				
Bermuda	20	208	(2)	24
Canada	885	12,368	1,396	17,845
Mexico	102	5,826	43	1,724
Panama	17	759	12	229
Other	3	445	3	834
Total[3]	1,026	19,606	1,454	20,656
South America:				
Argentina	4	461	4	649
Brazil	62	300	78	530
Chile	(2)	7	(2)	269
Colombia	(2)	92	(2)	92
Ecuador	(2)	190	(2)	159
Peru	5	283	2	144
Venezuela	2	194	(2)	132
Other	1	[r]41	2	14
Total[3]	72	1,568	86	1,989
Europe:				
Belgium	10	1,182	6	3,531
Denmark	8	1,086	6	1,632
Finland	4	94	3	76
France	2	514	1	564
Germany	14	2,804	34	3,760
Italy	5	599	3	701
Netherlands	71	2,367	14	5,035
United Kingdom	4	885	3	1,065
Other	2	816	4	822
Total[3]	119	10,347	74	17,186
Asia:				
Indonesia	5	208	(2)	36
Japan	60	48,955	84	39,116
Korea, Republic of	15	3,109	10	3,035
Singapore	3	3,144	8	3,879
Taiwan	12	1,775	22	3,099
Other	23	709	2	904
Total[3]	117	57,900	126	50,069
Middle East and Africa:				
Ghana	(2)	10	(2)	18
Israel	(2)	87	(2)	42
Saudi Arabia	(2)	36	1	103
South Africa, Republic of	(2)	140	7	166
Other	1	41	1	243
Total	1	314	9	572

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	F.a.s. value[1]	Quantity	F.a.s. value[1]
Oceania:				
Australia	2	623	2	462
Other	([2])	45	([2])	56
Total	2	668	2	518
Grand total	1,337	90,403	1,751	90,990
Grand total thousand short tons[4]	1,474	XX	1,930	XX

[r]Revised. XX Not applicable.

[1]Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

[2]Less than 1/2 unit.

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

[4]One metric ton equals 1,000 kilograms or 2,204.62 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

Source: Bureau of the Census.

TABLE 8

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

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	C.i.f. value[1]	Quantity	C.i.f. value[1]
Australia	41	1,758	42	1,762
Belgium	122	52	([2])	5
Canada	1	57	([2])	28
France	([2])	6	([2])	19
Germany	([2])	180	1	76
Italy	—	—	([2])	18
Japan	([2])	195	([2])	147
Mexico	([2])	19	—	—
Netherlands	([2])	3	—	—
Solomon Islands	—	—	([2])	7
Sweden	([2])	144	1	329
United Kingdom	([2])	31	([2])	2
Venezuela	([2])	10	([2])	45
Total[3]	164	2,454	44	2,439
Total thousand short tons[4]	181	XX	49	XX

XX Not applicable.

[1]Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.

[2]Less than 1/2 unit.

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

[4]One metric ton equals 1,000 kilograms or 2,204.62 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

Source: Bureau of the Census.

TABLE 9
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Argentina	[r]344	[r]325	[r]374	[r]307	350
Australia[e]	[r]2,000	[r]2,000	[r]2,000	[r]2,000	2,000
Austria	819	818	2,090	[r]5,884	6,000
Belgium	[r]2,505	2,556	2,554	[e]2,475	2,475
Bosnia and Herzegovina[e]	—	—	—	[r]50	50
Brazil[e]	[r]2,700	[r]2,700	[r]2,700	[r]2,700	2,700
Canada	[r]2,491	2,081	[r]1,495	[r]1,754	1,600
Chile[e]	[r]300	300	300	300	300
Croatia	—	—	—	[r]150	100
Cuba[e]	[r]550	500	500	[r]450	400
Denmark	[r]343	[r]207	[r] [e]202	[r] [e]194	194
Ecuador[e]	[r] [3]56	[r]52	[r]33	[r]51	46
Egypt[4]	41	507	500	[e]500	500
Estonia[5]	—	—	—	[e]30	25
Finland	274	[r]276	201	[r]169	160
France[e]	[r]7,500	[r]3,500	[r]3,500	[r]6,300	6,200
Germany:					
Western states	[r]9,762	[r]9,396	—	—	—
Eastern states	[r]3,352	[r] [e]1,850	—	—	—
Total	[r]13,114	[r]11,246	[r]11,005	[r]10,706	10,690
Greece	61	[r]94	[r]—	[r]—	—
Guatemala	31	30	17	[r]34	27
Hungary	[r]1,440	[r]1,248	[r]781	[r]844	780
Iceland[e]	5	5	5	5	5
India	[r]1,239	[r]1,139	[r]1,924	[r] [e]2,000	1,100
Indonesia	302	165	429	[e]400	350
Iran[6]	823	[e]870	832	[r]756	800
Ireland[e]	7	7	7	7	7
Israel	65	85	60	60	60
Italy[e]	4,500	4,300	4,200	4,000	4,000
Jamaica	15	17	16	16	16
Japan	4,378	[r]4,439	4,343	[r]3,864	3,880
Kenya	11	[e]12	[e]12	12	12
Korea, Republic of[e]	1	2	1	2	2
Latvia[5]	—	—	—	[e]108	87
Liberia[e]	10	5	—	—	—
Lithuania[5]	—	—	—	[e]80	60
Macedonia	—	—	—	[r]—	—
Malaysia	452	687	668	[r]579	370
Mexico	[r]1,216	[r]1,174	[r]1,198	[r]1,129	[3]1,175
Namibia[e]	—	—	—	[r](7)	(7)
Netherlands	25,647	25,137	[r] [e]25,000	[e]20,000	20,000
New Caledonia[e]	23	31	31	31	31
New Zealand	[r]419	[r]545	[r]594	[r] [e]600	600
Norway[e]	798	798	798	798	798
Pakistan	181	131	151	[r]135	160
Panama	[e]12	15	18	23	23

See footnotes at end of table.

TABLE 9—Continued

INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country[2]		1989	1990	1991	1992	1993[e]
Paraguay		1,939	[r] [e]2,000	[r] [e]2,000	[r]2,000	2,000
Peru[e]		75	100	[3]150	[r] [3]152	152
Philippines		185	292	[r]532	500	500
Portugal[e]		5	5	5	5	5
Serbia and Montenegro		--	--	--	[r]922	900
Slovenia[e]		--	--	--	[r]300	200
South Africa, Republic of		2,182	1,986	2,068	1,750	1,500
Spain[e]		[r]2,400	[r]2,200	[r]2,200	[r]2,200	2,200
Sweden[e]		699	699	699	699	699
Tanzania		13	6	4	4	4
Thailand		296	422	157	[e]170	150
Turkey[8]		495	[r]469	[r] [e]358	[r] [e]510	520
United Kingdom[e]		[r]4,500	[r]4,300	[r] [3]3,900	[r] [3]3,615	4,000
United States (sold or used by producers)		26,494	25,769	23,224	[r]25,195	26,220
Venezuela		378	443	343	[r]703	790
Yugoslavia[9]		3,143	2,448	2,100	--	--
Zimbabwe[10]		62	63	70	[r]77	80
Total	thousand metric tons	[r]117,539	[r]109,206	[r]106,349	[r]108,305	108,053
Total	thousand short tons	[r]129,564	[r]120,379	[r]117,230	[r]119,386	119,108

[e] Estimated. [r] Revised.

[1] Table includes data available through July 19, 1994.

[2] In addition to the countries listed, Angola, Antigua and Barbuda, The Bahamas, and China, among others, produce industrial sand, but current available information is not adequate to formulate estimates of production levels.

[3] Reported figure.

[4] Fiscal years beginning July 1 of that stated.

[5] Formerly part of the U.S.S.R., which was dissolved in Dec. 1991. Information was inadequate to formulate reliable estimates of production prior to 1992.

[6] Fiscal years beginning Mar. 21 of that stated.

[7] Less than 1/2 unit.

[8] Washed product.

[9] Dissolved in Apr. 1992.

[10] Includes rough and ground quartz as well as silica sand.

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1993, BY GEOGRAPHIC REGION

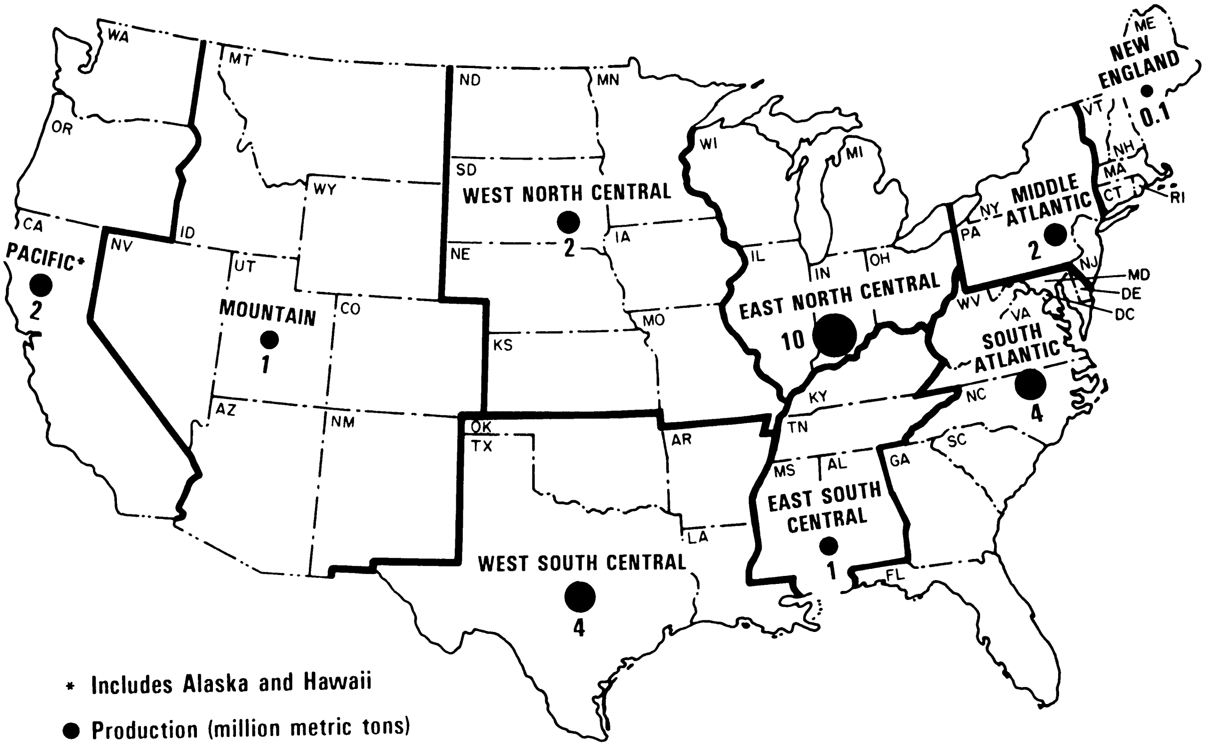
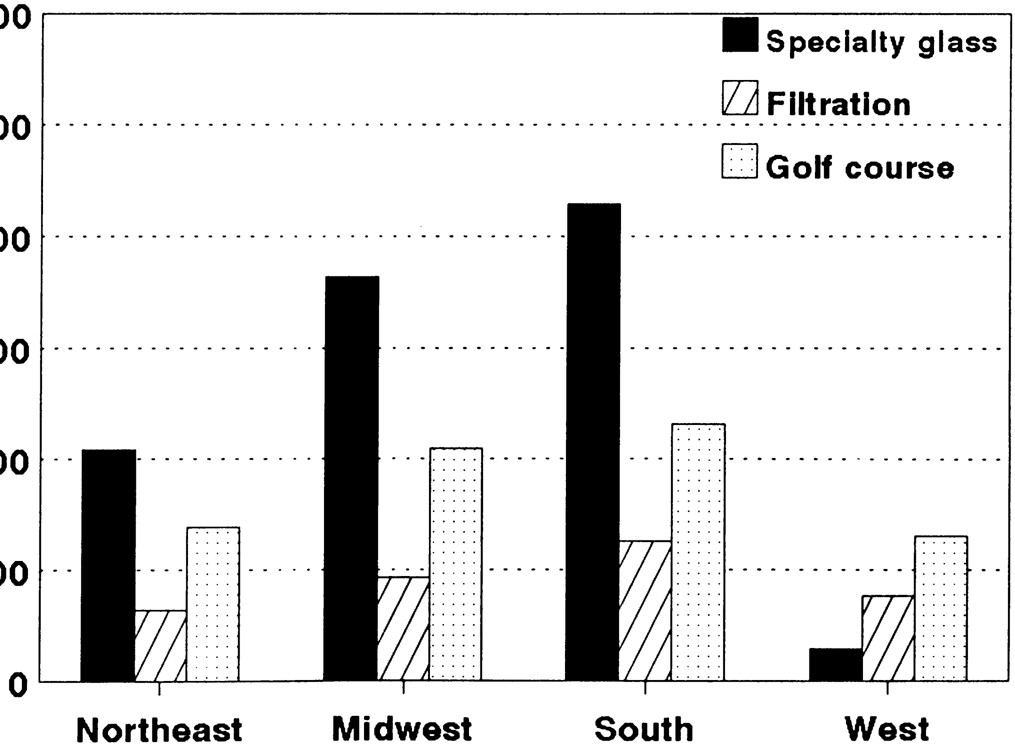


FIGURE 2

SAND USED IN SELECTED END USES, 1993

(Thousand metric tons)



SILICON

By Larry D. Cunningham

Mr. Cunningham, a physical scientist with 14 years of U.S. Bureau of Mines experience, has served as the commodity specialist for silicon since 1992. Domestic survey data and trade data were prepared by Mr. Kevin Bacon, statistical assistant.

Silicon (Si) is a light chemical element with metallic and nonmetallic characteristics. In nature, silicon combines with oxygen and other elements to form silicates. Silicon in the form of silicates constitutes more than 25% of the Earth's crust. Silica is a silicate consisting entirely of silicon and oxygen. Silica (SiO_2) as quartz or quartzite is used to produce silicon-base products for the aluminum, chemical, iron, and steel industries.

The average annual dealer import price for silicon metal and ferrosilicon declined from that of the previous year. Based on contained silicon, overall domestic production remained at about 370,000 metric tons and consumption of silicon increased to about 560,000 tons.

Overall U.S. trade volume of silicon exports was down by 20%, while overall trade volume of silicon imports decreased by 3%. The U.S. International Trade Commission (ITC) and the U.S. Department of Commerce (DOC) concluded their antidumping and countervailing duty investigations on ferrosilicon imports from a number of importing countries.

DOMESTIC DATA COVERAGE

Domestic production data for the silicon commodity are developed by the U.S. Bureau of Mines by means of monthly and annual voluntary surveys. The "Silicon Alloys" survey canvasses the operations listed in table 2. The figures in table 1 represent 100% of the production and shipments from these operations. *(See tables 1 and 2.)*

BACKGROUND

Definitions, Grades, and Specifications

Silicon metal and ferrosilicon are referred to by the approximate percentage of silicon contained in the material and by the maximum amount of trace impurities present. There are two standard grades of ferrosilicon, with one grade approximately 50% silicon and the other 75% silicon by weight. In addition to the standard grades of ferrosilicon, there are miscellaneous silicon alloys that contain silicon and other elements. The most common of these alloys are magnesium ferrosilicon and calcium silicon. However, other elemental additions include barium, boron, manganese, strontium, and titanium.

Metallurgical-grade and polycrystalline silicon metal are referred to by their minimum silicon content and maximum impurity level. Typical impurities cited for metallurgical silicon metal are aluminum, calcium, and iron. Typical polysilicon impurities include boron, carbon, and phosphorus and are commonly measured at the parts per million and parts per billion levels.

The American Society for Testing and Materials (ASTM) publishes standards for ferrosilicon and silicon metal. ASTM Specification A100 covers seven regular grades of ferrosilicon for steelmaking and foundry uses designated A, B, C, D, E, F, and G and subgrades designated as low-aluminum, boron-bearing, and calcium-bearing. ASTM recommends that the producer furnish with each shipment an analysis showing the silicon content and, on request, also include aluminum, boron, calcium, carbon, manganese, phosphorus, and sulfur contents. ASTM Specifications A518 and A861 cover high-silicon cast iron castings and high-silicon iron pipe and pipe fittings for corrosion-resistant uses.

Products for Trade and Industry

Several grades of ferrosilicon are produced and sold in the United States. Most of the ferrosilicon consumed domestically in 1993 was either 50%- or 75%-grade material, the majority 50%-grade material. The domestic silicon industry in 1993 continued to supply about 60% of all ferrosilicon products. Of the miscellaneous silicon alloys consumed in the United States, magnesium ferrosilicon is the most significant. Almost all ferrosilicon products are consumed by the iron and steel industry.

Metallurgical-grade silicon metal is used by the primary aluminum, secondary aluminum, and chemical industries. The products sold to these industries vary considerably in their specifications. The chemical and primary aluminum industries generally require more stringent specifications than those of the secondary aluminum industry. In addition, the chemical industry requires that the metal be ground into a fine powder rather than the lump form used by the aluminum industry.

The first crystalline silicon was made in 1854. Comprehensive investigations of the effects of silicon in steel stimulated a great demand for silicon in the steel industry in the 1880's, and with the development of the electric furnace in the late 1800's came expanded production of ferrosilicon. By 1949, the first silicon pure enough for use in transistors and other semiconductor devices was produced. Beginning in 1951, commercial production of high-purity silicon gave impetus to the rapidly expanding electronics industry.

Polycrystalline silicon (ultrapure, 99.9%) was a product largely confined to research until 1956, when its use in manufacturing components for commercial applications was estimated to have exceeded that used for research. By 1958, an estimated 20,412 kilograms of high-purity silicon valued at $16 million was consumed by the electronics industry for the manufacture of diodes, rectifiers, and transistors.

Geology-Resources

The United States has an abundance of silica deposits for the production of ferrosilicon and silicon metal. For the production of these materials, 98% to 99% purity is preferred. However, trace amounts of aluminum and iron also are acceptable. Physically, the material should not contain fines and should not crumble easily.

Technology

Silicon metal and ferrosilicon are produced by the reduction of silica (SiO_2) to silicon (Si) in a submerged arc electric furnace. A typical charge consists of silica as beneficiated quartz or quartzite; coal, coke, or charcoal as a reductant; wood chips for porosity; and, when producing ferrosilicon, iron in the form of steel scrap or iron ore. During the furnace operation, raw materials are periodically charged into the top of the furnace, and the molten metal or alloy is periodically tapped at the bottom of the furnace and cast into chills or ingots. The material is then crushed to specific size requirements starting at about 20 centimeters down to 200 mesh.

Metallurgical-grade silicon metal is the starting material for high-purity silicon consumed by the electronics industry. First, silicon metal is used to produce an intermediate product such as silicon trichlorosilane (TCS). A vapor deposition process is then used to form a rod or boule of high-purity polycrystalline silicon (polysilicon) from the TCS. A single crystal boule is made from polysilicon by two methods. The Czochralski (CZ) method uses a seed crystal to grow a rod of single crystal silicon from a molten crucible of polysilicon. The Float Zone (FZ) method uses an induction coil to produce a molten zone within a rod of polysilicon. The coil starts at one end of the boule where a seed crystal starts the crystal growth. The coil moves slowly down the boule, allowing a single crystal to be formed. After being sliced into wafers, the silicon is used by the electronics industry to produce integrated circuits.

Recovery of silicon from secondary sources is not normally practiced. The only secondary possibility is recovery from scrap metal. However, any value of contained silicon would be incidental to the value of the primary metal. In 1993, the average price for ferrosilicon was about $0.41 per pound and the average price for silicon metal was about $0.66 per pound. For the future, recycling of silicon in the form of ferrosilicon and silicon metal is expected to be insignificant.

Byproducts and Coproducts

Silicon metal and ferrosilicon furnaces produce a material that is referred to as silica fume, silica dust, or microsilica. Originally, this material was considered of little or no value. However, microsilica is now used as an additive in a number of different products, including high-strength concrete.

Economic Factors

Production of silicon metal and silicon alloys is extremely power intensive, requiring a power input, for some operations, of up to 14,000 kilowatt-hours per ton of silicon content.

The location of ferrosilicon and silicon metal smelters is normally determined by balancing marketing costs against processing costs. Consequently, on a worldwide basis, smelting plants are near iron and steel industries or trade routes serving them, where cheap fossil fuel or electric energy is available or where a combination of these factors exists. The availability of hydroelectric power in large quantities at competitive prices, the lack of a sizable steel industry, and the presence of deep natural and ice-free harbors contributed to Norway becoming the largest exporter of ferrosilicon in the world. The high cost of electric power, proximity to world trade routes, and the demands of an established iron and steel industry have made Germany, Japan, and the United Kingdom three of the world's largest importers of silicon metal and ferrosilicon. During the 1980's, Brazil established itself as a major producer of silicon ferroalloys and silicon metal, joining countries such as Canada, Iceland, and Norway that have low power costs. In contrast, high power costs have forced Japanese ferroalloy producers to cease production of silicon metal and drastically curtail silicon ferroalloy production.

By 1960, consumption of high-purity silicon by the electronics industry was more than 31,751 kilograms. However, the market was becoming saturated with material resulting from increased output by new plants and the expanded production from older ones. Prices were in the range of $150 to $330 per pound compared with an average price of $330 per pound for metal consumed in 1958. By the mid-1960's, improvements in silicon devices and the increased use of integrated circuits in the computer and aerospace industries had contributed to an accelerated consumption of high-purity silicon.

Demand for metallurgical-grade silicon alloys and metal is determined by the level of activity in the steel, ferrous foundry, aluminum, and chemical industries and is little affected in the short term by prices for these materials. As a result, prices tend to vary widely with changes in demand and supply.

From the period 1955-69, the price of silicon alloys and metallurgical-grade metal remained stable. During this 15-year period, the domestic producer price fluctuated between \$0.12 and \$0.145 per pound for the 50%-grade ferrosilicon and between \$0.181 and \$0.219 per pound for metal.

Prices began to rise in the early 1970's owing to higher costs of scrap iron, metallurgical-grade coal, electric power, and the cost of newly installed pollution control devices to comply with local and Federal Government standards, which became effective in 1975. Responding to increased demand, rising inflation, and higher energy costs, prices rose steadily from 1977 to 1981.

By the end of 1988, domestic producers reportedly were operating at close to capacity. However, the record-high prices of 1988 had declined significantly by yearend 1992. The steady decline in prices was mainly caused by the oversupply of material resulting from the reactivation of idle capacity; the development of new capacity in South America; and the escalation of low-cost imports from China, South America, and countries of the former U.S.S.R. Consequently, production cutbacks were scheduled by several domestic producers as global production outpaced demand, resulting in a continued soft world market. Prices rebounded in 1993 with the price for ferrosilicon at the highest level since 1990 and the price for silicon metal at the highest level since 1988.

Principal elements in the cost of silicon and ferrosilicon production are (1) delivered costs of the ore; (2) energy cost; (3) cost of reductant coke or low ash coal; (4) cost of iron in the form of steel scrap, if required; and (5) labor. The cost of all these elements, and particularly the cost of energy, has increased rapidly since 1970. In addition, new capital costs for pollution control equipment were added.

ANNUAL REVIEW

Legislation and Government Programs

In April, the U.S. Department of Energy's (DOE's) Sandia National Laboratories, NM, reportedly signed a 5-year \$100 million agreement with Sematech, a consortium of semiconductor manufacturers. Each party will provide about one-half of the funding under the agreement. The goal of Sematech is to increase the U.S. competitiveness in the production of computer chips. Sandia will assist Sematech in programs such as equipment modeling and design, materials and process analysis, and contamination-free manufacturing research. Over the previous 5 years, the U.S. Department of Defense reportedly provided about \$100 million per year to Sematech's research.[1]

During the year, the DOC and the ITC concluded their antidumping and countervailing duty investigations on ferrosilicon imports from Argentina, China, Egypt, Kazakhstan, Russia, Ukraine, and Venezuela. The agencies determined that ferrosilicon imports from these countries, with the exception of Argentina and Egypt, were sold at less-than-fair value and caused material harm to the domestic industry. The DOC assessed the dumping duty for China at 137.73%; Kazakhstan, Russia, and Ukraine at 104.18%; and Venezuela at 9.55%. Also, Venezuela was assessed a countervailing duty of 22.08%. Antidumping investigations in the case of ferrosilicon imports from Brazil were continuing.

The DOC and ITC investigations were instituted in response to petitions filed by AIMCOR, Alabama Silicon Inc., American Alloys, Globe Metallurgical Inc., Silicon Metaltech Inc. (American Silicon Technologies), and union locals of the United Autoworkers of America, the United Steelworkers of America, and the Oil, Chemical & Atomic Workers.

In February, the DOC announced Final Scope Rulings—Antidumping Duty Orders on Silicon Metal from Argentina, Brazil, and China. In 1991, the DOC and the ITC had determined that imports of silicon metal, containing between 96% and 99.99% silicon by weight, from these countries were sold at less-than-fair value in the United States and caused material harm to the domestic industry. The DOC assessed the dumping duty for China at 139.49% and Argentina at 8.65%. The duty for Brazil was assessed against individual producers over a range of 87.79% to 93.2%. In March 1992, petitioners in the original investigation requested that DOC determine that material containing a lower silicon content, between 89% and 96% silicon by weight, because of a higher aluminum content, is covered by the antidumping duty order in effect for silicon metal imports from China. After its formal inquiry, the DOC concluded that silicon metal with a high aluminum content containing between 89% to 96% silicon by weight is within the scope of the class or kind of material subject to the antidumping duty orders on silicon metal from Argentina, Brazil, and China.

In August, the DOC also announced the results of its preliminary administrative review of the antidumping duty order on silicon metal from Brazil. DOC's review of Brazil covered four manufacturers/exporters during the period March 29, 1991, through June 30, 1992, and indicated the existence of dumping margins. DOC preliminarily determined that a margin of 88.24% exists for Eletrosilex Belo Horizonte.

In mid-December, the DOC announced final results of its administrative review of the antidumping duty order on silicon metal from Argentina. DOC's review of Argentina covered two manufacturers/exporters during the period March 29, 1991, through July 31, 1992. DOC determined that a margin of 2.06% exists for Electrometalurgica S.A.I.C. (Andina) and a margin of 54.67% exists for Silarsa S.A. A margin of 8.65% exists for "all others," the rate established in the final notice of the initial duty order.

DOC's administrative review of the antidumping duty order on silicon metal from China was terminated in late December, with no changes being made to the initial duty order.

In August, the U.S. Trade Representative announced that the Generalized System of Preferences (GSP), which had expired on July 4, 1993, was extended to September 30, 1994. The GSP extension was part of the Budget Reconciliation Act signed by the President. The legislation extending the GSP was retroactive to July 4. Additionally, the legislation removed the statutory prohibition against providing GSP benefits to the countries that made up the former U.S.S.R. Under GSP, the United States grants duty-free access to goods from more than 140 developing countries and territories. U.S. import duties for silicon products range from duty free to 9% ad valorem for most-favored-nation (MFN) status and from $0.044 per kilogram of contained silicon to 45% ad valorem for non-MFN status.

In Proclamation 6599 of September 30, 1993, the U.S. President designated Russia as a beneficiary developing country for purposes of the GSP. GSP status for Russia is part of the administration's overall efforts to help that country pursue badly needed market reforms. Kazakhstan, Romania, and Ukraine also were being considered for GSP status.

Production

Overall gross production of silicon products in the United States decreased 2% compared with that of 1992. Production of silicon metal was relatively unchanged, while production of ferrosilicon and miscellaneous alloys was down by about 4%. Overall shipments of silicon-containing products decreased by 3%. Producer stocks of silicon-containing materials were down by 13% overall. Ferrous scrap used in the production of these products was estimated to be about 150,000 tons.

Alabama Silicon Inc. reportedly reopened its ferrosilicon plant in Bessemer, AL, in October. The plant, closed since early January 1992, had an annual capacity of about 18,000 tons. Alabama Silicon is receiving financial backing from AIOC Corp., New York, NY, a metals trading company. AIOC will have exclusive marketing rights to Alabama Silicon's ferrosilicon production.[2]

Simetco Inc., Canton, OH, reportedly filed a voluntary petition in September for chapter 11 bankruptcy protection for reorganization purposes. Simetco's silicon metal facility in Montgomery, AL, has a reported annual capacity of about 40,000 tons.[3]

Globe Metallurgical Inc., headquartered in Cleveland, OH, announced the purchase of a 12,000-ton-per-year silicon metal plant in Springfield, OR, from Dow Corning of Midland, MI. Globe, a major U.S. producer of silicon metal, completed the purchase of the plant in mid-1993 for an undisclosed amount. The plant will be staffed by former Dow employees who have accepted permanent positions with Globe. The plant's silicon metal production is intended to service the west coast aluminum market. The new acquisition, along with Globe's silicon metal production facilities in Beverly, OH, and Selma, AL, reportedly increases the company's annual silicon metal capacity to about 65,000 tons.[4]

Applied Industrial Materials Corp. (AIMCOR), Denver, CO, announced in late September its intention to sell the company's Metals and Minerals Group. AIMCOR is a major international supplier of industrial carbon products and a producer of ferroalloys. The Metals and Minerals Group, headquartered in Pittsburgh, PA, includes 11 plants, inclusive of AIMCOR's ferrosilicon facility in Bridgeport, AL; a laboratory facility; and 2 sales offices. The Group employs about 270 people in Canada, Mexico, and the United States. AIMCOR's decision to sell the Group is based on the company's long-term objectives of focusing on its carbon products business. The Group will be sold as one unit or as separate metals and minerals units.[5]

Union Carbide Corp., Danbury, CT, announced in July that the company had completed the sale of its OrganoSilicon Products, Systems and Services (OSi) business to DLJ Merchant Banking Partners L.P. and affiliates of the New York investment banking firm of Donaldson, Lufkin & Jenrette Inc. The $300 million selling price consists of $220 million in cash plus $80 million of preferred stock, convertible into 30% of the voting common stock in the new company. Union Carbide indicated that the transaction essentially concludes the company's asset sales program announced in December 1991, which was intended to reduce debt, improve debt to capitalization, and improve interest coverage.[6] Union Carbide's OSi worldwide sales in 1992 were reported to be about $350 million.[7] The OSi business manufactures fluids and chemicals used in fiberglass, reinforced plastics, textiles, coatings, automotive, adhesives, pharmaceutical, agricultural, electrical, personal care, thermoplastics, sealants, and other specialty markets. The new silicones company will be known as OSi Specialties Inc. and reportedly will retain the current work force of more than 1,100 employees worldwide.[8]

It was reported in late December that OSi Specialties had completed a $15 million project to upgrade and expand its organofunctional silanes production at the company's plant in Sisterville, WV. The 15% increase in capacity was said to be part of OSi's ongoing expansion program to meet growing market needs. Further expansions were planned at Sisterville and at a plant in Termoli, Italy.[9]

Consumption and Uses

The aluminum industry used silicon metal in the production of wrought and cast products, while ferrosilicon was used primarily as a deoxidizing and alloying agent in the production of iron and steel products. Metallurgical-grade silicon metal also was used as the basic raw material in the manufacturing of many chemical products and intermediates such as silicones and silanes. Overall reported consumption of silicon alloys and metal for most major end uses was up in 1993. *(See table 3.)*

U.S. apparent consumption of silicon metal and silicon-containing ferroalloys was estimated to be about 560,000 tons of contained silicon. Consumption of silicon metal was estimated at 225,000 tons, while consumption of ferrosilicon and miscellaneous silicon alloys was estimated to be about 335,000 tons. Compared with that of 1992, consumption of silicon metal increased by 15%, while consumption of ferrosilicon and other alloys was down slightly. Ferrosilicon and miscellaneous silicon alloys continued to account for about 60% of all the silicon materials consumed, based on silicon content.

Markets and Prices

Table 4 shows the average annual import price for 50%- and 75%-grade ferrosilicon as well as silicon metal. Prices are posted in cents per pound of contained silicon. Overall ferrosilicon prices were on the increase compared with those of the previous year, with the 50%- and 75%-grade material following similar price change patterns. The import price for 50%-grade ferrosilicon increased progressively from a range of $0.37 to $0.375 per pound to a range of $0.44 to $0.45 by yearend. The import price for 75%-grade ferrosilicon rose from a range of $0.355 to $0.363 per pound to $0.435 to $0.45 in mid-September, where it remained through December.

The import price for silicon metal started the year at $0.663 to $0.668 per pound, rose to $0.67 to $0.685 by midyear, then fell in the fourth quarter to finish the year at $0.59 to $0.62. *(See table 4.)*

Foreign Trade

U.S. exports of ferrosilicon decreased about 30% compared with those of 1992, based on gross weight, while total value of the exports was down by about 20%. About 70% of the exported material continued to be shipped to Canada and Mexico. Silicon metal exports increased by 25% based on gross weight, with total value of the exports up by more than 40%. Canada, Japan, and Mexico were major recipients of the materials.

U.S. imports of silicon-containing alloys were down by 19% compared with those in 1992. Imports of ferrosilicon categorized as "55% to 80% silicon, other" decreased by 6% based on gross weight, with the total value for this category down by 18%. Brazil and Norway were the leading suppliers for this category. Overall volume and value of ferrosilicon categorized as "Other," which included all ferrosilicon of less than 55% silicon content, decreased substantially. There were no imports from countries of the former U.S.S.R. in this category compared with more than 80% of the total in 1992. Brazil and Norway accounted for 28% and 33%, respectively, of total imports. The schedule of tariffs that applied during 1993 to U.S. imports of selected silicon materials is given in table 5.

Overall imports of silicon metal products increased substantially. Imports of silicon metal categorized as "99.00 to 99.99% silicon" rose significantly. Canada continued as the leading supplier, providing about 50% of both total volume and value. Imports of "Other" silicon metal increased substantially, with Russia supplying about 70% of both volume and value for this category.

The U.S. net import reliances for ferrosilicon and silicon metal products were estimated to be 38% and 28%, respectively, compared with 38% and 17% the previous year. The overall import reliance for silicon products was estimated to be 34%. *(See tables 5, 6, and 7.)*

World Review

Brazil.—In September, Italmagnesio S. A. of Brazil entered into a receivership period of 2 years, similar to U.S. chapter 11 bankruptcy protection, for the purpose of restructuring the company's debt. Annual production capacity at Italmagnesio's silicon alloys and metal facilities in the Minas Gerais and Sao Paulo states was reported to be about 60,000 tons. Production and sales were said to be continuing as normal at Italmagnesia's subsidiaries.[10]

Brazil's Commerce Secretariat reportedly proposed that a 5% import tax be imposed on aluminum, cast iron, cobalt, ferroalloys, lead, tin, and zinc. Domestic producers had claimed that they needed tariff protection owing to low world prices, high imports from the former U.S.S.R., and exchange rate difficulties. Consumers were in opposition to the tax, citing a potential increase in processor/consumer production costs.[11]

Anuário da Indústria Brasileira de Ferroligas (ABRAFE), the Brazilian ferroalloy producers' association, reported 1992 production as follows: 45%-grade ferrosilicon, 4,620 tons; 75%-grade ferrosilicon, 239,218 tons; calcium-silicon, 22,756 tons; and silicon metal, 93,734 tons. ABRAFE reported 1992 domestic sales as follows: 45% (50%)-grade ferrosilicon, 3,711 tons; 75%-grade ferrosilicon, 53,771 tons; calcium-silicon, 3,118 tons; and silicon metal, 9,896 tons. Exports in 1992 were reported as follows: 45% (50%)-grade ferrosilicon, 13,324 tons; 75%-grade ferrosilicon, 178,116 tons; calcium-silicon, 20,660 tons; and silicon metal, 67,916 tons.

China.—According to The TEX Report, Chinese exports of ferrosilicon were at an alltime high: 340,000 tons valued at $156.6 million, compared with 280,000 tons valued at $130.72 million in 1992.

European Union (EU).—In September, the European Commission announced that it had imposed provisional antidumping duties on ferrosilicon imports from China and the Republic of South Africa. The Commission assessed the dumping duty for China at 49.7% and South Africa at 47.4%. However, South African producer Rand Carbide was assessed a duty of 34.7%. The provisional duties became effective September 23, 1993, for a 4-month period. The Commission determined that imports from both countries injured producers in the EU. EU producers reportedly had claimed that substantial dumping of material was eroding EU market prices.[12]

The EU became effective November 1, 1993, and is the "umbrella" term encompassing the European Community, the Common Foreign and Security Policy, and the Justice and Home Affairs.[13]

In December, the European Commission also imposed antidumping duties on ferrosilicon imports from a number of other importing countries and companies. The duties resulted from investigations that reportedly began in

May 1992. The Commission assessed the dumping duty for Kazakhstan, Russia, and Ukraine at 74% each; Iceland and Norway at 6.8% each; Sweden at 7.4%; and Venezuela at 20.4%. The general duty for Brazil was assessed at 20.5% (with the exception of a 9.2% duty for Companhia Brasileira Carbureto de Calcio, a 22.8% duty for Companhia de Ferro Ligas da Bahia, and a 20.5% duty for Rima Eletrometalurgia S.A., Companhia Paulista de Ferro Ligas, and Minasligas-Companhia Ferroligas Minas Gerais, respectively). The duties became effective December 10, 1993.[14]

France.—Rhone-Poulenc of France reportedly signed an agreement with Germany's Possehl to acquire Possehl's silicon subsidiary for an undisclosed amount. Possehl specializes in room-temperature vulcanizing silicone elastomers.[15] Rhone-Poulenc's purchase of Possehl will strengthen the company's presence in Germany, which is the third largest silicones market worldwide.[16] Additionally, Rhone-Poulenc planned to invest $47 million at its Roussillon site to construct a hydrochloric acid recycling plant. The company uses the acid to produce methyl chloride, a raw material used for its silicones production business. The use of recycled hydrochloric acid reportedly will reduce the company's salt wastes and also result in a 30% reduction in water consumption. The recycling plant was expected to begin operation by the end of 1995.[17]

India.—Indsil Electrosmelt Ltd. made plans for the construction of a new ferrosilicon plant in the Palghat district of Kerala State. Annual production capacity was planned to be about 7,800 tons. Startup of the $3.87 million plant was scheduled for November.[18] Indsil also planned to build two new powerplants in Kerala to provide electricity for its ferrosilicon facility. Additionally, Silcal Metallurgie reportedly was investing in a new plant, also in the Palghat district, to produce ferrosilicon and silicon metal. The plant was scheduled for completion in March 1995 and was to have an annual capacity of about 16,500 tons of product. Travancore Electro-Chemical Industries Ltd. reportedly was seeking loans from the Industrial Bank of India and the World Bank to build two new powerplants in Kerala to support its ferrosilicon operation. Travancore's annual production of ferrosilicon was reported to be about 7,000 tons. Monnet Ferroalloys, a ferrochrome producer, made plans to install furnaces at its facility in Raipur for the production of ferrosilicon and high-carbon ferromanganse.[19] Also, Indian ferroalloy producers reportedly were asking the Government to impose antidumpimg duties on ferrosilicon imports from Bhutan, China, and South Africa. The duties would be similar to those imposed in September by the European Commission on ferrosilicon imports from China and South Africa. The Government was said to be resisting the imposition of such duties.[20]

Japan.—According to The TEX Report, Japan's production of ferrosilicon was about 32,800 tons, compared with about 41,600 tons in 1992. Imports of ferrosilicon into Japan totaled about 516,700 tons, compared with about 416,000 tons the previous year. China continued as the leading supplier, accounting for about 254,000 tons of the imports. Imports of silicon metal into Japan increased to about 151,800 tons. Silicon metal imports from China and Brazil totaled about 76,600 tons and 44,900 tons, respectively. Consumption of silicon metal by the Japanese aluminum alloy sector decreased to about 51,000 tons, owing in part to reduced automobile production.

South Africa, Republic of.—The TEX Report reported that Silicon Technology Pty. Ltd. (Silitech), a subsidiary of Chromecorp Technology Pty. Ltd., inaugurated its ferrosilicon plant at Ballengeich, Natal, South Africa in July. A 40-megavolt-ampere (M•VA) electric furnace reportedly was started in May, and a 56-M•VA furnace started in July. Annual combined ferrosilicon production capacity at the plant was planned to be about 55,000 tons.

Venezuela.—CVG Fesilven CA reportedly commissioned a new ferrosilicon furnace in May. The company now operates three ferrosilicon furnaces with a combined annual production capacity of about 80,000 tons.[21] Additionally, state-owned Fesilven announced plans to seek financial investment, domestic and foreign, in the company. Fesilven reportedly is 88% owned by the Venezuelan Government and 12% by private domestic and foreign banks.[22]

OUTLOOK

Demand for silicon metal is driven by consumption in the aluminum and chemical industries. For 1994, industry sources indicate that Western World silicon metal demand will increase by 4%. In the aluminum industry, silicon metal demand is expected to increase by about 3%, with the automotive sector contributing to this growth. Within the chemical industry, silicon metal is used to produce a wide variety of silicone-base products and intermediates. For 1994, industry sources indicate that Western World silicon metal demand in the chemical industry will increase by about 6%. Additionally, Chemical Week reported that the domestic silicon compounds industry will grow by more than 5% per year through 1997. Silicon growth in this sector is attributed to silicone elastomers (particularly injection-moldable silicone rubbers), silicon alloys used in superalloy production, and silicones used in household and personal care products, all of which are expected to increase about 7% per year during this period.[23]

Ferrosilicon is consumed primarily by the iron and steel industry. The industry uses ferrosilicon for deoxidation of molten metal and as an alloying agent. The outlook for steel is discussed in the Iron and Steel Annual Report. For 1994, no significant increase in Western World steel production is expected. Domestic steel production in 1994 is expected to experience little change over that of 1993. Domestic consumption of ferrosilicon is not expected to exceed the 390,000 tons consumed in 1990. Additionally, the past pattern of domestic ferrosilicon supply is expected to be altered in the future. In 1993, the DOC imposed antidumping and countervailing duties on a number of major importing nations alleging injury to the domestic ferrosilicon industry.

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[22] Metal Bulletin. No. 7805, Aug. 12, 1993, p. 11.

[23] Chemical Week. V. 152, No. 23, June 16, 1993, p. 75.

TABLE 1

PRODUCTION, SHIPMENTS, AND STOCKS OF SILVERY PIG IRON, FERROSILICON, AND SILICON METAL IN THE UNITED STATES IN 1993

(Metric tons, gross weight, unless otherwise specified)

Material	Silicon content (percentage)		Producers' stocks, Dec. 31, 1992	Gross production[1]	Net shipments	Producers' stocks, Dec. 31, 1993
	Range	Typical				
Silvery pig iron	5-24	18	W	W	W	W
Ferrosilicon	25-55	48	48,846	199,275	158,752	43,850
Do.	56-95	76	20,672	94,437	93,208	17,125
Silicon metal (excluding semiconductor grades)	96-99	98	10,391	165,179	164,400	6,630
Miscellaneous silicon alloys (excluding silicomanganese)	32-65	—	15,194	79,575	77,675	14,744

W Withheld to avoid disclosing company proprietary data.

[1] Ferrosilicon production includes material consumed in the production of miscellaneous silicon alloys.

TABLE 2

PRODUCERS OF SILICON ALLOYS AND/OR SILICON METAL IN THE UNITED STATES IN 1993

Producer	Plant location	Product
American Alloys Inc.	New Haven, WV	FeSi and Si.
American Silicon Technologies	Rock Island, WA	Si.
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi.
Elkem Metals Co.	Alloy, WV	Si.
Do.	Ashtabula, OH	FeSi.
Globe Metallurgical Inc.	Beverly, OH	FeSi and Si.
Do.	Selma, AL	Si.
Do.	Springfield, OR	Si.
Keokuk Ferro-Sil Inc.	Keokuk, IA	FeSi and silvery pig iron.
Simetco Inc.	Montgomery, AL	Si.
SKW Alloys Inc.	Calvert City, KY	FeSi.
Do.	Niagara Falls, NY	FeSi and Si.

TABLE 3

REPORTED CONSUMPTION, BY MAJOR END USE, AND STOCKS OF SILICON ALLOYS AND METAL IN THE UNITED STATES IN 1993[1]

(Metric tons, gross weight, unless otherwise specified)

Silicon content (percent)	Silvery pig iron	Ferrosilicon[2]				Silicon metal	Miscellaneous silicon alloys[3]	Silicon carbide[4]
Range	5-24	25-55	56-70	71-80	81-95	96-99	—	63-70
Typical	18	48	65	76	85	98	48	64
End use								
Steel:								
Carbon	—	27,703	—	23,912	74	11,177	1,286	52
Stainless and heat-resisting	—	38,371	(5)	57,000	(5)	402	298	—
Other alloy	(5)	12,256	(5)	25,574	(5)	23	(5)	72
Tool	—	(5)	—	(5)	(5)	—	—	—
Unspecified	22	64	2	2,352	443	—	454	—
Total[6]	22	78,394	2	108,839	517	11,602	2,038	123
Cast irons	10,947	103,392	2,413	45,870	462	80	21,777	34,276
Superalloys	—	W	—	74	16	W	—	—
Alloys (excluding superalloy and alloy steel)	W	W	—	W	—	W	—	—
Miscellaneous and unspecified	11	5,004	—	451	—	[7]189,786	215	—
Grand total[6]	10,980	186,790	2,415	155,234	995	201,468	24,030	34,400
Consumers' stocks, December 31	943	6,597	226	27,446	57	1,810	1,079	1,296

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1] Includes U.S. Bureau of Mines estimates.

[2] Includes briquets.

[3] Primarily magnesium—ferrosilicon but also includes other silicon alloys.

[4] Does not include silicon carbide for abrasive or refractory uses.

[5] Included with "Steel: Unspecified."

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

[7] Includes silicones, silanes, fumed silica, and other chemicals.

TABLE 4

TIME-PRICE RELATIONSHIP FOR SILICON PRODUCTS[1]

(Cents per pound)

Year	Silicon metal	Ferrosilicon[2] 50 percent	Ferrosilicon[2] 75 percent
1980	59.17	39.80	41.77
1981	61.04	41.54	40.01
1982	57.35	41.42	37.93
1983	53.77	37.12	36.67
1984	60.35	41.22	41.89
1985	58.77	37.52	35.71
1986	56.32	35.55	33.65
1987	58.06	38.51	36.78
1988	68.67	52.08	56.82
1989	58.75	49.57	48.96
1990	54.84	42.44	39.94
1991	61.50	38.34	36.98
1992	59.95	36.94	35.41
1993	66.40	40.76	40.61

[1] U.S. dealer import price.

[2] Prices based on contained weight of silicon.

Source: Platt's Metals Week.

TABLE 5
HARMONIZED TARIFF SCHEDULE FOR SILICON PRODUCTS

Item	HTS No.	Rate of duty effective January 1, 1993	
		Most favored nation (MFN)	Non-MFN
Ferrosilicon, 55% to 80% Si:			
More than 3% Ca	7202.21.1000	1.1% ad valorem[1,2]	11.5% ad valorem.
Other	7202.21.5000	1.5% ad valorem[1,2]	Do.
Ferrosilicon, 80% to 90% Si	7202.21.7500	1.9% ad valorem[3]	9.0% ad valorem.
Ferrosilicon, more than 90% Si	7202.21.9000	5.8% ad valorem[3]	40.0% ad valorem.
Ferrosilicon, other:			
Ferrosilicon, more than 2% Mg	7202.29.0010	Free	4.4 cents per kilogram Si.
Ferrosilicon, other	7202.29.0050	do.	Do.
Silicon, more than 99.99% Si	2804.61.0000	3.7% ad valorem[3]	25.0% ad valorem.
Silicon, 99.00% to 99.99% Si	2804.69.1000	5.3% ad valorem[4,5,6]	21.0% ad valorem.
Silicon other	2804.69.5000	9.0% ad valorem[7,8]	45.0% ad valorem.

[1] Free from certain beneficiary developing countries under the Generalized System of Preference (GSP), for products of Canada under the United States-Canada Free Trade Agreement, from beneficiary countries under the Caribbean Basin Economic Recovery Act (CBERA), for products of Israel under the United States-Israel Free Trade Area, and for products under the Andean Trade Preference Act (ATPA).

[2] Not duty free for Brazil.

[3] Free for products of Canada, from beneficiary countries under the CBERA, for products of Israel, and for products under ATPA.

[4] Free from certain beneficiary developing countries under the GSP, from beneficiary countries under the CBERA, for products of Israel, and for products under ATPA.

[5] Not duty free for Brazil and India.

[6] 2.6% ad valorem for products of Canada.

[7] Free from beneficiary countries under the CBERA, for products of Israel, and for products under ATPA.

[8] 4.5% ad valorem for products of Canada.

Source: U.S. International Trade Commission.

TABLE 6
U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY, IN 1993

(Metric tons)

	Gross weight	Contained weight	Value
Ferrosilicon:			
Over 55% silicon:			
Australia	160	96	$250,148
Brazil	59	38	95,332
Canada	6,303	3,782	5,085,068
Chile	54	32	43,036
Germany	433	260	609,480
Hong Kong	37	22	40,000
India	45	27	38,238
Japan	127	76	127,375
Mexico	3,488	2,192	2,895,580
Taiwan	204	122	214,509
Other	87	59	72,697
Total[1]	10,996	6,707	9,471,463
Other ferrosilicon:			
Australia	970	483	1,150,027
Canada	15,871	7,935	11,591,499
Egypt	839	420	748,799
India	264	131	374,824
Japan	2,638	1,299	6,085,524
Korea, Republic of	1,383	687	1,323,881
Mexico	1,839	919	1,520,054

See footnotes at end of table.

TABLE 6—Continued

U.S. EXPORTS OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY, IN 1993

(Metric tons)

	Gross weight	Contained weight	Value
Other ferrosilicon—Continued:			
Taiwan	498	241	525,435
Turkey	204	99	105,464
United Kingdom	3,027	1,514	2,761,348
Other	977	471	1,100,848
Total	28,510	14,199	27,287,703
Total ferrosilicon	39,506	20,906	36,759,166
Metal:			
Over 99.99% silicon:			
Australia	8	8	$233,457
Denmark	22	22	1,633,529
Italy	118	118	5,188,104
Japan	1,492	1,492	68,377,386
Korea, Republic of	201	201	9,429,378
Malaysia	161	161	30,283,561
Netherlands	17	17	795,330
Poland	10	10	242,085
Taiwan	11	11	560,238
United Kingdom	18	18	585,600
Other	49	49	2,956,911
Total[1]	2,106	2,106	120,285,579
99.00-99.99% silicon:			
Bolivia	13	13	18,926
Canada	19	19	26,128
Colombia	29	28	63,924
Cyprus	36	36	51,136
El Salvador	25	25	43,047
Germany	19	19	27,029
Korea, Republic of	12	12	29,076
Mexico	157	156	213,043
United Kingdom	318	315	446,351
Venezuela	452	448	707,222
Other	36	34	90,409
Total[1]	1,117	1,106	1,716,291
Other silicon:			
Canada	1,919	1,864	2,077,683
China	99	94	259,075
Germany	277	256	475,100
Hong Kong	127	124	167,968
Japan	1,607	1,556	3,666,887
Korea, Republic of	145	141	205,635
Malaysia	429	414	572,970
Mexico	1,912	1,857	2,547,642
Taiwan	307	298	420,494
United Kingdom	93	91	124,209
Other	478	450	777,816
Total[1]	7,395	7,144	11,295,479
Total silicon metal	10,618	10,356	133,297,349

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

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY, IN 1993

(Metric tons)

	Gross weight	Contained weight	Value
Ferrosilicon:			
55%-80% silicon, over 3% Ca:			
Argentina	100	61	$86,825
Brazil	84	54	124,679
China	172	103	154,977
France	62	38	94,668
Germany	4	3	8,604
Norway	184	139	216,279
Taiwan	51	36	44,951
Total	657	434	730,983
55%-80% silicon, other:			
Brazil	43,648	33,023	23,179,639
Canada	13,919	10,332	9,557,599
Iceland	13,145	9,979	7,347,555
Macedonia	3,105	2,329	1,724,074
Norway	66,231	50,144	39,627,966
Poland	9,375	6,977	5,290,688
Slovenia	3,423	2,611	2,114,783
South Africa, Republic of	3,810	2,857	2,172,449
United Kingdom	2,878	2,172	2,051,875
Venezuela	10,900	7,811	4,670,770
Other	949	685	2,432,378
Total[1]	171,383	128,921	100,169,776
80%-90% ferrosilicon:			
Turkey	18	15	6,221
Over 90% ferrosilicon:			
Australia	320	317	429,960
Brazil	238	224	168,831
Total[1]	558	540	598,791
Magnesium ferrosilicon:			
Brazil	1,742	789	1,057,640
Canada	35	17	18,419
Germany	776	423	2,591,593
Japan	79	37	168,500
Total[1]	2,631	1,267	3,836,152
Other ferrosilicon:			
Belgium	3	1	8,705
Brazil	9,910	4,186	1,023,344
Canada	10,415	3,688	3,141,513
China	34	13	51,778
France	5	3	13,228
Venezuela	4,500	2,430	947,500
Total[1]	24,867	10,320	5,186,068
Total ferrosilicon	200,114	141,497	110,527,991

See footnotes at end of table.

TABLE 7—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROSILICON AND SILICON METAL, BY GRADE AND COUNTRY, IN 1993

(Metric tons)

	Gross weight	Contained weight	Value
Metal:			
Over 99.99% silicon:			
Canada	1	1	$6,864
Czech Republic	2	2	414,047
Denmark	1	1	516,477
France	2	2	139,565
Germany	483	483	14,090,422
Italy	268	268	28,653,295
Japan	84	84	2,414,706
Korea, Republic of	42	42	951,744
Mexico	1	1	6,022
Ukraine	1	1	17,796
Other	1	1	120,502
Total	886	886	47,331,440
99.00%-99.99% silicon:			
Argentina	4,916	4,876	5,858,685
Australia	3,315	3,285	4,205,566
Brazil	338	335	391,347
Canada	13,184	13,088	18,137,396
China	160	158	144,784
France	593	589	730,612
Japan	[2]487	408	726,945
Netherlands	201	199	235,200
Norway	621	617	756,972
South Africa, Republic of	3,156	3,129	3,651,206
Other	111	110	173,836
Total[1]	27,082	26,795	35,012,549
Other silicon:			
Australia	201	198	246,376
Canada	879	864	1,113,853
China	2,473	2,560	2,210,323
Germany	616	559	881,240
Macedonia	5,090	5,010	5,402,069
Netherlands	548	530	476,990
Russia	31,283	30,393	29,644,553
South Africa, Republic of	901	887	1,014,991
Ukraine	1,921	1,864	1,907,689
United Kingdom	132	128	145,476
Other	220	209	225,754
Total	44,264	43,202	43,269,314
Total silicon metal	72,232	70,883	125,613,303

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

[2] Contains 77 tons of material with silicon content not yet verified.

Source: Bureau of the Census.

SILVER

By Robert G. Reese

Mr. Reese, a physical scientist with the Branch of Metals, has been the commodity specialist for silver for 12 years. Domestic survey data were prepared by Lisa Conley and Kevin Bacon, statistical assistants; and international data tables were prepared by Virginia Woodson, international data coordinator.

Domestic silver mine production declined for the third consecutive year, owing primarily to a decline in byproduct silver production attributed to lower nonferrous metals prices. Silver was produced by 115 mines in 20 States. Nevada, Arizona, and Idaho were the largest silver-producing states, accounting for about two-thirds of the production. The largest 15 mines each produced more than 30 tons of silver and accounted for nearly 87% of the total domestic production. The value of domestic production was $227 million.

Commercial-grade silver is material that is at least 99.9% pure silver. In the United States, about 20 companies produced commercial-grade silver from either primary or recycled material. Although most of these companies were headquartered in the northeast, many had collection sites or plants in locations throughout the country. Aiding the recycling of silver were many other companies throughout the country that collected the material and produced a semirefined product that could be converted to commercial-grade silver.

Many companies and probably thousands of artisans scattered throughout the country consumed silver in 1993; 30 of the largest companies accounted for more than 90% of the silver consumed in arts and industry. About 50% of the commercial-grade silver consumed in the United States was used in the manufacture of photographic products; 20% in electrical and electronic products; 10% in electroplated ware, sterlingware, and jewelry; and 20% in other uses.

DOMESTIC DATA COVERAGE

Domestic mine production data for silver were developed by the U.S. Bureau of Mines from four separate, voluntary surveys of U.S. operations. Typical of these surveys was the lode mine production survey of copper, gold, lead, silver, and zinc. Of the 115 silver-producing lode mines to which a survey form was sent, 112 responded, accounting for an estimated 92% of the total U.S. mine production shown in tables 1, 2, 4, and 5.

ANNUAL REVIEW

Legislation and Government Programs

Near the end of May, coins commemorating the 50th anniversary of U.S. involvement in World War II were available for sale through the U.S. Mint. Enacted on October 14, 1992, Public Law 102-414, the World War II 50th Anniversary Commemorative Coins Act, authorized the production of not more than 1 million $1 silver coins, 300,000 $5 gold coins, and 2 million half-dollar copper-nickel clad coins. The three coins were legal tender and included inscriptions of the coin's face value, the years "1991-1995," and the words "Liberty," "In God We Trust," and "E Pluribus Unum." The silver coin consisted of a 90% silver-10% copper alloy, weighed 26.73 grams, and had a diameter of 3.8 centimeters. As specified by Public Law 102-414, the silver coin was emblematic of the Battle of Normandy. The obverse depicts an American soldier advancing on the beach at Normandy, while the reverse depicts the sleeve insignia of Supreme Headquarters Allied Expeditionary Force and a quote from General Eisenhower's D-Day message to his troops. Included in the sales price of each coin was its face value and the cost of labor, materials, dies, machinery, and various expenses, including overhead, marketing, and shipping required to design and issue the coins. Also added to the price of each coin was a surcharge of $35 per gold coin, $8 per silver coin, and $2 per clad coin. The law authorized distribution of surcharges collected from coinage sales to the Battle Of Normandy Foundation and the American Battle Monuments Commission. As authorized, the Battle Of Normandy Foundation would receive the first $3,000,000 collected to create, endow, dedicate, and promote visits to a "United States D-Day and Battle of Normandy Memorial" in Normandy, France. The American Battle Monuments Commission would receive the next $7,000,000 collected for the expenses incurred in establishing a memorial on Federal land in the District of Columbia or its environs to honor members of the U.S. Armed Forces who served in World War II and to commemorate U.S. participation in that war. If coinage sales produced more than $10,000,000 in surcharges, the Battle Of Normandy Commission would receive 30% of the excess money, while the American Battle Monuments Commission would receive the remaining 70%. Any funds not spent by the two groups would be returned to the U.S. Treasury for disbursement to a fund established by "An Act to provide standards for placement of commemorative works on certain Federal lands in the District of Columbia and its environs, and for other purposes," approved November 14, 1986.

On December 14, the President signed Public Law 103-186, the Jefferson Commemorative Coin Act of 1993, which authorized the U.S. Mint to produce not more than 600,000 legal tender silver coins to commemorate the 250th anniversary of the birth of Thomas Jefferson. The coin was to be 90% silver and 10% copper, weigh 26.73 grams, and have a diameter of 3.8 centimeters. Included on each coin was a profile of Thomas Jefferson; a frontal view of his home, Monticello; the year, 1993; and the words "Liberty," "In God We Trust," "United States of America," and "E Pluribus Unum," along with the coin's face value of $1.00.

Public Law 103-186 required the Mint to use silver from the National Defense Stockpile to manufacture the coins. Besides the cost of designing and issuing the coins, (including labor, materials, dies, use of machinery, overhead expenses, marketing, and shipping), the price of each coin was to include a $10 surcharge. Surcharges collected from the sales of the first 500,000 coins were to be paid to the Jefferson Endowment Fund to be used as a source of support for Monticello and its historic furnishings and for the Fund's educational programs. Surcharges received from the sale of the remaining 100,000 coins were to be paid to the Corporation for Jefferson's Poplar Forest, to be used for the restoration and maintenance of Poplar Forest.

Production

Silver was produced from precious-metal ores at 76 lode mines and from base metal ores at 36 lode mines. In 1993, 15 mines each produced more than 30 tons of silver; their aggregated production equaled 87% of total domestic production. Silver also was produced at nine placer operations.

In mid-November, Cyprus Minerals Co. and AMAX Inc. merged, forming one of the world's largest mining companies, Cyprus Amax Minerals Co. Before the merger, Cyprus Minerals produced silver primarily as a byproduct of its copper operations. AMAX's principal precious metals asset was its 40% holding in Amax Gold Inc. Most of the silver-producing operations of the new company were located in the United States.

At yearend, Hecla Mining Co. and Equinox Resources Ltd., a Canadian company, executed an agreement, subject to various conditions, providing for Hecla to acquire Equinox. Equinox's principal assets included the American Girl Mine and the Rosebud project. The American Girl Mine, in Imperial County, CA, produced gold and byproduct silver. The Rosebud project in northern Nevada was estimated to contain 1.8 million tons of proven and probable ore grading 69 grams of silver and 9 grams of gold per ton.

Alaska.—Commercial production at the Greens Creek Mine ceased in April, reportedly in response to depressed metals prices. Although only in operation for part of the year, the Greens Creek Mine processed about 103,000 tons of ore and recovered nearly 58 tons of silver.[1] In 1992, the mine had processed 441,200 tons of ore and recovered nearly 218 tons of silver. During 1993, Kennecott Greens Creek Mining Co., manager of the mine, continued exploration of the deposit, and recalculated proven and probable reserves using different criteria and estimating techniques than used previously. The exploration activities reportedly resulted in the discovery of a significant new mineralized zone. At yearend 1993, Greens Creek's estimated proven and probable reserves were about 5.8 million tons grading 549 grams of silver per ton, 5 grams of gold per ton, 14.4% zinc, and 4.7% lead.

During the year, throughput improved at the Red Dog Mine following modification of the mine's concentrator. The changes were made in response to previous problems encountered in processing some difficult ore types. In the third quarter, Cominco Ltd., the mine's operator, undertook several other projects, including expansion of the grinding facilities, to increase Red Dog's production rate. The operation processed more than 1,700,600 tons of ore in 1993, compared with 1,435,200 tons of ore in 1992.[2] Average silver content of the processed ore declined from 99 grams to 96 grams per ton. Several of the projects undertaken during 1993 were intended to improve the operation's dust control. Dust control reportedly is a problem in the Arctic because the low temperatures make conventional treatments ineffective. Enclosing outside conveyors and stockpiles and constructing a specialized truck loading station were among the projects completed to improve air quality.

California.—Milling of stockpiled ore at Lac Mineral Ltd.'s mined-out Colosseum Mine continued in 1993. The open pit operation recovered a small quantity of gold and byproduct silver using a carbon-in-pulp processing plant. The company began closure of the minesite in June, and expected the work to be completed in 1994.

At the Shumake Mine, leaching resulted in the production of 303 kilograms of gold and 1 ton of silver. During 1992, the mine produced 846 kilograms of gold and 4 tons of silver.[3] Mining ceased at Shumake in February 1992 following exhaustion of ore reserves. Leaching was expected to end in 1994.

Idaho.—Production at the Black Pine Mine was adversely affected during the first half of the year. A harsh winter followed by a wet spring, combined with lower than expected ore grades, resulted in lower precious metals production. To offset these initial production shortfalls, Pegasus Gold Inc. operated the mine's processing plant at a higher rate during the remainder of 1993. Near midyear, additional carbon columns were installed to increase the processing plant's capacity. Ore occurs at Black Pine in a series of small deposits. During the year, Pegasus obtained permission to expand two existing pits at the minesite. In 1993, the mine produced 2 tons of gold and 890 kilograms of silver.[4]

Kinross Gold Corp. purchased the DeLamar Mine in August from Kennecott Corp. The purchase represented the second change in ownership of the mine during 1993. Kennecott initially acquired the mine as part of its purchase of NERCO Inc., the resource subsidiary of

Pacific Corp. To dispose of the noncoal assets of Nerco, Kennecott subsequently sold the mine to Kinross. In 1993, the DeLamar Mine produced 1.3 tons of gold and nearly 53 tons of silver, essentially unchanged from the previous year when the mine produced 1.2 tons of gold and 57 tons of silver.[5]

At the Lucky Friday Mine, continued success in reducing operating costs enabled the mine to operate throughout the year despite depressed prices for most of the year. For the year, the mine produced 66 tons of silver, 30 kilograms of gold, nearly 18,000 tons of lead, 4,000 tons of zinc, and 300 tons of copper from 163,000 tons of ore.[6] In 1992, Lucky Friday produced 63 tons of silver, 30 kilograms of gold, 19,000 tons of lead, 3,800 tons of zinc, and 308 tons of copper.

The Sunshine Mine continued to operate at about one-half capacity throughout 1993. The mine's operating rate had been cut in early June 1991, owing in part to low silver prices. For the year, silver production declined slightly, owing in part to a rock burst during the fourth quarter. Reported silver production was about 71 tons, compared with 79 tons in 1992.[7] The mine was expected to continue operating at this reduced level until either the silver price increased sufficiently to justify reopening the closed portions of the mine or the exploration program found enough high-grade ore to justify increasing the operating rate.

Montana.—Gold and silver production increased at the Beal Mountain Mine for the second consecutive year. Company officials attributed the increased production primarily to the efforts of the mine's employees. In 1993, Beal Mountain recovered nearly 2 tons of gold and 267 kilograms of silver. In 1992 and 1991, the mine produced 249 kilograms and 243 kilograms of silver, respectively.[8]

Montana Resources Inc., 49.9% owned by ASARCO Incorporated, milled more than 15 million tons of copper ore from its Continental Pit. The resulting concentrate contained approximately 24 tons of byproduct silver.[9]

At its Kendall Mine, Canyon Resources Corp. mined approximately 1.6 million tons of ore and extracted about 2 tons of gold and 1 ton of silver.[10] Although all known ore at the open pit mine was expected to be depleted during 1994, leaching was expected to continue into 1996.

Production at the Montana Tunnels Mine remained essentially unchanged from the previous year despite adoption of a revised mining plan to exploit deeper reserves discovered in late 1992. To access the new deep reserves, the revised plan required the near-term mining of additional waste rock and lower grade ore. To minimize the impact of the new plan, company officials increased mill throughput. During 1993, Montana Tunnels mined 4.5 million tons of ore and recovered 2 tons of gold, nearly 44 tons of silver, 6,400 tons of lead, and 16,300 tons of zinc.[11] Precious metal production in 1992 was 2 tons of gold and 41 tons of silver.

Asarco temporarily closed the Troy Mine in April in response to continued low silver prices. During its 4 months of operation, concentrates produced at the Troy Mine contained approximately 25 tons of silver.[12]

Production at the Zortman/Landusky Mine declined for the second consecutive year, and operating costs reportedly increased. Company officials attributed the higher costs in part to increased investment in reclamation and other factors. For 1993, the Zortman/Landusky Mine recovered more than 3 tons of gold and nearly 17 tons of silver.[13]

Nevada.—With two separate purchases, Placer Dome increased its land holdings near its Bald Mountain gold mine. In January, Placer acquired the rights to 41 unpatented claims for $5 million. In August, Placer purchased all the assets of USMX Inc. in the Alligator Ridge mining district, which included two gold-silver-producing areas and associated plant and equipment. With the acquisitions, Placer has the right to explore and produce gold on nearly 39,000 hectares. The Bald Mountain Mine, a heap-leach operation, produced nearly 3 tons of gold and a small quantity of silver during the year.[14]

Although Battle Mountain Gold Co. depleted the ore reserves of the Fortitude deposit, additional deposits near its Battle Mountain Complex were either under development or evaluation by yearend. In 1993, Battle Mountain recovered approximately 2 tons of gold and 4 tons of silver compared with 6 tons and 13 tons of gold and silver, respectively, in 1992.[15] For 1993, the company processed nearly 140,000 tons of ore through its on-site carbon-in-pulp mill and leached an additional 1.6 million tons. Future gold and silver production at the Battle Mountain Complex is expected to be from the Reona and Phoenix (formerly known as the Fortitude Extension) deposits.

Leaching continued at the mined-out Buckhorn Mine through yearend, producing a small quantity of gold and byproduct silver. In 1994, company officials expected to continue leaching at Buckhorn as part of its heap decommissioning program. Workers completed reclamation of the mine's pits, waste dumps, and access roads.

Production at the Bullfrog Mine increased during the year owing, in part, to the continuation of high-grade ore shoots first encountered in 1992. Other factors contributing to the higher production were reaching full production at Bullfrog's underground operations and changes made to the mine's operating plan and mill. In 1993, the mine produced 11 tons of gold and nearly 15 tons of silver.[16]

Among the assets acquired by Kinross through its purchase of the noncoal holdings of Nerco in August was the Candelaria Mine. Although mining activity had been suspended since November 1990, gold and silver production continued through the leaching of previously mined ore. Studies undertaken by Kinross revealed the potential for profitably operating the mine. Subsequently, following rehabilitation of some plant facilities, the mine returned to production in

November.

In late 1993, Kennecott, operator of the Denton-Rawhide Mine, increased crusher capacity at the mine from 3.4 million tons to 4.4 million tons. Kennecott accomplished the expansion through the addition of a surge pile and associated materials handling equipment. For the year, Denton-Rawhide produced 3 tons of gold and 31 tons of silver.[17]

Although ongoing reclamation at the Florida Canyon Mine resulted in a reduction in the number of acres disturbed by the operation, the mine set new production records for the second consecutive year. Company officials attributed the higher production in part to improved ore grades, higher ore throughput, expanded plant capacity, and improved recoveries. For 1993, Florida Canyon produced more than 3 tons of gold and a small quantity of byproduct silver.[18]

Silver production at the McCoy/Cove Mine increased significantly for the third consecutive year. In 1993, the mine produced 387 tons of silver, compared with 246 tons in 1992 and 175 tons in 1991.[19] Company officials attributed the increased production, in part, to the replacement of small, higher cost equipment and increased mill throughput combined with higher recoveries and higher grade feed material. The McCoy/Cove Mine consisted of two deposits, about 2 kilometers apart. Production at the Cove deposit initially utilized both surface and underground methods. However, the company suspended underground operations in early 1993 when the pit bottom reached the depth of the underground workings. At the McCoy deposit, the pit remained closed, and only the underground operation produced ore. It was expected that the underground operations at the McCoy deposit would be completed in 1994. The discovery of additional reserves at McCoy may permit reopening the pit at some future date. Gold production also increased from 9 tons in 1992 to 12 tons in 1993.

Mining ceased at the Paradise Peak Mine following exhaustion of the mine's known reserves in August. Although the mill closed in May following exhaustion of millable reserves, heap leaching continued through yearend. FMC Gold Co., owner and operator of the mine, reported that the mill processed 533,000 tons of ore and added an additional 3.6 million tons to the leach pads. The company began reclamation of the mine site during the year and was expected to continue reclamation in 1994, during which time some additional gold and silver was expected to be recovered from the leaching operation. In 1993, the mine produced approximately 5 tons of gold and 25 tons of silver.[20] In 1992, the mine produced about 8 tons of gold and 60 tons of silver.

Despite a slight drop in the quantity of ore mined, 1993 silver production at the Rochester Mine was the highest in the mine's 7 years of operation. Gold production also increased. For the year, employees mined 6.6 million tons of ore and recovered 185 tons of silver and 2 tons of gold.[21] Company officials attributed the increased production in part to slightly higher ore grades. In 1992, the mine produced about 6,674,000 tons of ore and recovered about 169 tons of silver and 2 tons of gold. Prior to 1993, the largest quantity of silver produced at the Rochester Mine was 178 tons in 1991.

Other States.—Cyprus Amax Minerals Co. halted mill operations at the Copperstone Mine in Arizona. Mining at the open pit mine ended in 1992 following the exhaustion of economically recoverable ore reserves. Reclamation of the site, which produced gold and a small quantity of byproduct silver, continued throughout 1993.

At its Leadville Mine, Asarco processed nearly 200,000 tons of ore, producing concentrates containing approximately 11 tons of silver, essentially unchanged from the previous year.[22]

In 1993, the San Luis Mine in Costilla County, CO, produced 2 tons of gold and 840 kilograms of silver.[23] In 1992, the mine produced 2 tons of gold and 871 kilograms of silver.

In Missouri, at its Sweetwater Mine, Asarco produced lead concentrate containing 5 tons of silver. In 1992, the Sweetwater Mine produced approximately 3 tons of silver in concentrate. Similarly, for 1993 and 1992, Asarco's West Fork Mine produced 8 tons and 10 tons of silver, respectively, in concentrate.[24]

Production at the Magmont Mine in Missouri continued to decline. Company officials continued to forecast the 1994 shutdown of the mine owing to ore exhaustion. In 1993, Magmont milled slightly more than 631,000 tons of ore compared with nearly 873,000 tons of ore in 1992.

In December, Lac Minerals prematurely halted leaching operations at the Richmond Hill Mine in South Dakota owing, in part, to continued problems with acid rock drainage at the site. The problem, first discovered in the summer of 1992, was the subject of several in-depth studies. By yearend, Lac used the study results to develop a remediation and reclamation plan for closing the site. In 1993, the open pit heap-leach operation recovered 333 kilograms of gold and 490 kilograms of silver.[25]

In Utah, Kennecott received the permits necessary for construction of a new copper smelter at the Bingham Canyon Mine. Construction began in July and was expected to be completed by mid-1995. For 1993, byproduct gold and silver production at Bingham Canyon, at 16 tons and 137 tons, respectively, was essentially unchanged from the previous year's output.[26]

Production at Hecla Mining Co.'s Republic Unit continued to drop as ore grades declined. In 1993, the mine treated 101,000 tons of ore and produced approximately 2 tons of gold and 9 tons of silver.[27]

World Review

Estimated world silver production decreased slightly in 1993 as the output of most countries remained essentially unchanged from that of the previous year. Lower production in Australia, Canada, Chile, and the United States more than negated slightly higher outputs in many other countries. Analysts attributed the lower overall world production to a drop in silver recovered as a byproduct at many nonferrous metal mines. The lower output of these operations reflected the lower prices for their primary product.

CPM Group estimated that world fabrication demand for silver, excluding coinage, increased in 1993 by more than 14%, to 21,000 tons, owing primarily to continuing significant growth in demand for silver in India.[28] Demand for silver in industrialized countries such as the United States, however, remained essentially unchanged.

OUTLOOK

The dominant component of domestic silver supply remains byproduct silver, recovered in the processing of other nonferrous metals, such as copper, gold, lead, and zinc. Most nonferrous ores contain some silver. Processing these ores concentrates the silver either in a waste stream or with the principal product. Once concentrated, the additional cost to recover the silver is minimal. As a result, in many instances the quantity of silver produced is probably more dependent on the price of the primary metal than on the price of silver. Another important consideration when forecasting domestic silver supply is the ongoing effort to reduce operating costs. It is believed that recent declines in domestic supply reflect primarily price movements for both silver and other nonferrous metals. However, recent improvements in some prices, including that of silver, will likely result in domestic silver production ranging between 1,400 and 2,000 tons during the years 1994-96. Worldwide, mine production of silver should remain at about 15,000 tons.

During the next few years, the industrial demand for silver likely will follow the general economy, either upward or downward, but remain at approximately 3,700 tons. Worldwide, silver demand will grow slightly as new markets in less-developed countries gradually begin to open.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Silver. Ch. in Mineral Commodity Summaries, annual.
Mineral Industry Surveys, Gold and Silver, monthly.

Other Publications

American Metal Market, New York.
Engineering and Mining Journal, Chicago, IL.
Jewelers' Circular-Keystone, Radnor, PA.
Metals Week, New York.
Mining Journal, London.
The Northern Miner, Toronto, Canada.
The Silver Market, compiled by Handy & Harman, New York.

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[1] Hecla Mining Co. 1993 10K Report, 78 pp.

[2] Cominco Ltd. 1993 Annual Report, 65 pp.

[3] Work cited in footnote 1.

[4] Pegasus Gold Inc. 1993 Annual Report, 49 pp.

[5] Kinross Gold Corp. 1993 Annual Report, 54 pp.

[6] Work cited in footnote 1.

[7] Sunshine Mining Co. 1993 Annual Report, 25 pp.

[8] Work cited in footnote 4.

[9] ASARCO Incorporated. 1993 10K Report, 99 pp.

[10] Canyon Resources Corp. 1993 Annual Report, 45 pp.

[11] Work cited in footnote 4.

[12] Work cited in footnote 9.

[13] Work cited in footnote 4.

[14] Placer Dome Inc. 1993 10K Report, 118 pp.

[15] Battle Mountain Gold Co. 1993 Annual Report, 64 pp.

[16] LAC Minerals Ltd. 1993 Annual Report, 72 pp.

[17] The RTZ Corp. PLC 1993 Annual Report, 72 pp.

[18] Work cited in footnote 4.

[19] Echo Bay Mines Ltd. 1993 10K Report, 104 pp.

[20] FMC Gold Co. 1993 Annual Report, 28 pp.

[21] Coeur d'Alene Mines Corp. 1993 10K Report, 71 pp.

[22] Work cited in footnote 9.

[23] Work cited in footnote 15.

[24] Work cited in footnote 9.

[25] Work cited in footnote 16.

[26] Work cited in footnote 17.

[27] Work cited in footnote 1.

[28] The Silver Institute. World Silver Survey 1994, 122 pp; available upon request from the Silver Institute, 1112 16th St., NW, Suite 2401, Washington, DC 20036

TABLE 1
SALIENT SILVER STATISTICS

		1989	1990	1991	1992	1993
United States:						
Mine production	metric tons	2,008	2,121	1,855	1,804	1,645
Value	thousands	[r]$355,072	[r]$328,684	[r]$240,944	$228,563	$227,378
Refinery production:						
Domestic and foreign ores and concentrates	metric tons	1,718	1,939	1,879	[r]2,157	1,712
Secondary (old scrap)	do.	714	454	215	[r]145	162
Exports:						
Refined	do.	430	736	787	911	705
Other	do.	850	1,112	894	843	998
Imports for consumption:						
Refined	do.	3,062	2,698	2,525	2,662	2,183
Other		244	657	1,626	2,328	1,589
Stocks, Dec 31:						
Industry	do.	544	583	618	677	735
Future exchanges	do.	7,795	8,636	8,755	9,382	10,454
Department of the Treasury	do.	997	840	1,028	775	NA
Department of the Defense	do.	81	32	23	29	34
National Defense Stockpile	do.	2,973	2,866	2,611	2,255	1,851
Apparent demand, refined[1]	do.	5,063	4,355	3,832	4,057	3,257
Coinage	do.	264	265	285	NA	NA
Price, average per troy ounce[2]		$5.50	$4.82	$4.04	$3.94	$4.30
Employment[3]		2,800	2,600	1,900	1,600	1,100
World:						
Mine production	metric tons	[r]16,425	[r]16,489	[r]15,672	[r]14,737	[e]14,089
Consumption:[4]						
Industry and the arts	do.	[r]16,718	[r]17,741	[r]18,752	19,297	19,791
Coinage	do.	1,141	[r]1,002	[r]862	914	1,179

[e]Estimated. [r]Revised. NA Not available.

[1] Defined as refinery production from primary material plus refinery production from old scrap plus imports of bullion minus exports of bullion. Represents not only the quantity of silver required by the domestic fabricating industry, some of which may be placed in stocks, but also the quantity of silver demanded by U.S. investors.

[2] Platt's Metals Week Annual Handy & Harman quotation.

[3] Mine Safety and Health Administration.

[4] Silver Market 1993. Compiled by Handy & Harman.

TABLE 2

MINE PRODUCTION OF SILVER IN THE UNITED STATES, BY STATE

(Metric tons)

State	1989	1990	1991	1992	1993
Arizona	171	173	149	165	200
California	21	21	15	18	14
Colorado	W	23	20	W	W
Idaho	439	442	337	254	190
Missouri	53	42	35	32	40
Montana	195	220	222	197	127
Nevada	625	646	583	614	713
New Mexico	78	48	W	W	22
Oregon	W	W	—	(1)	—
South Dakota	4	10	7	6	5
Utah	185	143	W	W	W
Washington	W	W	W	W	14
Other States[2]	239	354	484	517	318
Total[3]	2,008	2,121	1,855	1,804	1,645

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

[1] Less than 1/2 unit.

[2] Includes Alaska, Illinois, Kentucky, Michigan, New York, South Carolina, Tennessee, Wisconsin, and States indicated by symbol "W."

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

TABLE 3
TWENTY-FIVE LEADING SILVER-PRODUCING MINES IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of silver
1	McCoy and Cove	Lander, NV	Echo Bay Mining Co.	Gold ore.
2	Rochester	Pershing, NV	Coeur Rochester Inc.	Do.
3	Bingham Canyon	Salt Lake, UT	Kennecott-Utah Copper Co.	Copper ore.
4	Red Dog	NW Arctic, AK	Cominco Alaska Inc.	Zinc ore.
5	Sunshine	Shoshone, ID	Sunshine Mining Co.	Silver ore.
6	Lucky Friday	do	Hecla Mining Co.	Lead-zinc ore.
7	Mission Complex[1]	Pima, AZ	ASARCO Incorporated	Copper ore.
8	Greens Creek	Southeastern Alaska, AK	Kennecott Greens Creek Mining Co.	Zinc ore.
9	Kinkross-Delamar	Owyhee, ID	Kinkross Delamar Co.	Gold ore.
10	Montana Tunnels	Jefferson, MT	Pegasus Gold Corp.	Zinc ore.
11	Sierrita	Pima, AZ	Cyprus Minerals Co.	Copper ore.
12	White Pine	Ontonagon, MI	Copper Range Co.	Do.
13	Troy	Lincoln, MT	ASARCO Incorporated	Do.
14	Denton-Rawhide	Mineral, NV	Kennecott Rawhide Mining Co.	Gold ore.
15	Candelaria	do	NERCO Metals Inc.	Silver ore.
16	Ray Unit	Pinal, AZ	ASARCO Incorporated	Copper ore.
17	Continental	Silver Bow, MT	Montana Resources Inc.	Do.
18	Morenci	Greenlee, AZ	Phelps Dodge Corp.	Do.
19	Paradise Peak	Nye, NV	FMC Gold Co.	Gold ore.
20	Zortman-Landusky	Phillips, MT	Pegasus Gold Corp.	Do.
21	Bagdad	Yavapai, AZ	Cyprus Minerals Co.	Copper ore.
22	San Manuel	Pinal, AZ	Magma Copper Co.	Do.
23	Chino	Grant, NM	Phelps Dodge Corp.	Do.
24	Pinto Valley	Gila, AZ	Magma Copper Co.	Do.
25	West Fork	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.

[1] Includes Eisenhower, Mission, Pima, and San Xavier Mines.

TABLE 4
SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

Year and State	Placer (metric tons of silver)	Lode			
		Gold ore		Silver ore	
		Metric tons	Metric tons of silver	Metric tons	Metric tons of silver
1989	W	155,188,564	528	4,450,703	524
1990	W	185,647,818	623	W	W
1991	W	r159,557,729	505	W	W
1992	(1)	r155,266,335	612	W	281
1993:					
Alaska	(1)	—	—	—	—
Arizona	—	—	—	—	—
California	(2)	26,531,650	14	—	—
Colorado	—	W	W	—	—
Idaho	—	W	W	W	W
Illinois	—	—	—	—	—
Michigan	—	—	—	—	—
Missouri	—	—	—	—	—
Montana	—	15,209,352	W	W	W
Nevada	(2)	148,444,811	713	(2)	(2)
New Mexico	—	—	—	—	—
New York	—	—	—	—	—
South Carolina	—	W	W	—	—
South Dakota	—	2,445,301	5	—	—
Tennessee	—	—	—	—	—
Utah	—	W	W	—	—
Washington	—	472,758	14	—	—
Wisconsin	—	—	—	—	—
Total	(1)	208,596,618	795	W	W
Percent of total silver	XX	XX	48	XX	W

See footnotes at end of table.

TABLE 4—Continued

SILVER PRODUCED IN THE UNITED STATES, BY STATE, TYPE OF MINE, AND CLASS OF ORE

	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	230,558,434	529	16,890,785	W	407,088,486	2,008
1990	240,618,804	490	W	514	443,350,711	2,121
1991	261,207,859	480	W	414	[r]439,178,877	1,855
1992	[r]262,986,082	473	W	439	[r]439,566,883	1,804
1993:						
Alaska	—	—	W	W	W	W
Arizona	172,356,438	200	(5)	(5)	172,356,438	200
California	—	—	7	(1)	26,531,657	14
Colorado	—	—	W	W	W	W
Idaho	—	—	W	W	W	190
Illinois	—	—	W	W	W	W
Michigan	W	W	—	—	W	W
Missouri	—	—	4,923,080	40	4,923,080	40
Montana	W	W	W	W	35,843,658	127
Nevada	—	—	(1)	(1)	148,444,811	713
New Mexico	16,953,327	22	—	—	16,953,327	22
New York	—	—	W	W	W	W
South Carolina	—	—	—	—	W	W
South Dakota	—	—	—	—	2,445,301	5
Tennessee	—	—	W	W	W	W
Utah	W	W	—	—	W	W
Washington	—	—	—	—	472,758	14
Wisconsin	W	W	—	—	W	W
Total	262,220,372	453	W	W	483,683,354	1,645
Percent of total silver	XX	28	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] Withheld to avoid disclosing company proprietary data, included in gold ore.

[3] Includes gold-silver, lead, zinc, copper-lead, lead-zinc, copper-zinc, copper-lead-zinc ores, and old tailings, etc.

[4] Includes silver recovered from fluorspar ores.

[5] Withheld to avoid disclosing company proprietary data, included in copper ore.

TABLE 5
LODE SILVER PRODUCED IN THE UNITED STATES, BY STATE

Year and State	Cyanidation		Smelting of concentrates			Smelting of ore		Other processes[1]		Total ore processed[2] [3] (metric tons)	Total silver recovered[3] (metric tons)
	Ore treated (metric tons)	Silver recovered (metric tons)	Ore concentrated (metric tons)	Concentrates smelted (metric tons)	Silver recovered (metric tons)	Ore smelted (metric tons)	Silver recovered (metric tons)	Ore treated (metric tons)	Silver recovered (metric tons)		
1989	158,054,354	790	248,846,575	5,164,847	1,195	W	W	W	W	407,088,486	2,008
1990	184,108,524	784	259,153,747	6,214,949	W	87,210	W	1,230	(4)	443,350,711	2,121
1991	[r]162,893,207	[r]20	276,137,341	5,885,793	W	135,336	W	W	W	[r]439,178,877	1,855
1992	[r]61,631,213	744	[r]277,495,004	[r]5,883,708	W	W	W	W	W	[r]439,566,883	1,804
1993:											
Alaska	—	—	W	W	W	—	—	—	—	W	W
Arizona	—	—	W	2,937,934	200	W	(4)	—	—	172,356,438	200
California	26,531,650	14	—	—	—	7	(4)	—	—	26,531,657	14
Colorado	W	W	W	W	W	—	—	—	—	W	W
Idaho	W	W	W	W	W	—	—	—	—	W	190
Illinois	—	—	W	W	W	—	—	—	—	W	W
Michigan	—	—	W	W	W	—	—	—	—	W	W
Missouri	—	—	4,923,080	440,700	40	—	—	—	—	4,923,080	40
Montana	W	W	W	W	106	W	W	W	W	35,843,658	127
Nevada	148,444,811	713	—	—	—	(4)	(4)	—	—	148,444,811	713
New Mexico	—	—	16,915,415	432,605	21	37,912	1	—	—	16,953,327	22
New York	—	—	W	W	W	—	—	—	—	W	W
South Carolina	W	W	—	—	—	—	—	—	—	W	W
South Dakota	2,445,301	5	—	—	—	—	—	—	—	2,445,301	5
Tennessee	—	—	W	W	W	—	—	—	—	W	W
Utah	W	W	W	W	W	—	—	—	—	W	W
Washington	452,825	12	19,933	915	2	—	—	—	—	472,758	14
Wisconsin	—	—	—	—	—	W	W	—	—	W	W
Total	208,574,577	821	274,830,987	5,861,314	W	W	W	W	W	483,683,354	1,645

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."

[1] Includes metal recovered at lode mines by gravity methods.

[2] Includes old tailings and some nonsilver-bearing ores not separable, in amounts ranging from 0.04% to 0.12% of the totals for the years listed. Excludes fluorspar, molybdenum, and tungsten ores from which silver was recovered as a byproduct and excludes ores leached for recovery of copper.

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

[4] Less than 1/2 unit.

TABLE 6

SILVER PRODUCED IN THE UNITED STATES BY CYANIDATION[1]

(Metric tons)

Year	Extraction in vats, tanks, and closed containers		Leaching in open heaps or dumps[2]	
	Ore treated	Silver recovered[3]	Ore treated	Silver recovered[4]
1989	38,855,007	300	119,199,347	490
1990	45,120,367	290	138,988,157	494
1991	[r]36,127,100	[r]253	[r]126,766,107	[r]467
1992	[r]45,294,189	[r]325	[r]116,337,024	[r]419
1993	41,356,497	312	167,218,080	509

[r] Revised.

[1] May include small quantities recovered by leaching with noncyanide solutions and by proprietary processes.

[2] May include tailings and waste ore dumps.

[3] May include small quantities recovered by gravity methods.

[4] May include metal recovered by leaching of previously mined ore at some inactive mines.

TABLE 7

U. S. REFINERY PRODUCTION OF SILVER

(Metric tons)

Raw material[1]	1989	1990	1991	1992[r]	1993
Concentrates and ores	1,718	1,939	1,879	2,157	1,993
Scrap	2,209	1,675	1,696	1,759	2,066
Total	3,927	3,614	3,575	3,916	4,059

[r] Revised.

[1] Includes imported materials.

TABLE 8
U.S. EXPORTS OF SILVER, BY COUNTRY[1]

Year and country	Ore and concentrates[2]		Waste 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)
1989	607	$166	770,788	$145,340	78,664	$15,478	430,110	$77,812	1,280,169	$238,797
1990	21,861	3,994	1,077,421	159,194	13,184	2,353	735,993	119,892	1,848,458	285,434
1991	229	49	840,228	124,015	53,127	8,486	787,475	115,224	1,681,058	247,774
1992	8,505	1,503	745,221	110,381	88,894	16,104	910,587	125,531	1,753,207	253,519
1993:										
Australia	—	—	—	—	—	—	16,172	2,086	16,172	2,086
Belgium	—	—	101,369	14,351	—	—	785	141	102,154	14,492
Brazil	—	—	109	18	—	—	42	10	151	28
Canada	862	124	422,086	56,406	—	—	152,717	24,745	575,665	81,275
China	1,141	224	5,129	667	—	—	—	—	6,270	891
France	—	—	9,547	1,366	74,203	10,304	—	—	83,750	11,670
Germany	59	8	47,821	10,649	878	109	1,069	209	49,827	10,975
Hong Kong	—	—	730	94	—	—	31,161	3,748	31,891	3,842
Italy	59	12	2,597	377	—	—	2,411	379	5,067	768
Japan	—	—	9,009	1,200	494	65	106,191	15,067	115,694	16,332
Korea, Republic of	—	—	798	102	—	—	46,401	6,897	47,199	6,999
Netherlands	—	—	3,368	438	—	—	—	—	3,368	438
Singapore	—	—	23,948	2,865	—	—	77,746	11,238	101,694	14,103
Sweden	—	—	19,520	2,669	—	—	—	—	19,520	2,669
Switzerland	—	—	54,098	7,971	22,146	4,486	1,171	206	77,415	12,663
United Arab Emirates	—	—	—	—	—	—	136,946	17,288	136,946	17,288
United Kingdom	—	—	189,035	42,167	5,416	1,038	114,258	15,367	308,710	58,573
Uruguay	—	—	—	—	—	—	16,475	2,492	16,475	2,492
Other	149	27	3,243	580	152	29	1,677	319	5,221	955
Total[3]	2,269	395	892,407	141,921	103,289	16,032	705,225	100,191	1,703,190	258,538

[1] Bullion also moves in both directions between U.S. markets and foreign stocks on deposit in the Federal Reserve Bank. Monetary silver excluded.

[2] Includes silver content of base metals ores, concentrates, and matte imported for refining.

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

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF SILVER, BY COUNTRY[1]

Year and country	Ore and concentrates[2]		Waste 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)
1989	10,975	$3,246	90,753	$96,254	142,739	$27,943	3,061,548	$578,781	3,306,015	$706,223
1990	101,189	24,595	507,649	86,421	48,449	8,741	2,697,926	437,380	3,355,213	557,138
1991	21,422	3,659	1,452,501	153,299	151,836	25,740	2,525,134	338,514	4,150,893	521,212
1992	25,352	3,855	1,774,085	54,492	528,715	102,118	2,661,622	340,898	4,989,774	501,363
1993:										
Argentina	—	—	64	851	—	—	2,507	315	2,571	1,166
Australia	—	—	1,341	100	—	—	—	—	1,341	100
Canada	9,309	1,522	93,266	13,853	23,772	2,905	890,249	124,336	1,016,597	142,615
Chile	—	—	1,803	365	184,661	61,447	32,912	4,166	219,376	65,978
China	—	—	816	5	—	—	—	—	816	5
Dominican Republic	—	—	496	255	12,186	2,357	13,492	1,754	26,175	4,366
Estonia	—	—	152,779	7,982	—	—	—	—	152,779	7,982
Finland	—	—	18,000	29	—	—	—	—	18,000	29
France	—	—	55,037	620	—	—	—	—	55,037	620
Germany	26	5	175,254	2,512	—	—	(4)	1	175,280	2,518
Hong Kong	—	—	13,677	174	—	—	—	—	13,677	174
Israel	—	—	2,500	25	—	—	—	—	2,500	25
Japan	—	—	4,238	209	—	—	—	—	4,238	209
Kazakhstan	—	—	12,450	200	—	—	—	—	12,450	200
Malaysia	—	—	191,898	5,424	—	—	—	—	191,898	5,424
Mexico	26,015	4,800	6,356	7,024	47,146	10,255	847,276	113,517	926,794	135,597
Netherlands	12	2	112,297	412	—	—	—	—	112,309	413
Peru	25	28	519	183	12,647	1,512	395,285	52,421	408,476	54,144
Philippines	—	—	36,913	245	—	—	—	—	36,913	245
Russia	—	—	43,009	864	—	—	204	32	43,214	896
South Africa, Republic of	—	—	6,002	518	—	—	—	—	6,002	518
Taiwan	—	—	19,408	156	—	—	—	—	19,408	156
United Kingdom	—	—	323,479	3,828	—	—	262	47	323,741	3,875
Other	303	49	884	202	804	114	958	128	2,949	494
Total[3]	35,692	6,405	1,272,486	46,036	281,217	78,590	2,183,146	296,716	3,772,542	427,748

[1] Bullion also moves in both directions between U. S. markets and foreign stocks on deposits in the Federal Reserve Bank. Monetary silver excluded.

[2] Includes silver content of the base ores, concentrates, and matte imported for refining.

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

[4] Less than ½ unit.

Source: Bureau of the Census.

TABLE 10

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Algeria[e]	3	3	3	[r]4	4
Argentina	83	[r]76	[r]70	[r][e]46	47
Australia	1,075	[r]1,173	1,180	[r]1,248	1,100
Austria	17	[e]20	29	[e]20	20
Bolivia	267	311	376	[r]282	300
Brazil[3]	[r]114	[r]171	[r]154	[r]155	155
Bulgaria[e]	59	54	[r]37	[r]35	35
Burma	6	6	5	[r]5	5
Canada (shipments)	[r]1,371	[r]1,501	1,339	[r]1,214	901
Chile	545	655	[r]678	[r]1,029	940
China[e]	125	[r]130	150	170	200
Colombia[4]	7	7	8	8	8
Costa Rica[e]	[6](5)	(5)	(5)	(5)	(5)
Croatia	—	—	—	[r][e]1	1
Czech Republic[7]	—	—	—	—	6
Czechoslovakia[e][8]	[r]21	[r]16	[r]9	[r]6	—
Dominican Republic	23	22	22	[r]15	13
Ecuador[e]	(5)	(5)	(5)	(5)	(5)
Fiji	1	1	[r](5)	1	1
Finland	31	29	30	[e]27	25
France	[r]24	[r]26	[r]29	[r]16	16
Germany:					
Eastern states	[r]53	[r]35	—	—	—
Western states	[r]6	[r]6	—	—	—
Total	[r]59	[r]41	[r]4	[r]1	—
Ghana[e]	1	1	1	2	2
Greece	61	63	70	[r]61	60
Greenland	15	[r]9	—	—	—
Honduras	50	18	39	[r][e]39	40
India	35	33	32	[e]32	35
Indonesia	74	67	80	[r]100	100
Iran[e]	41	38	40	[r]50	60
Ireland	[e]7	[e]8	11	13	14
Italy[4][9]	96	103	176	[r]129	130
Japan	156	150	171	[r]178	136
Kazakhstan[e][4]	—	—	—	900	900
Korea, North[e]	50	50	50	50	50
Korea, Republic of[4]	239	238	265	[r]333	330
Macedonia	—	—	—	[r][e]10	10
Malaysia	13	13	13	15	21
Mali[e]	(5)	(5)	(5)	(5)	(5)
Mexico	[r][e]2,400	[r]2,424	[r]2,295	[r]2,098	[6]2,128
Morocco	237	241	296	[r]213	212
Namibia	108	92	91	[r][e]89	72
New Zealand	5	5	11	[e]19	20
Nicaragua	1	1	[r]1	2	[6]2
Papua New Guinea	94	106	125	[r]95	100

See footnotes at end of table.

TABLE 10—Continued

SILVER: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Peru	1,840	1,762	1,770	[r]1,573	1,573
Philippines	51	47	38	31	33
Poland	1,003	832	[r]899	[r]798	800
Portugal	[r]19	42	[e]43	[r]38	35
Romania[e]	[r]100	[r]80	[r]80	[r]73	70
Russia[e] [4]	—	—	—	800	800
Saudi Arabia	13	16	16	[r]16	[6]18
Serbia and Montenegro	—	—	—	[r]66	65
Slovenia	—	—	—	[r] [e]([5])	—
Solomon Islands	([5]	([5])	([5])	([5])	([5])
South Africa, Republic of	180	161	171	[r]183	193
Spain	[r]668	[e]500	[r] [e]208	[r]160	150
Sweden	228	243	239	[r]281	280
Taiwan	6	[r]4	—	—	—
Tunisia	1	1	[e]1	[e]1	1
Turkey[e]	[r]49	[r]53	[r]64	[r]103	110
U.S.S.R.[e] [4] [10]	2,500	2,500	2,200	[r]—	—
United States	2,008	2,121	1,855	1,804	[6]1,645
Yugoslavia[4] [11]	[r]133	105	[r]84	—	—
Zaire[e]	70	84	80	[r]60	80
Zambia[12]	20	17	14	[r]21	19
Zimbabwe	22	21	19	[r]17	20
Total[13]	[r]16,425	[r]16,489	[r]15,672	[r]14,737	14,089

[e] Estimated. [r] Revised.

[1] Recoverable content of ores and concentrates produced unless otherwise specified. Table includes data available through July 1, 1994.

[2] In addition to the countries listed, Botswana produces silver (probably 1 kilogram or less per year) and Thailand may produce silver, but information is inadequate to make reliable estimates of output levels.

[3] Of total production, the following quantities, in kilograms, are identified as placer silver (the balance being silver content of other ores and concentrates): 1989—58,000; 1990—52,000; 1991—40,000; 1992—42,000 (revised); and 1993—40,000 (estimated).

[4] Smelter and/or refinery production.

[5] Less than 1/2 unit.

[6] Reported figure.

[7] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[8] Dissolved Dec. 31, 1992. All production from 1989-92 came from the Czech Republic.

[9] Includes production from imported ores.

[10] Dissolved in Dec. 1991.

[11] Dissolved in Apr. 1992.

[12] Year beginning Apr. 1 of that stated.

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

SLAG—IRON AND STEEL

By Cheryl Cvetic Solomon

Ms. Solomon, a physical scientist with 8 years of U.S. Bureau of Mines experience, has been the commodity specialist for iron and steel slag since 1990. Domestic survey data were prepared by Robin Kaiser, statistical assistant.

Iron and steel slags are byproducts of the iron and steel industry. They are used not only in construction and roadbuilding, but also in other ways such as in waste stabilization. Slags are used in road bases, various types of concrete aggregates, fill, glass manufacture, mineral wool, railroad ballast, and soil conditioning.

Research during the year not only continued to study blended slag in cement, but also investigated other uses for slag such as uses in bricks and tiles as well as uses in adsorbing toxic chemical constituents.

Total slag consumption decreased by 11%, partly due to a decrease in production. Domestic consumption of reported iron slag showed a 15% decrease when compared with that of 1992, while the consumption of reported steel slag decreased by almost 4%.

DOMESTIC DATA COVERAGE

Data for sales, use, and transportation of iron and steel slag are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. processors. Of the 99 operations canvassed, 97 responded, representing 99% of the total sales or use quantity data shown in table 1. Quantity data were estimated for the remaining operations. Value data had to be estimated for several operations using reports from prior years adjusted by industry trends.

BACKGROUND

Definitions, Grades, and Specifications

Slags are produced in many metallurgical operations, but this publication deals exclusively with iron slag and steel slag produced during the ironmaking and steelmaking processes.

In the production of iron, the blast furnace is charged with iron ore, flux stone (limestone and/or dolomite), and coke for fuel. Two products are obtained from the furnace: molten iron and slag. The slag consists primarily of the silica and alumina from the original iron ore combined with calcium and magnesium oxides from the flux stone. It comes from the furnace as a liquid at temperatures of about 2,700° F, resembling molten lava.

The blast furnace operation is a continuous process. The raw materials are fed into the top, and the products, molten iron and liquid slag, are drawn off at regular intervals throughout the entire day. Slag is produced at an average worldwide rate of 220 to 370 kilograms of slag per ton of hot metal or pig iron. The slag is usually run into iron ladles for conveyance to the cooling pit, or it may run straight into a cooling pit close to the furnace. When the material cools and solidifies, the gases create voids within the structure. These voids impart special engineering properties when the slag is used as an aggregate.

The density and porosity of the slag are affected by the conditions of cooling as well as by its chemical composition. Depending upon the manner in which the molten slag is cooled and solidified, three distinct types of blast furnace slag can be produced: air-cooled, expanded, and granulated.

Air-cooled slag is allowed to run into a pit adjacent to the furnace or is transported in large ladles and poured into a pit some distance away. Solidification takes place under the prevailing atmospheric conditions, after which cooling may be accelerated by water sprays on the solidified mass. After a pit has been filled and cooled sufficiently to be handled, the slag is dug, crushed, and screened to desired aggregate sizes.

Expanded slag is formed by controlled processing of molten blast furnace slag with water, or with water and other agents such as steam or compressed air, or both. The formation of gases and steam increases the cellular or vesicular nature of the slag, producing a lightweight product. Several methods of expanding the slag are employed involving the pouring of molten slag in open pits or the use of mechanical devices, one of which produces particles in pellet form. Expanded slag is a strong, lightweight aggregate suitable for making lightweight concrete, either as building blocks or as structural elements for buildings or for bridge decks.

Granulated slag is produced when molten slag is cooled rapidly by means of high-pressure water jets and solidifies into a glassy, granular product. This is the most rapid cooling process, producing little or no crystallization. The granulated slag may be crushed and screened or pulverized for various applications.

The steel industry also produces steel slag during the steelmaking process. The manufacture of steel involves the removal from the iron of excess quantities of carbon and silicon by oxidation. Steel slag is composed of roughly 50% lime. The other two main constituents are silica and iron oxide. The steel slag contains significant iron quantities and few voids, making it a tough, hard, heavier material. Different types of steel slag are generated from the open-hearth, basic oxygen, and electric arc furnaces.

Air-cooled and expanded slag are defined by ASTM Standard C 125-88.[1] Granulated slag is specified by ASTM C 989-88, "Standard Specification for Ground Iron Blast Furnace Slag for Use in Concrete and Mortars," which was first published in 1982.[2]

The specifications for steel slag aggregate used in asphaltic concrete are covered by ASTM D 5106-91, "Standard Specification for Steel Aggregates for Bituminous Paving Mixtures."[3]

Industry Structure

In general, most slag processors operate under contracts of 3 to 10 years with steel companies. The services the slag processors typically offer to the steel mill industry are hauling and transporting the slag away from the mill site, processing the slag, and recovering and distributing metallics and nonmetallics. Because slag hauling and processing facilities are capital intensive, the slag processors usually try to negotiate a long-term initial contract with the steel company to recover the capital investment. Subsequent contracts may be shorter.

Depending upon the specific situation at the mill site, the slag processor may assume ownership of the slag at the point of discharge or process it for a fee and/or market the finished product and pay royalties to the steel company on sales. Some steel companies may allow the processor to share in royalties on these sales. Although there are many variations in the way a particular slag processor and steel mill will set up their agreement, two possible options are considered here. The slag company may be paid to haul and transport the slag, process it, and market the finished product. The steel company, in turn, receives a royalty on the completed sale and a purchase discount on material recycled to the mill. Second, in a minority of the contracts, the slag processor takes ownership of the material and pays little or no royalties to the mill. In this situation, the slag processor would be assuming 100% of the site development and capital costs, including facilities for screening, metallic separation, and crushing and heavy equipment, such as slag pot haulers, to move the material.

Technology

Slag processing systems include the following, in A. W. Cooper's "Slag Handling in the Ironmaking Industry."[4]

Pit Granulation.—Molten slag is poured, either from a slag ladle or directly from the furnace, into a pit filled with water, or is hit with sprays of water to rapidly quench it. The blast furnace slag forms granules that have a glassy or vitrified structure. The slag granules are then separated from the granulation water and transported to the drying and grinding plant.

Gravel Layer Filter Bed System.—Pit granulation is developed further with the gravel layer filter bed system. The slag is granulated at the furnace in a granulation head by high-pressure water sprays. The slag slurry flows down a runner to an agitating tank where water is injected to keep the slag in suspension. The slag is dewatered and then excavated by a computer-controlled bucket crane. The gravel layer filter bed keeps the water in the system in a closed circuit, thus preventing water pollution. Blue Circle Cement Inc. of Sparrows Point, MD, has operated a gravel layer system since 1981.

Filter Hopper System.—Filter hopper systems use large dewatering silos lined with screens to dry the slag. This system extends the filtering system upward to conserve plant space. However, because the filtering is less efficient in the filter hopper system, pumping the slurry is necessary in the filter hopper.

Slag Pelletizer.—The slag pelletizer was developed by National Slag Ltd. in Hamilton, Ontario, as a means of bringing very high hydrogen sulfide gas emission levels typical of the "pit foaming" process under control.[5] Pelletized slag is produced by expanding molten blast furnace slag under water sprays and then passing the flow of this pyroplastic material over a spinning drum on which fins are mounted. The fins break up the slag, which then forms into pellets owing to surface tension. Although previous expanding processes have been of the batch type, this is a continuous process so that gaseous emissions are effectively diluted by generation over a long period of time. Because of this rapid cooling, the pelletizer can be thought of as an "air granulator."

The pelletizer has been installed in at least eight countries. Currently in Canada, about 400,000 tons of slag is pelletized annually and separately ground for use as a cementing material by the St. Lawrence Cement Co., Lafarge Canada Inc., and St. Mary's Cement. The pelletizers are installed near Hamilton, Ontario, where the major steel producers are located.

Operating Factors

Environmental Requirements.—Slag processors have had to be aware of environmental considerations, in much the same manner as have other mineral processing or manufacturing industries. During the past decade, concerns about the environment as embodied in the Clean Air Act of 1990 or Solid Waste and Clean Water legislation have grown. Concurrently, recycling and reuse of materials have become firmly established.

In keeping with public and private emphasis on improving the environment and preventing environmental harm, the slag industry has taken an active stance toward environmental responsibility in slag plant operations. Installation of new equipment, incorporation of improved operating procedures, and increased emphasis on such slag processing as slag granulation and other types of processing have all favorably impacted the slag industry.

At the same time, the emphasis on reuse of materials has meant that slag, which has been used as far back as Roman times, has been given renewed interest as a useful byproduct that serves as a substitute for mined aggregates. In addition, the use of slag as a commercial product is vastly more useful to the environment than it would be if it were landfilled.

Because of the different ways in which iron and steel slags can be utilized and the variety of steel slags available in the market, the slag processor can advise the user of iron and steel slags as to the best possible use for any given slag.

ANNUAL REVIEW

Legislation and Government Programs

The Interstate Commerce Commission proposed exempting from regulation about 30 commodities that railroads transport.[6] Commodities that would no longer come under commission scrutiny included crushed or broken stone or riprap, aggregate or ballast sand or gravel, rock salt, etc. Blast furnace slag products such as pig iron and slag also were to be deregulated.

Production

Slag was produced in 30 States and by 18 companies. *(See tables 2 and 3.)*

The Edward C. Levy Co. was one of Detroit's largest private businesses.[7] The company was involved in processing and marketing slag as its first line of business and in natural aggregates, such as sand and gravel. The Edward C. Levy Co. owned Lyon Sand and Gravel Co., Detroit Lime Co., Asphalt Products Co., Clawson Concrete Co., Cadillac Asphalt Paving Co., Burroughs Materials Co., Oakland Sand and Gravel Co., and North Mickelson Sand and Gravel.

Heckett Co. processed iron and steel slag at 22 plants. Harsco, of which Heckett Co. is the subsidiary, entered into a purchase agreement with MultiServ International N.V., a major international provider of metal reclamation and related steel mill purchases. The combined operation of Heckett and MultiServ provided steel mill services to more than 130 locations in 28 countries, making it the largest worldwide provider of such steel mill services.

Harsco also won a contract to supply steel mill services to the recently started Mexicali, a Mexican minimill owned by Compania Siderurgica de California. Harsco negotiated a 10-year, $8 million slag handling and metallic recovery contract for work at the mill located just south of the border between Los Angeles, CA, and Phoenix, AZ. Harsco had five other such contracts with Mexican steelmakers and was expected to sign more in the near future.[8]

The Levy Co. of Portage, IN, fully reconstructed approximately 26 kilometers (km) of the I-94 highway between LaPorte and Gary, IN, with blast furnace slag. The slag was used as subbase, open-graded drainage layer, asphalt, and concrete. Total amount of slag used on the highway was 425,000 tons. The Levy Co. also used steel furnace slag chips in a 48,000-ton asphalt project. The slag comprised 65% of the project by weight.

Standard Lafarge closed its West Aliquippa plant during the year. Standard Lafarge provided the subbase for portions of the I-79 highway in western Pennsylvania.

Consumption and Uses

Sales of slag products generally reflected demand from the construction industry. The Department of Commerce reported that value of new construction in 1993, $470.4 billion, increased by 8% compared with that of 1992.[9] The value of highway and street construction, $37.3 billion, was estimated to have increased by approximately 7% from that of 1992.

Many of the projects involving slag in 1993 were related to highway repaving projects. Blast furnace slag was used as a ground product to replace portland cement in concrete, as a special lightweight aggregate in blocks and highrise buildings, as a concrete aggregate replacing common concrete aggregates and sands, as a highly skid-resistant asphalt aggregate, and as a road base where the rough, interlocking surface and shape and cementitious properties enhance its load-bearing values.

Air-cooled blast furnace slag was the predominant form of iron slag processed in the United States, accounting for 85% of blast furnace slag sales in 1993. In 1993, 10,477,000 tons of air-cooled slag was used with a value of $61,685,000. The most significant end use in 1993 for air-cooled slag was as a road base. Air-cooled blast furnace slag also was used as an asphaltic concrete aggregate, other concrete aggregate fill, mineral wool, glass manufacture, railroad ballast, and sewage treatment. *(See table 4 for related data.)*

Consumption of combined expanded and granulated slag was 1,864,000 tons valued at $41,943,000. Granulated slag was predominantly used in the manufacture of cement and expanded slag in the manufacture of lightweight concrete blocks.

Steel slag is principally used for highly skid-resistant asphalt road surfaces, road bases, and asphaltic aggregates.

Reported steel slag consumption decreased by almost 4% compared with that of 1992. *(See table 5.)* Steel slag used in asphaltic concrete increased by 21% while that of fill decreased by the same amount. Steel slag used on road bases increased by approximately 11%.

Transportation

Most slag is used within about a 50-km radius of its source. Trucking costs make slag uncompetitive with mined aggregates when transportation distances exceed about 50 km. Some slag may be delivered over greater distances to areas that do not have other aggregates for use in construction and roadbuilding.

Of all the iron and steel slag products sold in 1992, 84% traveled by truck, with an average marketing range of 45 km; 4% traveled by waterway, with an average range of 404 km; and 4% traveled by rail, with an average range of 400 km. The remaining 8% was used at the plant where it was processed. *(See table 6.)*

Markets and Prices

The average price, f.o.b. plant, for all blast furnace slag was approximately $8.40 per ton, almost 9% more than that of 1992. *(See table 7.)* Air-cooled blast furnace slag averaged 5.89 per ton, virtually the same as that in 1992. However, with the exception of the 1991 data, prices for air-cooled slag increased year after year since the early 1970's. Granulated and expanded slag price information was withheld to avoid disclosing company proprietary data. The unit value for steel slag increased from $3.19 per ton in 1992 to $3.43 per ton in 1993.

Foreign Trade

Statistics developed by the U.S. Department of Commerce, Bureau of the Census, indicated that approximately 162,000 tons of granulated blast furnace slag was imported during 1993. Ninety-seven percent of these imports was from Canada. Sixty-one percent reportedly entered through Cleveland, OH, almost 39% through Buffalo, NY, and less than 1% through Savannah, GA. The Canadian imports may be expanded or pelletized slag.

Exports of granulated slag were 3,498 tons. Sixty-three percent of the slag exports went to Canada, with the remaining going to eight other countries.

World Review

A summary was made of blast furnace slag production in Europe, including Austria, Belgium, Finland, France, Germany, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. Approximately 25 million tons of blast furnace slag was produced. It was estimated that 55% of this was granulated slag.

Australia.—Approximately 3 million tons of iron and steel slag was produced, about the same as that in 1992. There were no significant changes in slag production from 1992 at the iron and steel production centers in Australia. About 375,000 tons of blast furnace slags was used in Australian cements, with another 500,000 tons used in road construction and as an aggregate in concrete. Slag production and consumption centered around the iron and steel slag produced by BHP Steel in two areas in Australia—Port Kembla and Newcastle.

In the Port Kembla area of New South Wales was the slag processor Australian Steel Mill Services (ASMS), a consortium of Edward C. Levy Co. of Detroit, MI, and Queensland Cement Co., a wholly owned subsidiary of Holderbank Co. Approximately 1.3 million tons of blast furnace slag was processed into 700,000 tons of air-cooled slag and 600,000 tons of granulated slag. Approximately 50% to 60% of both types was used for road pavements, concrete aggregate, and cement manufacture. The rest was stockpiled. Approximately 500,000 tons of basic oxygen furnace (bof) slag was produced, with 100,000 tons used for road pavements and the rest stockpiled.

Significant progress was made in the recognition of blast furnace slag as a heavy-duty pavement material with its use as a subbase layer for the third runway at Sydney's major airport. About 300,000 tons of a blast furnace slag mix was supplied to the project. Competition from other aggregates, including mined aggregate, was intense for this and all other civil projects in the Port Kembla area.

BHP announced that it intended to construct a new blast furnace at Port Kembla, confirming that the complex would remain as an integrated unit for the foreseeable future. The new furnace was to replace two smaller older furnaces.

The Australasian Slag Association released a 24-page booklet entitled "A Guide to the Use of Slag in Roads." The booklet was published in conjunction with the State Roads and Traffic Authority as part of its drive to make greater use of recycled materials. The booklet also was endorsed by Vicroads, the Victorian State roads authority.

In Newcastle, there were three slag contractors, Boral Quarries, of Boral Ltd.; Steel Cement, Ltd. (owned mainly by a consortium of Australian and Japanese companies); and Steelstone Services of Australia. The first two contractors produced approximately 500,000 tons of blast furnace slag; 50% was air-cooled slag used in road pavements and construction and 50% was granulated slag used in cement manufacture and road construction. The latter contractor produced about 200,000 tons of steel slag, of which 50,000 tons was used for road construction and the balance was stockpiled.

All blast furnace slag produced in Newcastle was used productively in the marketplace and more could have been sold if it had been available. Sales were assisted by the shortage of natural rock close to the main market area. Small shipments of granulated blast furnace slag (gbfs) were exported to Hawaii where its silicate content was used as a soil conditioner. Some export sales of gbfs also were made to Southeast Asia.

The State Roads and Traffic Authority of New South Wales began to make extensive use of road pavement material in the Newcastle region comprising 70% basic oxygen furnace slag, 25% blast furnace granulated slag, and 5% fly ash. The use of the blast furnace slag mix in this manner was expected to be expanded. All of the components in the mix were byproducts from the BHP steel mill.

Approximately 350,000 tons of blast furnace slag and 125,000 tons of steel slag also were produced in Whyalla, South Australia, but the plant was not near a significant market, and this slag was therefore not sold. Electric arc furnace slag also was produced in Melbourne, Victoria, and in Newcastle, New South Wales.

Blast furnace slag cement marketed in Australia conformed to Australian Standard AS 1317. AS 1317 permitted slag to represent 20% to 65% of the total cementitious content.[10]

Belgium.—As in the past, all the production of blast furnace slag, about

2.3 million tons in 1992, was granulated. This 18% reduction in the amount of blast furnace slag available, compared to that in 1991, was due to decreased hot-metal production as well as to a reduced rate of slag produced per ton of hot metal. The cement industry was by far the main customer. An increase in the price of the slag over the $9 per ton of 1991 accompanied the reduction in production.

Steel slag production was also slightly reduced from the 1 million tons produced in 1991. The applications for steel slag remained principally for forest, farm and industrial roads, parking lots, stabilization of deposits, and hydraulic engineering. The cement industry consumed small quantities of steel slag for use in making clinker and for agriculture as soil liming agent. The production of electric arc furnace (EAF) slag rose. The EAF slag could enter the heavy-duty road market more easily than the BOF slag because it was not classified under the common designation of "steel slag." The EAF slag was also more stable than BOF slag because of its lower free lime content.

Canada.—Lafarge Canada purchased the Spragg slag cement plant in Blind River, Ontario, from Koch Minerals at yearend. The Spragg plant processes slag from Algoma steel. Lafarge Canada also operated the Stony Creek slag plant in Hamilton, Ontario. Stony Creek processes the slag from Dofasco and Stelco in Hamilton, Ontario.

Ninety thousand cubic meters of steel slag was used to provide stability to the soil under Highway 416 leading into Ottawa. The slag project took 1 year and cost $2.5 million.[11]

France.—In 1993, 12.57 million tons of pig iron and 4.27 million tons of blast furnace slag were produced, or 360 kilograms (kg) of slag was produced for every ton of pig iron. This compared with 13 million tons of pig iron and 4.7 million tons of blast furnace slag produced in 1992. Of this slag, approximately 2.12 million tons was granulated, 2 million was air-cooled, and 0.15 million was pelletized or processed in other ways. Sales of slag, 5 million tons compared with 6.9 million tons in 1992, included the slag produced, slag from stocks, and older slag banks. The amount of granulated and pelletized cement sold was 2.5 million tons, less than the 3.5 million tons in 1992. Of the granulated and pelletized slag, 1.9 million tons was used in cement, 0.3 million tons was used for coarse slag and slag sand on roadways, 0.2 million tons of lightly crushed slag was used on roadways, 0.02 million tons was a mixture of granulated slag and crushed air-cooled slag used to make road bases, and 0.08 million tons was used by the company or for other uses. Seventy-one percent of the granulated slag was utilized in France, up by 8% compared to that in 1992, and the remainder was utilized abroad.

Sales of crushed air-cooled slag were 2.4 million tons, less than the 2.7 million in 1992, and included slag from stocks and from older slag banks. Of the air-cooled slag, 55% was used on roadways, 30% as coarse slag, 9% for concrete and slag bricks, 2% for ballast, and 4% in other uses. Two thousand tons of expanded slag was sold. Ninety-eight percent of the air-cooled and expanded slag was used in France, the same as in 1992.

There were approximately nine blast furnaces in operation. Sollac at Dunquerque had three blast furnaces, Sollac at Fos-Sur-Mer had two, Lorfonte at Rombas had two, and Lorfonte at Hayange had two. Production at the SMN Unimetal blast furnace at Caen, which had granulated 100% of production, stopped in 1993.

Steel slag (not including EAF slag) was processed mainly at Dunkerque and Fos. Compared with 12.43 million tons in 1992, 11.77 million tons of liquid steel was produced in 1993. Seventy-four thousand seven hundred tons of slag was used in the blast furnace and 91,200 tons was used in the steel furnace. In 1993, 217,400 tons of steel slag was sold, compared with 242,700 tons in 1992. Of the amount in 1993, 29% was used on roads, 25% used at the cement plant, 20% in agriculture as fertilizer, and 26% used in various other ways. Steel slag banks amounted to 247,300 tons in 1993 compared with 612,000 tons in 1992.

Germany.—There was 6.81 million tons of blast furnace slag produced in Germany and 7.41 million tons was sold, compared with 7.08 and 8.25 million tons, respectively, in 1992. Almost 88% of the slag produced came from nonphosphorus pig iron production, 1.9% from basic Bessemer pig iron production, and 2.1% from special pig iron production. Some of the blast furnace slag sales were taken from stores of slag produced in prior years. About 57% of the slag was air-cooled slag used for road construction, 39% was granulated slag for cement, 3% was granulated slag for road construction, 1% was foamed slag for road construction, and less than 1% was air-cooled slag for fertilizer. There was 4.24 million tons of steel slag produced in Germany, compared with 4.7 million in 1992, with 88% being sold. Sixty percent was used as aggregate for roads, 18% was recycled back to the blast furnace, 12% was for landfill, 7% was for fertilizer, and 3% was for other uses.

Slag used in Germany must conform to special requirements for leachability (in addition to conforming to certain technological requirements). The leaching was done according to German Standard DIN 38 414. There were no common limits within Germany for the application of byproducts. Therefore, the state of Northrhine-Westfalia (Nordrhein-Westfalen) created special limits for each of 11 byproducts. According to the leachability of the slags, they could be used as aggregates in various fields of application, such as aggregates in road construction in asphalt or unbound layers; in ground water protection areas as an aggregate under layers impermeable to water (such as asphalt or concrete layers), and in other ways.

India.—India produced approximately 35 million tons of steel and blast furnace slag, 30 million tons of fly ash from thermal powerplants, and 3 million tons of lime sludge.[12]

The Steel Authority of India (SAIL) was expected to convert enormous quantities of byproducts generated from its ironmaking and steelmaking processes into materials suitable for use in construction and as substitutes for mined aggregate.[13] The byproducts were blast furnace slag, steel slag, and fly ash from the powerplants, among others. SAIL produced approximately 1,000 kg of these solid byproducts for each ton of steel.

The Tata Steel cement plant at Sonadih in Madhya Pradesh began cement production in 1993.[14] Sonadih was part of a 1.73-million-ton-per-year cement project with plants in two locations, Sonadih and Jojobera. The Jojobera plant was expected to begin producing portland slag cement in January 1994. The blast furnace slag was to be made available by the Tata Steel Works. The company was planning to market its products with Associated Cement Cos., Ltd. Sagar Cements also had two plants with 1,000 tons per day of capacity, consisting of 400 tons per day of ordinary portland cement at Mathampally and 600 tons per day of portland blast furnace slag at Salur.[15] Sagar Cements established a slag cement grinding unit at Kharasavalasa district, Andhra Pradesh, with a capacity of 600 tons per day of portland blast furnace slag cement. The unit was to have a slag dryer, cement mill, and packaging plant. Sagar Cements was to receive 70,000 tons annually of high-quality slag from the Vishakapatnam Steel Plant for 10 years.

Japan.—In 1993, 35.2 million tons of slag was produced, compared with 35 million in 1992. Sixty-five percent was blast furnace slag and the remaining was steel slag, virtually the same as that in 1992. In 1993, 21.82 million tons of blast furnace slag was consumed compared with 24.08 million tons in 1992. Also in 1993, 14.27 million tons of slag was used in cement, 88% being granulated and the rest air-cooled slag. During the year, 4.37 million tons of slag was used for roads or railroads, 1.17 million was used for public works, 754,000 tons went for coarse concrete and fine aggregate, 360,000 was used as fertilizer, 292,000 was used to improve the soil, and 602,000 tons was consumed in other uses.

Although the amount of total blast furnace slag has remained about the same since 1976, the amount of granulated slag that has been processed has grown from 3 million tons in 1976 to 14.46 million in 1993. The amount of air-cooled slag conversely decreased from 23 million tons in 1976 to 7.5 million tons in 1993.

There were two types of steelmaking slag, one was BOF slag and the other was EAF slag. The amount of the former production was 9.8 million tons and that of the latter was 2.47 million tons in 1993. EAF slag was expected to increase following the increased steel production by the electric arc process. In 1993, 9.3 million tons of BOF and 2.4 million tons of EAF slags were used (although only 70% of the EAF slags is accounted for here). More than 4 million tons of steel slags was used in public works, 1.85 million tons was recycled, 1.55 million tons was used on roads, 1.33 million tons was used in landfills, 628,000 tons was used in cement, 382,000 tons was used for soil improvement, and 109,000 tons was used as fertilizer; 1.92 million tons went for other uses.

Owing to its promotion of technology for the advanced reuse of energy and resources, the Japanese steel industry has been viewed as a representative recycling industry. All of the blast furnace slag is usefully recycled, much of it as an ingredient of cement, while more than 75% of BOF and EAF slag is recycled.[16]

The following standards exist for slag in Japan: JIS A 5011 covers Air-Cooled Iron Blast-Furnace Slag Aggregate for Concrete, JIS A 5012 covers Granulated Blast Furnace Slag Fine Aggregate for Concrete, and JIS A 5015 covers Slag for Road Construction—blast furnace and steel slag.

Other standards were published by The Japan Society of Civil Engineers on the design and construction of concrete containing ground granulated blast furnace slag used as an admixture, by the Nippon Slag Association on the design and construction of road base and subbase with crushed blast furnace slag, and by the Japan Road Association on the design and construction of asphalt pavement.[17]

Netherlands.—Blast furnace slag production amounted to about 1.2 million tons. Ninety-seven percent of the iron slag was granulated and almost entirely sold to the cement industry. A small quantity was used in mixtures for road building. The remaining part was air cooled and used as a component for road building.

Steel slag production from BOF steelmaking amounted to about 500,000 tons. About 16% of this steel slag was returned to the BOF as process slag, 20% was used in marine engineering, and 24% was used in road construction as the main component in mixtures with granules. The remaining 40% was put in stock and could be used in large projects as a replacement for sand. Much attention was given to upgrade steel slag by means of separation and aging so that it would be an acceptable replacement for natural aggregates used in road construction and concrete production.

New Zealand.—The main producer of slag in New Zealand was BHP New Zealand Steel Co. Iron-bearing sand was the source of metallics, iron was obtained through the smelter process, and steel by the KOBM process. The slag was processed and marketed by a joint-venture company comprising BHP and the Slag Reduction Co. of Scunthorpe, England, trading as the Slag Reduction Co. (New Zealand) Ltd. The company created markets for slag products in conventional uses such as asphalt and road pavements as well as in other uses such as filter media for wetlands and oxidation ponds.

KOBM slag also was used as a soil conditioner, particularly for growing lettuce and carrots. Sales of slag products were close to production levels. In addition, approximately 16,000 tons of electric arc furnace slag was produced by Pacific Steel.

Russia.—A joint venture was set up at a plant in Chelyabinsk to make concrete and steel out of raw ore and steel accumulated at the Satkinskij Metallurgical Enterprise defense production.[18] The joint venture was established by Commonwealth Connection, a U.S. company, for joint venture with Russia. The Multilateral Investment Guarantee Agency (MIGA), a World Bank affiliate, provided $9.9 million in insurance for Multiserv Russia, S.A., for its investment in machinery and equipment for a steel slag processing operation in Magnitogorsk, Russia. This was MIGA's first coverage in Russia.

United Kingdom.—The amount of blast furnace slag produced in 1993 was approximately 3.3 million tons, just slightly more than that in 1992. The percentage of granulated slag and pelletized slag, about 28%, was expected to increase as the new granulator at Llanwern came into full production. In Britain, all air-cooled blast furnace slag, about 22% of the total blast furnace slag, was sold as aggregate in coated materials and asphalts, principally for roads. The remaining 50% of blast furnace slag went to unbound road use and general construction. The latter figure included a small amount sold as a filter medium for water treatment.

Slag was produced in the United Kingdom at the British Steel plants—Scunthorpe and Teesside in England and Llanwern and Port Talbot in Wales. In England, East Coast Slag, owned by British Steel and Tarmac PLC, marketed the slag produced at Scunthorpe and Teesside. In Teesside, the iron slag was produced at Redcar and the steel slag was produced at Lackenby. In Wales, Cambrian Stone, owned by British Steel and Wimpey Hobbs of George Wimpey PLC, marketed the slag produced at Llanwern and Port Talbot.

There were two granulators, one at Scunthorpe and one at Llanwern, which were commissioned in 1993. Two of the plants in the United Kingdom also used pelletized slag.

British Steel produced 1.5 million tons of BOF slag in 1993. Approximately 200,000 tons of BOF slag was sold for use in roads, in unbound and in bituminous mixes.

British Steel negotiated selling equipment from the Scottish Ravenscraig plant, which closed in 1992, to an Indonesian company, Gunawan Dianjaya, which planned to reassemble it in northeast Malaysia. The plant would be the largest steel plant in Southeast Asia.[19] Castle Cement of Glasgow, Scotland, which had received slag from this plant prior to its closure, imported slags from France and received raw materials from Redcar and Port Talbot in South Wales. The material was ground, processed, and marketed in Scotland. About 100,000 tons of this processed slag was sold in 1993.

There was interest in the United Kingdom in limiting freshly quarried aggregates to build highways, roads, offices, and houses in England and Wales. Because the supply of aggregates was expected to be limited, a price rise was expected. Recycled materials, such as blast furnace slag, were expected to benefit.[20]

The principal means of regulating slag was the British Standard (BS). In addition, other Digests issued by the Building Research Establishment, although not carrying the force of a BS, were conformed to by slag processors. BS 6699 was used for blast furnace slag used in cement, ground granulated blast furnace slag (ggbfs). This ggbfs was for supply directly to the concrete manufacturer, ready-mixed, site-mixed, or precast. The BRE Digest No. 363 covered sulfate resistance of concrete and specified a 14% maximum Al_2O_3 content. BS 1047 covered air-cooled blast furnace slag for aggregates.

Current Research

A new mud-to-cement conversion technology eliminated mud displacement problems, improved zonal isolation, and eliminated mud to cement incompatibility, which was common with conventional cementing practices.[21] Ggbfs and common inexpensive alkaline activators could be added to any water-based mud to form a cementitious slurry. The slurry was simple to use, cost effective, and was shown to significantly reduce mud disposal costs in environmentally sensitive areas because most of the mud was used as the base for the cement instead of being disposed or discarded.

At the Institute of Materials in Austria, slags as a replacement for natural sand in cements were shown to be equivalent to the sand.[22] Production and processing of slag could be tailored to out perform the aggregates currently used. Applications of slag were presented for the concrete, plastering, and environmental technology industries.

The effect of the addition of 15% and 30% fly ash or 50% ggbfs to ordinary portland cement on the corrosion resistance of the reinforcement in concrete was studied in a program of long-term exposure in seawater. The use of these admixtures resulted in a decrease in the corrosion rate, especially after long exposure times. The most effective protection was given by the 30% fly ash mix. This result was related to the chloride content and the chloride binding capacity of the admixtures.[23]

The cement and concrete research group of the King Fahd University of Petroleum and Minerals continued to conduct fundamental and applied research toward the production of durable concrete compatible with the environmental conditions of the countries along the Arabian Gulf.[24] The drastic shortening of the useful service life of reinforced concrete structures in the eastern coastal areas of Saudi Arabia owing to reinforcement corrosion, sulfate attack, and salt weathering was of major concern to the construction industry in this region. Evaluating the performance of high-performance materials, such as fly ash, blast furnace slag, and silica fume in resisting reinforcement corrosion has been the active research area of the group.

Ggbfs used to partially replace portland cement and silica fume in cement pastes were investigated under different curing regimes at the People's Republic of China Tongji University, Department of Material Science and Engineering.[25] The influence of long-term hydration at 25° C, hydrothermal curing at 80° C, and strong drying at

200° and 400° C on the composition and microstructures of slag-portland cement was investigated by using various methods. The slag was found to be an additive that improved the intrinsic properties of the cement paste.

Research conducted in Czechoslovakia studied the influence of an alkali-silicate admixture on mortar properties.[26] The admixture significantly increased the strength of the mortars made from portland cement and silica fume or blast furnace slag. The admixture allowed the value of compression strength to be accelerated when it was added to mortar incorporating slag and with slag mortar. Further results showed that mortars with the admixture had an increased content of hydration products and substantially more dense pore structure than mortars of the same composition, but without the admixture.

In Australia, it was determined that the manufacture of cements based on calcium sulfoaluminate required lower firing temperatures and lower grinding energy as compared to ordinary portland cements.[27] Some of these low-energy cements could be formulated to develop high early strength and other performances similar to ordinary portland cement. It was found that a number of byproducts such as blast furnace slag, fly ash, bauxite fines, and phosphogypsum could be employed without affecting the hydraulic behavior of the cement. Blast furnace slag and fly ash also could be used as blending components of the fired products.

An investigation was conducted at the University of Delft in the Netherlands into the cement equivalence factors for fly ash in concrete.[28] The work was part of research aimed at taking the contribution of fly ash to strength development and other properties of concrete into account on the minimum cement content and maximum water-cement ratio required to achieve these properties by the Dutch Concrete Standards. Ordinary Portland Cement, rapid hardening portland cement, and portland blast furnace slag cement were studied. Concrete compositions with a range of water-cement ratios, two fly ash-cement ratios, and three curing regimes were studied as functions of concrete compressive development. The equivalence factor increased when the water-cement ratio decreased. This dependence was lowest for the portland blast furnace slag cement and decreased with increasing age.

A study was made at the Cemkut GMBH in Budapest, Hungary, of the grinding and quality characteristics of composite cements produced from clinker and two additional interground additives such as granulated blast furnace slag, fly ash, trass, and limestone.[29] The grindabilities of cements made up of three components proved to be better than that of the clinker. Water demand and workability depended upon the particle-size distribution, which was influenced by the grindability and nature of the interground additives. The more easily ground components had wider particle-size distributions and generally had lower water demands. To achieve standard strengths, the composite cements had to be more finely ground than cements without interground additives. In addition to having favorable grinding characteristics, composite cements made of clinker, ggbfs, and limestone also gave the best consistencies at high compressive strengths.

The permeability and mechanical properties of blast furnace slag concretes made of neutral (CaO/SiO_2 almost equal to 1) and low alumina content (Al_2O_3 almost equal to 8.5%) slags were investigated at the Technical Research Center of Finland.[30] Portland cement, blended cement, and alkali-activated slag concretes were compared with one another. The influence of the type of cementing materials on the mechanical properties was investigated. The effect of microcracks in the alkali-activated slag concrete on the mechanical properties of concrete was studied.

Studies were done at the University of Aberdeen in Aberdeen, Scotland, and at CSIRO in New South Wales, Australia, to study the reducing characteristics of blast furnace slag and their influence on the redox potential of slag-cement pore solutions.[31] The continued and increasing use of slag cements in the construction industry was expected to require consideration of the effect of the electrochemically reducing pore solution on the passivation of steel reinforcement in the cement system. Studies on steel embedded in portland cement and slag cement matrices were presented. The model proposed that the reducing components of blast furnace slag would impede the early formation of oxidized passive layers on steel in high blast furnace loaded blast furnace slag and ordinary portland cement concretes and could gradually degrade previously formed oxide layers. Thus, the corrosion behavior of steel in blast furnace slag and ordinary portland cement matrices was considered to be different from that in other cementitious systems.

Blast furnace slag containing CaO, SoO_2, Al_2O_3, and MgO as main constituents was investigated as a possible raw material for tile manufacturing.[32] Samples were made from 50% to 80% by weight slag and modified by varying amounts of SiO_2, Al_2O_3, Li_2O, and TiO_2. The properties of the tile thus prepared were investigated using differential thermal analysis, X-ray diffraction, and scanning electron microscopy.

Stroikeramika, a Leningrad tilemaking plant, also conducted experiments with ceramic wall tiles to assess the possibility of using blast furnace slag to manufacture these tiles.[33]

Samples of blast furnace slag from the East-Slovak Metallurgical Works in Kosice were studied at the Institute of Civil Engineering, in Bratislavia, Slovakia. Various ages and granulometry were investigated with respect to their chemical and mineralogical composition.[34] The blast furnace slags' tendency to ferrous and gamma-dicalcium disintegration was assessed as well as their hydraulic activity under normal and hydrothermal conditions. The experiments showed the slags to be uniform in their properties and suitable for their application as aggregate for concrete.

Trinecke Zelezarny, an iron company in Trinec in the Czech Republic, began manufacturing slag-pumice and slag-concrete bricks at its Hutni Metallurgy Waste division.[35] No mortar materials were needed for vertical joints. The bricks could be used for all kinds of masonry, including ceilings.

Ggbfs was used to make sand-lime bricks in India.[36] Laboratory results revealed that good quality bricks could be produced at sufficiently low pressure of 5 megapascals and the manufacturing process of these bricks did not require firing or autoclaving for strength development.

The phosphorus removal efficiency of three gravel-based constructed wetland systems was investigated in a study conducted at the University of Western Sydney Hawkesbury, Sydney, Australia, in which secondary sewage effluent was treated.[37] Laboratory phosphorus adsorption experiments were conducted with regional gravels and alternative adsorptive media, including industrial slag and ash byproducts. The results of a range of adsorption capacities indicated that further investigations into the use of industrial byproducts to treat industrial waste substrata were warranted.

At the National Center for Metallurgical Research in Madrid, Spain, granulated blast furnace slag was used to reduce the toxicity of electric arc steelmaking flue dust by means of a stabilization process.[38] The process made it possible to immobilize the metal contents that make the flue dust a hazardous product. Stabilization first involved pelletizing the steelmaking flue dust and then coating these pellets with a mix composed of slag-based hydraulic binders. Experiments indicated that various slag binding mixes containing portland cement, gypsum, and lime reduced the mobility of flue dust metals. The mobility of the metals has lead to flue dust being classified as a hazardous product.

SsangYong Cement of South Korea provided a grant to the National University of Singapore to fund joint research into the study of how to produce more durable cement.[39] The joint project was to explore the potential of portland blast furnace slag cement.

The granulated slag of a steel plant was analyzed for major and minor components.[40] It was found to contain iron and manganese (along with some other metals in traces) in a state suitable for causing electrochemical reduction of a number of extraneously added metal ions. By controlling parameters such as weight of slag used, pH, concentration, and flow rate, a scheme for the selective removal of toxic metal ions such as Hg(II), Pb(II), Cu(II), and Zn(II) was carried out. The method showed promise in the removal of toxic metal ions from solutions and effluents.

OUTLOOK

The total amount of blast furnace slag produced was not expected to increase during the next year because the amount of pig iron was expected to stay at about the 48-million-ton level. (See Iron and Steel Annual Report 1993.) In addition, gradual improvements have been made in the ironmaking process. One of these is that the amount of fluxstone, such as limestone or dolomite, that is added to the blast furnace has decreased somewhat over the past few years. This directly affects the amount of slag produced, or the total amount available to be sold.

Of the types of blast furnace slag, granulated slag used in cement was likely to increase somewhat relative to air-cooled slag due to a number of factors. Portland cement was forecast to be in short supply at least through 1994, and granulated slag could replace this portland cement at a lower cost. In addition, granulation of slag impacted favorably on energy usage because less portland cement would be manufactured, a process that utilizes large amounts of energy. With respect to other environmental considerations, granulation of slag was favorable compared to other types of iron blast furnace processing in that there are fewer emissions to the air with granulation. Research was expected to continue to emphasize the advantages of the chemical properties of slag when blended with cement. Prices of granulated slag were expected to rise as the price of portland cement rose, with the upper limit being the price of cement.

Production of steel slag was expected to rise owing to a slight increase in steel production. EAF slag production was expected to continue to increase relative to BOF slag production. Consumption of steel slag as a whole was not expected to increase significantly.

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TABLE 1

IRON AND STEEL SLAGS SOLD OR USED[1] IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Blast furnace slag						Steel slag		Total slag[3]	
	Air-cooled		Expanded [2]		Total iron slag[3]					
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1989	12,504	66,574	1,548	29,143	14,051	95,717	6,691	24,056	20,743	119,772
1990	13,741	77,863	1,315	26,448	15,057	104,311	6,851	22,268	21,908	126,578
1991	10,889	66,393	2,404	43,484	13,293	109,877	6,959	23,732	20,252	133,609
1992[r]	12,711	74,526	1,737	37,000	14,448	111,528	6,936	22,136	21,384	133,664
1993	10,477	61,685	1,864	41,943	12,340	103,627	6,672	22,857	19,012	126,484

[r] Revised.

[1] Value based on selling price at plant. Includes estimated value data for several operations.

[2] Includes granulated to avoid disclosing company proprietary data.

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

TABLE 2

BLAST FURNACE SLAGS SOLD OR USED IN THE UNITED STATES, BY REGION AND STATE

(Thousand metric tons and thousand dollars)

	1992				1993			
	Air-cooled, screened and unscreened		Total, all types		Air-cooled, screened and unscreened		Total, all types	
	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]	Quantity	Value[1]
North Central:								
Illinois, Indiana, Michigan, Ohio	[r]8,609	[r]49,894	[r]9,511	[r]62,879	6,919	40,543	8,078	55,345
Middle Atlantic:								
Maryland, New York, West Virginia	W	W	W	W	W	W	W	W
Pennsylvania	1,687	11,237	1,764	12,301	1,329	8,710	1,412	9,647
Total	W	W	W	W	W	W	W	W
Undistributed[2]	[r]2,415	[r]13,395	[r]3,173	[r]36,348	2,230	12,431	2,851	38,635
Grand total[3]	[r]12,711	[r]74,526	[r]14,448	[r]111,528	10,477	61,685	12,340	103,627

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Undistributed."

[1] Value based on selling price at plant.

[2] Includes Alabama, Kentucky, Utah, and those indicated by symbol "W."

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

TABLE 3

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1993

Company	Plant location	Slag source				Blast furnace slag type
		Iron blast furnace	Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
Alexander Mill Services	Blytheville, AR				X	—
Do.	Kankakee, IL				X	—
Do.	Charlotte, NC				X	—
Do.	Holsopple, PA				X	—
Do.	New Castle, PA				X	—
Do.	Washington, PA				X	—
Do.	Cayce, SC				X	—
Do.	Seguin, TX				X	—
Do.	Plymonth, UT				X	—
Blue Circle Atlantic Inc.	Sparrows Point, MD	X				Granulated.
Buffalo Crushed Stone	Buffalo, NY	X				Air-cooled.
CSR America	Middletown, OH	X				Do.
Dunbar Slag Co. Inc	Wheatland, PA	X		X		Do.
Heckett Co.	Fontana, CA	X	X			Air-cooled.
Do.	Wilton, IA				X	—
Do.	Chicago, IL	X				Air-cooled.
Do.	Sterling, IL				X	—
Do.	East Chicago, IN		X			—
Do.	Indiana Harbor, IN		X			—
Do.	Ashland, KY	X	X			Air-cooled.
Do.	Coalton, KY				X	—
Hempt Bros., Inc.	Steelton, PA				X	—

TABLE 3—Continued

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1993

Company	Plant location	Slag source				Blast furnace slag type
		Iron blast furnace	Steel			
			Basic oxygen furnace	Open hearth	Electric arc furnace	
International Mill Service	Fort Smith, AR				X	—
Do.	Pueblo, CO		X			—
Do.	Claymont, DE				X	—
Do.	Tampa, FL				X	—
Do.	Cartersville, GA				X	—
Do.	Alton, IL				X	—
Do.	Chicago, IL	X			X	Air-cooled.
Do.	Granite City, IL		X			—
Do.	Huntington, IN				X	—
Do.	Laplace, LA				X	—
Do.	Jackson, MI				X	—
Do.	Monroe, MI				X	—
Do.	St. Paul, MN				X	—
Do.	Perth Amboy, NJ				X	—
Do.	Newport, KY				X	—
Do.	Owensboro, KY				X	—
Do.	Kansas City, MO				X	—
Do.	Jackson, MS				X	—
Do.	Canton, OH		X			—
Do.	Mansfield, OH				X	—
Do. (Warren Plant)	Warren, OH		X			—
Do.	do.				X	—
Do.	Youngstown, OH				X	—
Do.	Butler, PA				X	—
Do.	Fairless Hills, PA			X		—
Do.	Provo, UT	X		X		Air-cooled.
Do.	Seattle, WA				X	—
Do.	Riverton, NJ				X	—
Do.	Marion, OH				X	—
Do.	Middletown, OH		X		X	—
Do.	Mingo Junction, OH		X		X	—
Do.	McMinnville, OR				X	—
Do.	Portland, OR				X	—
Do.	Sand Springs, OK				X	—
Do.	Beaver Falls, PA				X	—
Do.	Burgettstown, PA				X	—
Do.	Coatesville, PA				X	—
Do.	Midland, PA				X	—
Do.	Pricedale, PA		X		X	—
Do.	Reading, PA				X	—
Do.	Georgetown, SC				X	—
Do.	Jackson, TN				X	—
Do.	Beaumont, TX				X	—
Do.	El Paso, TX				X	—
Do.	Jewett, TX				X	—

TABLE 3—Continued

PROCESSORS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1993

Company	Plant location	Iron blast furnace	Slag source: Steel: Basic oxygen furnace	Slag source: Steel: Open hearth	Slag source: Steel: Electric arc furnace	Blast furnace slag type
International Mill Service—Continued	Longview, TX				X	—
Do.	Midlothian, TX				X	—
Do.	Saukville, WI				X	—
Do.	Weirton, WV		X			—
Koch Minerals	Gary, IN	X				Air-cooled, expanded and granulated.
Do.	Weirton, WV	X				Granulated.
Edward C. Levy Co.	Detroit, MI	X	X		X	Air-cooled and expanded.
The Levy Co. Inc.	Burns Harbor, IN	X	X			Air-cooled.
Do.	East Chicago, IN	X				Do.
Maryland Slag Co.	Sparrows Point, MD	X				Do.
Standard LaFarge Co.	Granite City, IL	X				Do.
Do.	Cleveland, OH	X				Air-cooled and expanded.
Do.	Cuyahoga, OH			X		—
Do.	Lordstown, OH	X		X		Granulated.
Do.	McDonald, OH	X		X		Air-cooled.
Do.	Mingo Junction, OH	X				Do.
Do.	Warren, OH	X				Do.
Do.	Youngstown, OH			X		—
Do.	West Alliquippa, PA	X				—
Do. (Brown Reserve)	West Mifflin, PA	X				Air-cooled.
Do. (Duquesne)	do.	X	X	X		Do.
Do.	Weirton, WV	X				Do.
Stein, Inc.	Cleveland, OH		X			—
Do.	Lorain, OH		X			—
United Slag Co.	Rancho Cucamonga, CA				X	—
Vulcan	Alabama City, AL	X				Air-cooled.
Do.	Fairfield, AL	X	X			Do.
Warner Co.	Bala-Cynwyd, PA	X				Expanded.
Waylite Corp.	Bethlehem, PA	X	X	X		Air-cooled and expanded.

TABLE 4
AIR-COOLED BLAST FURNACE SLAG SOLD OR USED IN THE UNITED STATES, BY USE[1]

(Thousand metric tons and thousand dollars)

Use	1992		1993	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	[r]2,262	[r]14,068	2,048	13,124
Concrete aggregate	[r]1,322	[r]9,180	1,004	7,412
Concrete products	469	2,863	442	2,246
Fill	[r]1,497	[r]5,563	1,459	6,409
Glass manufacture	W	W	W	W
Mineral wool	[r]753	[r]4,917	507	3,621
Railroad ballast	[r]178	[r]831	157	678
Road base	[r]5,496	[r]30,018	4,377	23,373
Roofing, built-up and shingles	70	844	43	538
Sewage treatment	W	W	W	W
Soil conditioning	W	W	W	W
Other[2]	665	[r]6,242	439	4,285
Total[3]	[r]12,711	[r]74,526	10,477	61,685

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Value based on selling price at plant.

[2] Includes ice control, miscellaneous, and uses indicated by symbol "W."

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

TABLE 5
STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY USE[1]

(Thousand metric tons and thousand dollars)

Use	1992		1993	
	Quantity	Value	Quantity	Value
Asphaltic concrete aggregate	903	4,272	1,094	4,921
Fill	[r]1,152	[r]3,230	905	2,366
Railroad ballast	224	772	116	323
Road bases	2,400	[r]7,258	2,660	8,119
Other[2]	[r]2,257	6,604	1,896	7,128
Total	[r]6,936	[r]22,136	[3]6,672	22,857

[r] Revised.

[1] Excludes tonnage returned to furnace for charge material. Value based on selling price at plant.

[2] Includes ice control, soil conditioning, and miscellaneous uses.

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

TABLE 6

SHIPMENTS OF IRON AND STEEL SLAG IN THE UNITED STATES IN 1993, BY METHOD OF TRANSPORTATION

Method of transportation	Quantity (thousand metric tons)
Truck	15,935
Waterway	743
Rail	752
Not transported (used at plant site)	1,582
Total	19,012

TABLE 7

AVERAGE VALUE PER TON AT THE PLANT FOR IRON AND STEEL SLAG SOLD OR USED IN THE UNITED STATES, BY TYPE

(Thousand metric tons and thousand dollars)

Year	Iron blast furnace slag		Steel slag	Total slag
	Air-cooled	Total iron slag		
1989	5.32	6.81	3.59	5.78
1990	5.67	6.92	3.25	5.78
1991	6.10	8.27	3.41	6.60
1992[r]	5.86	7.72	3.19	6.25
1993	5.89	8.40	3.43	6.65

[r] Revised.

TABLE 8

AVERAGE SELLING PRICE AND RANGE OF SELLING PRICES AT THE PLANT FOR IRON AND STEEL SLAG IN THE UNITED STATES IN 1993, BY USE

(Dollars per metric ton)

Use	Iron blast furnace slag			
	Air-cooled		Steel slag	
	Average	Range	Average	Range
Asphaltic concrete aggregate	5.44	4.30- 9.21	3.63	2.33- 6.59
Cement manufacture	W	W	—	—
Concrete products	3.63	3.27- 6.04	—	—
Fill	2.72	1.17- 9.71	1.81	1.10- 5.38
Glass manufacture	W	W	—	—
Mineral wool	5.44	5.26- 8.75	—	—
Railroad ballast	2.72	2.65- 8.25	1.81	2.00- 2.52
Road bases	3.63	2.42- 8.60	1.81	.50- 5.00
Roofing, builtup and shingles	9.98	6.98-15.02	—	—
Sewage treatment	W	W	—	—
Soil conditioning	W	W	W	W
Other	3.63	2.20- 9.47	2.72	1.22- 16.60

W Withheld to avoid disclosing company proprietary data.

SODA ASH

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 15 years U.S. Bureau of Mines experience, has been the commodity specialist for soda ash since 1979. Domestic survey data were prepared by Maria Arguelles, statistical assistant; and international data tables were prepared by Ted Spittal, international data coordinator.

Virtually every home has materials containing glass, soap and detergents, paper, textile, and food. All of these consumer products contain soda ash—a compound made from the mineral trona that most people have never heard of. Chemically, soda ash is known as sodium carbonate. It is the 11th largest inorganic chemical in terms of production of all domestic inorganic and organic chemicals, excluding petrochemical feedstocks. Internationally, there are two types of soda ash—natural and synthetic. The United States is the world's largest soda ash-producing nation with the world's largest natural deposit of trona, the ore from which soda ash is refined. Because the majority of world output is made synthetically, which usually is more expensive to manufacture, U.S. natural soda ash is extremely competitive in world markets. *(See table 1.)*

DOMESTIC DATA COVERAGE

Soda ash production data are collected by the U.S. Bureau of Mines from monthly, quarterly, and annual voluntary surveys of U.S. soda ash operations. Of the six soda ash operations to which a survey request was sent, all responded, representing 100% of the total production data shown in this report.

Reported consumption data by end use are collected quarterly from the marketing and sales departments of each company within the industry. Import and export statistics are obtained from the U.S. Department of Commerce, Bureau of the Census, and analyzed using trade data provided by the Journal of Commerce's Port Import Export Reporting Service (PIERS). The export data collected by the Census Bureau may not correspond to the export data provided by the soda ash producers in the quarterly survey of soda ash sales or the PIERS data. The discrepancy between the export data sets is because Census data report the transaction on the date the cargo physically departed from the U.S. port whereas soda ash producers consider a shipment as exported when it leaves the plant. The overland transit time between the plant and port and any carryover export inventory, both in domestic and foreign warehouses or teamtracks, are the major reasons for the difference between the export data.

BACKGROUND

Although soda ash represented about 2.3% of the total $32 billion nonfuel mineral industry that was surveyed by the U.S. Bureau of Mines in 1993, its use in many familiar household products consequently contributes substantially to the gross national product of the United States. Soda ash is one of the basic inorganic chemicals produced in the world. Most countries do not have economic deposits of sodium carbonate-bearing minerals and must produce soda ash by various manufacturing techniques, which are labor-, capital-, and energy-intensive. In addition, the processes generate byproduct sodium chloride and calcium chloride, which are usually discharged as waste effluent that contribute to environmental problems.

Natural soda ash was probably first obtained as evaporite incrustations along the edges of alkaline lakes in Lower Egypt. It was used about 3,500 B.C. to make ornamental glassware, as evidenced by many of the early Egyptian glass artifacts. The Egyptians also mixed lime and soda ash to make caustic soda. The caustic soda was combined with silicate minerals obtained from the Sinai Desert. This made a soluble silica, which was added to aluminum-rich Nile River silt, producing a silica-aluminate cement mortar with superior bonding properties. In the Old Testament, it was referred to as neter but has also been known as natrium, kali, trona, and natron. Until the 18th century, soda ash was obtained mainly by burning seaweeds and marine plants, leaching the soluble material from the ashes, and evaporating the solutions to dryness. About 13 tons of ash yielded 1 ton of sodium carbonate and 14 kilograms (30 pounds) of iodine as a byproduct. The final material was very impure but could be used in the manufacture of glass and soap and detergents. Pliny, a Roman historian in the first century A.D., listed soda ash in the manufacture of glass, as a medicine for colic pains and skin eruptions, and for making bread.

In 1791, Nicolas Leblanc, a French chemist, developed a process for making soda ash from "salt cake" (from salt and sulfuric acid), coal, and limestone. The French Revolution interfered with its development, and his patent and factory were confiscated with him receiving only token compensation. Napoleon returned his factory to him but Leblanc was not able to raise enough capital to reopen it, and he committed suicide in 1806. More than 30 years passed before the process first became successful in Liverpool, England. The process was not used successfully in the United States except during a short period from July 1884 to January 1885 at Laramie, WY.

Ernest and Alfred Solvay developed an improved method for making soda ash from salt, coke, and limestone, with ammonia as a catalyst, in the early 1860's. That process was first used in the United States in 1884 at Syracuse, NY, in a plant that continued to produce soda ash until 1986. It was the first of about 10 synthetic Solvay plants that were in operation by 1939 in the United States, and ironically, the last one to close. The Solvay process gained in popularity over the years and is now the basic method used throughout the world for making synthetic soda ash. In addition to the Solvay plants, there were three electrolytic process plants in Tyrone, PA, Covington, VA, and Luke, MD, that were operated by West Virginia Pulp and Paper Co. in 1939.

The site of the first commercial production of natural soda ash in the United States was from two deposits known as the Soda Lakes near the present town of Fallon, NV. Asa L. Kenyon acquired title to Little Soda Lake in 1855 and sold it to Higgins and Duffy in 1868, when the first 300 tons of natural soda ash was produced. Production of adjacent Big Soda Lake began in 1875 and reached its peak in 1887. The brines became diluted as the lake levels rose in 1907 because regional dam construction affected the local water table. Searles Lake in California was originally mined for borax as early as 1874. Soda ash production began in 1926 by the West End Chemical Co. American Potash Corp., formerly the American Trona Corp., was the second company to produce soda ash at Searles Lake in 1931.

Definitions, Grades, and Specifications

The following terms are used in the soda ash industry:

Ammonia-Soda Process.—Also known as the Solvay process and lime-soda process.

Dense Soda Ash.—Has a bulk density of 0.96 to 1.06 grams per cubic centimeter (60 to 66 pounds per cubic foot). It is produced by hydrating light soda ash followed by dehydration through calcination to produce denser crystals. In Eastern Europe, dense ash is made by compressing light ash between rollers to increase the density, followed by screening.

Light Soda Ash.—Has a bulk density of 0.51 to 0.62 gram per cubic centimeter (32 to 39 pounds per cubic foot). It is produced by calcining the sodium sesquicarbonate precipitate recovered from the carbonation towers or vacuum crystallizers.

Natural Soda Ash.—Soda ash produced from trona ore, sodium carbonate-bearing brines, or surface mineralization.

Soda Ash.—Synonymous with sodium carbonate. It is a general term that can apply to soda ash produced from natural sources or from various chemical processes.

Sodium Sesquicarbonate.—Can refer to the name for the chemical composition of trona or the chemical process that produces a light- to intermediate-grade of soda ash having an average bulk density of 0.8 gram per cubic centimeter (50 pounds per cubic foot).

Synthetic Soda Ash.—Term for soda ash produced from one of several chemical processes, such as the Solvay process.

Trona.—The principal ore from which soda ash is made. It is composed of sodium carbonate, sodium bicarbonate, and water. The monoclinic crystals are prismatic to tabular, with colors ranging from translucent (spar variety) to shades of brown, which vary depending on the amounts of contained organic matter. Trona has a specific gravity of 2.17 with a hardness of 2.5 to 3 on the Mohs scale. About 1.8 tons of trona is required to produce 1 ton of soda ash.

The terms "soda ash" and "sodium carbonate" are used interchangeably. The material manufactured from Wyoming trona normally contains more than 99.8% sodium carbonate, and the sodium chloride content ranges between 0.01% to 0.02%. The amount of iron is less than 10 parts per million. Searles Lake brines are processed to yield a product of similar high quality, with salt and sodium sulfate as the principal trace impurities. The average material produced by a Solvay soda ash plant is about equal to the natural product in sodium carbonate content, but often contains a larger quantity of salt. Dense soda ash, because of its greater bulk density, may command a higher price than the light variety and is preferred for glass manufacture because the light soda ash leads to frothing in the glass melt. Light soda ash is preferred by many chemical and detergent industries because it dissolves more readily. Sodium sesquicarbonate has an intermediate bulk density and is used in some detergent and bath salts.

The average Wyoming dense soda ash produced by the five Wyoming producers is nearly identical. All the companies provide chemical and physical analyses of their material and list the typical specifications of their products. The typical range of specifications for the various constituents are sodium carbonate, 99.6% to 99.8%; sodium sulfate, 0.02% to 0.15%; sodium chloride, 0.01% to 0.08%; and small trace amounts of arsenic, boron, calcium, copper, magnesium, and silica dioxide. The dense soda ash produced at Searles Lake contains 99.8% sodium carbonate, 0.10% sodium sulfate, and 0.10% sodium chloride. Although some product literature available from some of the European synthetic soda ash companies indicate that the composition data are averages of routine work control analyses and should not be considered as specifications, a typical chemical analysis lists the sodium carbonate content as 99.4%; sodium sulfate, 0.03%; sodium chloride, 0.2% to 0.4%; and small concentrations of iron oxide, calcium, and magnesium.

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 "Specifications 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. Technical-grade soda ash meets Federal specification O-S-571 F, Type II (LITE®) and III (Dense). It also meets American Well Water Assocation Standard B201-87. Photographic-grade sodium carbonate complies with the standards specified by the American Standard Institute PH 4.227-1974. Food-grade sodium carbonate is covered by the Food Chemicals Codex.

Industry Structure

The U.S. soda ash industry is composed of six companies; five in Wyoming and one in California. All produce natural soda ash only either from sodium carbonate-rich brines or from underground mining of trona ore. Foreign investment in U.S. soda ash operations has risen from 10% of capacity in 1981, when Societe Nationale Elf Aquitaine of France bought Texasgulf Chemical Co., to 46% in 1993. Five of the six U.S. companies have either Australian, Belgian, French, or Japanese partners. FMC Wyoming Corp. remains the only U.S. producer without any foreign ownership. The refinancing of the Harris Chemical Group in late 1993 resulted in terminating the share held by Oriental Chemical Industries of the Republic of South Korea. *(See tables 2 and 3.)*

Geology-Resources

The definitions of resources, reserves, and reserve base are published in U.S. Geological Survey Circular 831, Principles of a Resource/Reserve Classification for Minerals. Briefly, "resources" describe the quantity of ore present, regardless of grade or ease of extraction. The "reserves" are the portion of the resource that are economic to mine using the current technology and value of the commodity.

There are numerous sodium carbonate-bearing mineral occurrences throughout the world; however, only 95 deposits in 26 countries have been geologically evaluated.[1] Although several of these deposits have been quantified, most are economically insignificant or too remote to be commercially developed. The largest and the most economically significant deposit is the trona deposit in southwest Wyoming. All soda ash deposits can be classified in one of five modes of occurrences. In decreasing order of economic importance, they are as follows: buried, surface or subsurface brines, crystalline shoreline or bottom crusts, shallow lake bottom crystals, and surface efflorescences.

There are 14 sodium carbonate-bearing minerals that contain varying percentages of sodium carbonate. They are, in descending order of sodium carbonate content (with bicarbonate converted to carbonate), thermonatrite, 85.5%; Wegscheiderite, 74.0%; trona, 70.4%; nahcolite, 63.1%; bradleyite, 47.1%; pirssonite, 43.8%; tychite, 42.6%; northupite, 40.6%; natron, 37.1%; dawsonite, 35.8%; gaylussite, 35.8%; shortite, 34.6%; burkeite, 27.2%; and hanksite, 13.6%.

The trona found in the Green River Formation in southwest Wyoming is an excellent example of a buried trona deposit. The Wilkins Peak Member contains 42 beds of trona, 25 of which have a thickness of 0.91 meter (3 feet) or more. Eleven of these exceed 1.83 meters (6 feet) in thickness covering an area more than 3,100 square kilometers (1,200 square miles). The trona beds were deposited about 50 million years ago in the early to middle Eocene epoch in an ancient freshwater lake, named "Lake Gosiute" by Clarence King in 1878. The sodium and carbonate constituents of trona owe their respective origins to the leaching of the extensive pyroxene-andesite volcanic ash layers and the seasonal influxes of carbonate-rich sediments into the local depositional basin. In addition, subterranean thermal springs contributed a significant quantity of dissolved alkaline carbonates as well as sodium, calcium, silica, and bicarbonate ions. Trona can precipitate only in the presence of abundant carbon dioxide, which probably was supplied from the atmosphere and/or the biogenic decay of Eocene plant and aquatic remains. For 4 million years, Lake Gosiute went through many stages of filling and evaporation, thereby depositing more than 42 beds of trona on the lake bottom along with repetitive beds of marlstone, limestone, oil shale, and sandstone-mudstone. The decrease of the inflow to the lake was probably in response to climatic changes that resulted in the final evaporation of the waters. The former Lake Gosiute is the present Green River Basin.

Assuming 1.8 tons of trona yields approximately 1 ton of soda ash, about 47 billion tons (52 billion short tons) of identified soda ash resources could be obtained from the 56 billion tons (62 billion short tons) of bedded trona and the 47 billion tons (52 billion short tons) of interbedded or intermixed trona and halite that are in beds greater than 1.22 meters (4 feet) thick. Approximately 34 billion tons (37 billion short tons) of reserve base soda ash could be obtained from the 36 billion tons (40 billion short tons) of halite-free trona and the 25 billion tons (27 billion short tons) of interbedded or intermixed trona and halite in beds more than 1.83 meters (6 feet) thick. Although about 15 million tons (16 million short tons) of trona is presently being mined annually, with these minable reserves Wyoming could supply all domestic requirements for more than 3,100 years at the 1991 demand level. As technology improves in the future, mining of the subeconomic grades of ore would further extend the life of the trona deposit to more than 5,100 years. With Wyoming reserves estimated at 20 billion tons (22 billion short tons), the United States, through this one deposit, could supply the world all the soda ash to meet the current demand levels for about 630 years.

The U.S. Government established a Known Sodium Leasing Area (KSLA) in Wyoming within the perimeter of the trona depositional basin. The trona within the KSLA is subject to Federal and State leasing regulations and private lease agreements. Although most of the leasable trona averages 93% sodium sesquicarbonate, several areas contain lower grade trona because of local depositional contamination along the lake margins, thereby reducing the reserve estimates of that particular area.

A series of Pleistocene playa lakes rich in evaporate minerals found in California comprise the second largest reserves of sodium carbonate in the United States. Subsurface sodium carbonate-bearing brines and crystalline material comprise the resource at Searles Lake, which is a nearly dry playa 15 kilometers (9 miles) long by 11 kilometers (7 miles) wide with an area of about 104 square kilometers (40 square miles). Surface sodium-bearing crystalline minerals predominate at Owens Lake, which was first mined in 1885 by the Inyo Development Co. Both deposits have combined reserves of about 817 million tons (900 million short tons).

Two potential sources of soda ash—nahcolite (natural sodium bicarbonate) and dawsonite (sodium-aluminum-carbonate)—are associated with oil shale in the Piceance Creek basin in northwest Colorado. Identified resources of 29 billion tons (32 billion short tons) of nahcolite and 17 billion tons (19 billion short tons) of dawsonite, equivalent to 18 billion tons and 6 billion tons (20 billion short tons and 7 billion short tons), respectively, of sodium carbonate resources, would be available as a byproduct of oil shale processing or as single mineral extraction. These deposits were formed in middle Eocene time with the nahcolite occurring as aggregates (62%), disseminated crystals (24%), and impure beds (14%).

The only other commercial natural soda ash deposit in the Western Hemisphere, excluding those in the United States, occur at Lake Texcoco, near Mexico City, Mexico. Two caliche layers at a depth of 46 meters (150 feet) act as a filter and reservoir for the sodium carbonate-rich brine resource. With an average concentration of about 7% sodium carbonate, the resource contains about 180 million tons (200 million short tons) of available soda ash.

The Rift Valley of eastern Africa has several alkaline lakes resembling those of California. Only Lake Magadi in Kenya is presently in production. The soda ash reserves of these lakes are renewed annually from natural active volcanic sources. Other African countries that may become future suppliers of soda ash are Chad, Ethiopia, Niger, the Republic of South Africa, Tanzania, and Uganda. Botswana developed its Sua Pan salt and soda ash deposit in 1991. Elsewhere, deposits of natural soda ash occur in Bolivia, Brazil, Canada, India, Pakistan, the former U.S.S.R., and Venezuela. Plans are under way to develop deposits in China at Xilin Gol and in the Wulan Buh desert area. A trona deposit in Turkey near Beypazari also has been under consideration for development with several companies conducting exploration, drilling, and market feasibility studies.

Technology

Soda ash from Wyoming trona is mined, crushed, dried, dissolved, filtered, recrystallized, and redried. In California, soda ash from sodium carbonate-bearing brines is solution mined, carbonated, filtered, dried, decomposed, bleached, and recrystallized to dense soda ash.

Exploration.—Because of the scarcity of economic soda ash deposits in the world, many nations continue to search for new prospects. Smaller and less well-known deposits often are reevaluated by different groups at different times and with usually the same results. As new techniques of exploring are developed and used, such as Landsat satellite remote sensing imagery and side-scanning radar, new deposits may be discovered.

In the United States, exploring for soda ash continues. An area near the junction of the Black's Fork and Green River in southwest Wyoming has potential. Some of the ground water near Farson, WY, contains dissolved trona and organic matter creating a "black trona water." In Oregon, a few companies have expressed interest in evaluating the sodium carbonate deposits at Summer Lake and Abert Lake, which are near several pulp and paper manufacturers. These manufacturers have traditionally obtained their soda ash and caustic soda pulp-bleaching chemicals from Wyoming and Washington producers, respectively. As soda ash and caustic soda prices increase and overland transportation costs rise, these Oregon deposits may have commercial significance because their locations are nearer to the pulp markets.

Mining.—Commercial mining of Wyoming trona began in 1948, with the first mining on Federal land commencing in 1950. Between 1950 and 1993, more than 253 million tons (279 million short tons) of trona (equal to about 141 million tons or 155 million short tons of soda ash) has been mined. Only about 0.8% of the 36 billion tons (40 billion short tons) of halite-free trona reserve base has been used since mining began.

Underground mining of Wyoming trona is similar to coal mining, except that trona is a harder mineral than coal. The five present Wyoming soda ash producers use room-and-pillar, longwall, shortwall, and solution mining techniques individually or in combination. The room-and-pillar method has an ore extraction efficiency rate of about 45% (55% of ore remains as pillars for structural integrity), the longwall and shortwall methods each have efficiency rates of about 75%, and solution mining has an efficiency rate of about 30%. These rates are important when calculating the amount of reserves that are minable. Based on the types of mining techniques, the author used a 60% average extraction efficiency rate to calculate reserves (remaining 40% stays in-place as pillars for structural integrity and unavailable for present extraction). The ore is undercut, drilled, blasted, mucked, crushed, and transported to the surface by well-established methods and various state-of-the-art mining equipment. The conventional blasting method using prilled ammonium nitrate and fuel oil (ANFO) is a standard and reliable method. Continuous mining uses vehicles equipped with a rotating cylindrical cutter. Continuous miners are used by Tg Soda Ash, Inc., in its shortwall technique. The longwall technique was used by General Chemical (Soda Ash) Partners and is now used by FMC Wyoming Corp. Adopted from coal mining use, the longwall method uses a special track-mounted shearer that moves in front of a hydraulic-operated roof support system.

FMC has pioneered the use of solution mining to dissolve and recover deeply buried trona. Using an array of injection and recovery wells, a solvent (dilute sodium hydroxide) is introduced under pressure to dissolve the underlying trona. This technique has had moderate success since its first commercial debut in 1985. Beginning in 1990, FMC used the majority of the output from its solution mining for the manufacture of caustic soda, from which some sodium cyanide was produced.

To reduce mining costs and maintain their competitiveness in the world, many Wyoming soda ash companies implemented continuous belt and mobile track conveyor systems to transport trona underground more efficiently. This new haulage system has replaced ore-carrying shuttle cars, reduced the mine work force, and increased the quantity of ore mined per shift. Companies also have been considering eliminating conventional mining but retaining other mining methods sometime in the foreseeable future to further reduce labor, safety, and other operating costs.

Subterranean brines between 15 and 107 meters (50 and 350 feet) below the surface at Searles Lake in California are extracted using an array of injection and recovery wells drilled down to specific depths where mineral concentrations favor maximum extraction. The Argus plant of North American Chemical Co. uses sodium carbonate-rich brines found in the Mixed Layer zone 67 meters to 95 meters (220 feet to 310 feet) below the surface. Solar concentration ponds are used to aerate and concentrate the brine to improve processing efficiency.

Processing.—Crushed trona is calcined in a rotary kiln at 163° to 204° C (325° to 400° F) to dissociate the ore by the monohydrate process, which produces only dense soda ash with carbon dioxide and water as byproducts. The calcined material is combined with water to dissolve the soda ash and to allow separating and discarding of the insoluble material such as shale and shortite by settling and/or filtration. The waste material is piped in a slurry to containment basins, also known as tailing ponds. The resulting clear liquid is concentrated as necessary by triple-effect evaporators or mechanical vapor recompression crystallizers, and the dissolved soda ash precipitates as crystals of sodium carbonate monohydrate, $Na_2CO_3 \cdot H_2O$. The crystallization temperature is about 100° C (212° F), which is below the transition temperature of monohydrate to anhydrous soda ash. Other dissolved impurities, such as sodium chloride or sodium sulfate, remain in solution. The crystals and liquor are separated by centrifugation. The sodium carbonate monohydrate crystals are calcined a second time at 300° F to remove water of crystallization. The resultant finished product is cooled, screened, and shipped by rail or truck in bags or bulk.

An alternate method of soda ash production from trona is the sesquicarbonate process. Crushed trona is first dissolved and filtered to remove insoluble impurities. The liquor is evaporated in vacuum crystallizers, and the sodium sesquicarbonate precipitate is cooled to 38° C (100° F) and centrifuged to produce a pure product, which has uses as such. The sesquicarbonate can be further calcined at 204° C (400° F) to produce anhydrous soda ash of light to intermediate density.

The complex brines of the lower level of Searles Lake are first treated with carbon dioxide gas obtained from the gases emitted from the calciners and from the monoethanolamine (MEA) towers that process the powerplant flue gases into purified CO_2. The carbon dioxide gas reacts with the brine 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 to light soda ash. The decarbonated brine is cooled to recover borax and Glauber's salt. The light soda ash is fed to rotary bleaching units that operate at 427° C to eliminate any residual organics. The product is concentrated and conveyed to sodium monohydrate crystallizers operating at 88° C to produce larger sized crystals. The material is screened, dewatered, washed, and dried and dehydrated in steam tube dryers at 260° C. The final product is 99.7% sodium carbonate.

At Owens Lake in California, crude soda ash has been mined and processed by Lake Minerals Corp. by simply digging perimeter channels that allow the interstitial fluids to drain. The surface was tilled to promote evaporation to reduce moisture content, followed by harvesting with front-end loaders.

At Lake Magadi, Kenya, crude trona is dredged from surface crusts, crushed, washed, and calcined to convert the sodium sesquicarbonate to soda ash. At Lake Texcoco in Mexico, underground brines were recovered and sent to a surface spiral concentrator to promote the solar concentration of the sodium carbonate in solution. On the Kola Peninsula in Russia, soda ash is recovered from processing nepheline-bearing rocks. Nepheline, a sodium-potassium-aluminum silicate, is calcined in rotary kilns to yield alumina, potash, and soda ash. The alumina content of the rocks is about one-half that of bauxite but the mining and processing produces byproduct soda ash. The Petukhi and Tanatar (Mikhaylovskiy) natural soda ash lakes in Altay Kray of West Siberia provide some source of natural product.

Synthetic soda ash using the Solvay process uses salt and limestone as raw materials. A purified sodium chloride brine is saturated with ammonia and carbon dioxide gas to produce ammonium bicarbonate, which reacts with the salt to form sodium bicarbonate and ammonium chloride. The sodium bicarbonate is calcined at 177° to 218° C (350° to 425° F) to light soda ash, and the gases produced are recycled back to the liquid phase. The liquid containing ammonium chloride is reacted with milk of lime to recover the ammonia and to produce byproduct calcium chloride. Limestone and coke are required to make the milk of lime. Dense soda ash is produced by hydrating light ash to produce larger sodium carbonate monohydrate crystals. The crystals are dehydrated in dryers to change the bulk density. To produce 1.0 ton of synthetic soda ash requires about 2.8 tons of steam, 1.7 tons of salt, 1.4 tons of limestone, 0.6 ton of coal for the boilers, and about 0.2 ton of coal for the dryers. Disposition of effluent streams containing high concentrations of calcium chloride and sodium chloride is a major problem for all Solvay soda ash plants. The Solvay process discharges about 1.7 tons of waste products that include sodium chloride and calcium chloride.

Other chemical processes can produce synthetic soda ash. In Japan, an ammonium chloride coproduction process, a variation of the Solvay process, is used to convert 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 also was developed in Japan and uses less energy than the traditional Solvay process. An electrolysis-free process to produce vinyl chloride monomer with coproduct soda ash was developed in the Netherlands but has not been in commercial operation. The method yields soda ash instead of caustic soda and uses steam and carbon dioxide instead of electricity. The energy consumption is reported to be one-half that of the Solvay process.

Recycling.—There is no recycling of soda ash by producers; however, many glass container manufacturers are using cullet glass, thereby reducing soda ash consumption.

Byproducts and Coproducts

Borax, potassium chloride, sodium chloride, and sodium sulfate are produced as coproducts with soda ash by North American Chemical in California. In Wyoming, only value-added products, such as sodium bicarbonate, sodium hydroxide (caustic soda), sodium sesquicarbonate, sodium sulfite, and sodium tripolyphosphate, are produced from trona ore. Soda ash-bearing purge liquors and waste streams, normally considered waste byproducts, have been sold to powerplants for flue gas desulfurization because of their sodium carbonate content.

Substitutes

Sodium hydroxide can be substituted for soda ash in some applications, but usually only at a higher cost and when available. About 1.3 tons of soda ash must be used to have the same chemical effect as 1.0 ton of caustic soda. Soda ash is usually shipped in dry, bulk form whereas caustic soda is transported as a liquid in various-sized closed containers.

An alternate source of soda ash is nahcolite, natural-occurring sodium bicarbonate found in a vast deposit in Colorado. The nahcolite could be converted to soda ash by calcination.

Economic Factors

Prices.—The list prices of natural and synthetic soda ash historically were identical until the mid-1970's when higher energy costs and costs to implement the controls imposed by antipollution legislation caused the synthetic soda ash price to increase compared to that of the natural material. New natural soda ash producers came on-stream in 1976 and 1982 and contributed to slight changes in price-value trends. Changes in the domestic demand pattern also affected average annual values, especially after 1980, when domestic demand declined.

The list prices quoted in trade journals or by producers differ from the annual average values reported to and by the U.S. Bureau of Mines. The values are the combined total revenue of California and Wyoming natural bulk, dense soda ash sold on an f.o.b. plant basis at list-prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. This value may or may not correspond to the posted list prices.

Tariffs.—The United States imposes a 1.2% ad valorem tariff on imports of soda ash from countries having most-favored-nation (MFN) status. There is a 8.5% ad valorem tariff on imports from non-MFN sources.

Many nations levy import tariffs or antidumping duties of varying percentages on U.S. soda ash. In Western Europe, an antidumping duty of 67.5 European Currency Units (about $67.13 per ton) had been imposed on U.S. soda ash sold on the continent; however, the duty was rescinded in late 1990. Import tariffs in some other countries in 1993 were as follows: India, 112.75%; Philippines, 25%; Australia, 12.50%; Argentina, 10.50%; Brazil, 10%; Mexico, 10%; Taiwan, 10%; Thailand, 10%; Colombia, 10%; Republic of South Korea, 8%; Indonesia, 5%; Japan, 3.9%; and Malaysia, 2%. Some of these duties will decline over time.

Although the United States sought to obtain as its highest priority in the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) negotiations a zero-for-zero tariff elimination, the tariff proposal was not accepted. A compromise was to be introduced in early 1994 that would harmonize several chemical tariffs to 5.5% over various periods of time depending on the present rate of duty in a particular GATT country. This was known as the Chemical Tariff Harmonization Agreement (CTHA). Under this agreement, the 10% duty on imports into the European Union [EU—formerly the European Community (EC) as of November 1, 1993] would be reduced to 5.5% by July 1999. The planned rate of reduction is: July 1995 to 9.34%; July 1996 to 8.38%; July 1997 to 7.42%; July 1998 to 6.46%; and July

1999 to 5.5%.

Taxes.—The total effective tax rate on the Wyoming trona industry is about 12.64% and comes from two major taxes. The trona severance tax of 5.5% is a State excise tax on minerals as they are removed from the ground and are applied as a percentage of assessed valuation. The collected taxes are disbursed to the Permanent Wyoming Mineral Trust Fund (2.0%), the General Fund (2.0%), and the Capital Facilities Revenue Account (1.5%). The property, or ad valorem, tax is about 7.14% of the assessed value of trona produced from the mines. The ad valorem taxes on trona are higher than any other Wyoming minerals, including oil, gas, and coal. Other ad valorem taxes are placed on the assessed value of real property (buildings and equipment) and State sales and use taxes on equipment and facilities.

Royalties.—Soda ash mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides royalty payments to the U.S. Government. The Federal royalty is 5% of the quantity or gross value of the output of the product at the point of shipment to market. Each Federal lease also has other costs, such as bonds, acreage rental fees, sodium prospecting permit application fees, and permit bonds.

In Wyoming, the soda ash deposit within the KSLA is under the jurisdiction of the U.S. Government [administered by the Bureau of Land Management (BLM)], the State, and the Union Pacific Railroad, which was given alternate 0.4-hectare (1-square-mile) sections north and south of the railway it constructed in the 1860's. Of the almost 370,301 hectares (915,000 total acres) of sodium mineral estate, the Federal ownership is 55.7%, Union Pacific, 38.1%; and the State, 6.2%. Sixteen lessees hold 53 active and inactive Federal leases having a total of 306,669 hectares (75,783 acres). To prevent a possible land monopoly, no lessee may hold more than 6,216 hectares (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.

An effort was made in December 1992 to raise the Federal royalty rate from 5% to 8% on all new Wyoming sodium leases and any to be renewed. The proposed action was opposed by all five Wyoming soda ash producers and the issue continued into early 1993 when the BLM evaluated the comments raised by the industry before implementing the recommendation. After further study, the BLM, in August, recommended that the royalty rate should be increased to 8% and the proposal was forwarded higher within the U.S. Department of the Interior for final endorsement; however, no decision was made by yearend.[2]

In California, the Federal Government maintains 33 sodium mineral leases having 10,846 hectares (26,799 acres). The major lessee is North American Chemical Co., which produces soda ash, sodium sulfate, and borax on its sodium leases on Searles Lake. Salt also is produced on-site by Pacific Salt Co.

Depletion Provisions.—The mineral depletion allowance granted to the mining industry through legislation passed by the U.S. Government has been an important inducement for companies willing to accept the risk and high cost of mining development. The concept of depletion allowances for minerals is similar to the depreciation of other assets. Although cost depletion and percentage depletion are two methods used to compute depletion deductions, most companies prefer to use the latter. About 100 mineral categories are entitled to percentage depletion. The rates range between 5% and 22% of the gross income from the mineral property, depending on the mineral and location (foreign or domestic), and are subject to a limitation of 50% of the net income from the property. The significance of percentage depletion is that the deduction is based on the quantity of the first marketable product (soda ash and not trona) and not necessarily on the amount invested. The mineral depletion allowance for soda ash is 14% for U.S. companies mining from domestic or foreign sources.

Operating Factors

Operating factors are different for mining companies than for manufacturing facilities engaged in producing natural soda ash and synthetic soda ash, respectively. The shift in U.S. soda ash production from synthetic to natural has been caused by higher costs attributed to the greater energy and labor requirements of the Solvay process and to environmental regulations. Within the natural soda ash industry, the operating factors vary for producing the commodity from brines and from trona ore.

Environmental Requirements.—U.S. natural soda ash facilities do not have difficult problems disposing of effluents. Residual insoluble material is piped to surface tailing ponds and allowed to settle. Some soda ash in solution that is not economically recoverable from processing is discharged and is converted to sodium decahydrate in the ponds and precipitates on the bottom of ponds to become an additional source of soda ash if needed. For example, FMC has been dredging some of its sodium decahydrate that has been accumulating since 1950. Some pond water is recirculated into the mines and used as drilling and cutting coolant. Because of changes in environmental legislation in Wyoming, Solvay Minerals Inc. has begun discharging its waste material into abandoned sections of its underground mine, thereby using less surface area on the surface for tailing ponds. The expense of underground discharge is partially offset with the reduction in costs of constructing and maintaining surface tailing ponds.

The alkaline surface ponds, with a pH up to 10.5, have posed some problems for migratory fowl that land on the ponds. The alkaline solutions strip the insulative natural oils from the feathers, thereby increasing the vulnerability of the birds to death from hypothermia. Also, birds have drowned because of the weight of sodium decahydrate that crystallizes on them when the temperature falls below 4° C (40° F). All trona producers have established a rehabilitation program to recover and release contaminated birds and to minimize the mortality and morbidity rate.

Land surrounding trona operations in Wyoming is relatively undeveloped, and the influx of large numbers of workers has caused great strain on the local facilities for housing, schools, shopping, and entertainment. Soda ash companies have provided financial assistance to aid local government in handling any overloads caused by the migration of their employees and families into the community. The companies have given financial aid to employees purchasing homes in the surrounding communities and other fringe benefits such as low-cost transportation to and from work.

Toxicity.—Although soda ash is not considered a highly toxic substance, contact with the eyes may be injurious and prolonged contact with the skin may cause irritation, especially to those who have allergic reactions to alkaline materials. It also has been found to be corrosive to the stomach lining if ingested. It has an acute oral lethal dose (LD50) of 2.8 grams per kilogram (when tested on a rat) and a primary skin irritation index (PSII) of 2.54 (when tested on a rabbit). Simultaneous exposure to soda ash and lime dusts should be minimized because in the presence of moisture, as from perspiration, the two materials combine to form caustic soda, which is very harmful. Soda ash is not flammable, and the dust is not explosive.

Employment.—According to a survey conducted by the U.S. Bureau of Mines, the Wyoming soda ash industry employed 1,191 people in the 5 trona mines and 1,540 people in the soda ash refineries in 1993. The total quantity of trona mined by these workers was 14,491,288 tons in 1993. Of the five Wyoming companies, only FMC and General Chemical are unionized. The workers are represented by United Steelworkers Union Local 15320.

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. Excluding energy costs to transport the material to market, this is one of the major reasons why U.S. natural soda ash has maintained its competitiveness in the world market and why several synthetic soda ash producers have expressed interest in obtaining a partnership or ownership in the U.S. soda ash industry.

An early U.S. Bureau of Mines energy study using 1973 data indicated that 15.8 million British thermal units (Btu's) was required to produce 1 ton of synthetic soda ash, whereas the energy requirement to produce the same quantity from trona was 7.2 million Btu. The domestic soda ash industry has reduced its energy requirements significantly since 1973 by replacing gas-fired dryers with steam-tube units and installing mechanical vapor recompression units to replace triple-effect evaporators. The industry has also converted to coal exclusively or combined with other fuel sources. Plants operated by Tg and Solvay Minerals and the Argus plant operated by North American Chemical Co. use coal only. As a result of these energy-saving measures, the Wyoming soda ash industry lowered its energy requirement to a range of 4.5 to 6 million Btu, depending on the individual producer. An estimated one-half of the energy consumed in natural soda ash refining using triple-effect evaporators is for evaporating, one-third is for calcining, and the remainder, for drying.

These energy requirements exclude the amount of energy needed to ship soda ash to foreign markets. Although it has been estimated that it would take about 2.9 million Btu of additional energy to transport soda ash by rail and by ship to Western Europe, nevertheless natural soda ash production requires less energy than the Solvay process or any other synthetic technique.

Transportation.—The western geographic locations of the domestic natural soda ash industry often pose problems because of the great shipping distance to most foreign customers. Even within the United States, the majority of domestic consumption is in the Midwest and east of the Mississippi River. Overland and ocean transportation rates become important factors in the delivered price of soda ash and must be considered seriously in negotiations with foreign consumers who often have alternate supply sources. Bulk freight rates usually can be reduced by shipping in larger volumes, such as in 7,500-ton unit trains.

The railroad is the dominant mode of transportation for the shipment of soda ash. In Wyoming, the Union Pacific Railroad provides the main service to the industry. All bulk soda ash that is railed is carried in covered hopper cars, each handling about 98 tons. Although the railroad companies make their cars available, most soda ash companies have their own sizable fleet.

Beginning in 1985, soda ash was shipped in large quantities by truck. Bonneville Transloaders, Inc. trucked soda ash from Green River to the Burlington Northern Railroad's line at Shoshoni, WY. Of the almost 8.4 million tons (9.2 million short tons) of soda ash produced in Wyoming, Bonneville trucks about 770,000 tons (850,000 short tons) out of Green River. Other trucking companies have started similar operations with the Southern Pacific (shipping more than 227,000 tons or 250,000 short tons per year) and Denver Rio Grande Railroads to compete with Union Pacific.

The railroad companies 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 1993, most of which was shipped to South America. The Columbia-Snake customs district in the Pacific Northwest has a bulk loading terminal that transported the most soda ash in 1993, 70% of the U.S. total exports. Asia, Europe, and South America were the three largest regions that received soda ash through this customs district.

ANNUAL REVIEW

Issues

There has always been competition between natural soda ash and synthetic soda ash production beginning in the 18th century with soda ash extracted from the burnt remains of seaweed and the manufactured product obtained from the Leblanc process. For the next 200 years, natural soda ash mined from mineral deposits has competed with that derived by newer chemical processes, such as the Solvay process. This competition became very evident in the early 1980's when the European industry sought to limit imports from the United States by successfully appealing to the then EC Commission [name changed to European Union (EU) effective November 1, 1993] for an antidumping investigation. This ultimately resulted in the imposition of an antidumping duty that remained in place until late 1990 when the Commission rescinded the duty after it conducted its own investigation of the European producers that showed they effectively restricted trade opportunities with U.S. producers.

Many foreign synthetic soda ash producers now have become advocates of having a presence in the Green River natural soda ash community. With the European producers' acquisitions or partnerships of some of the U.S. facilities (Societe Nationale Elf Aquitaine of France owning Tg Soda Ash, Rhône Poulenc of France owning 51% of Rhône-Poulenc Basic Chemical Co., and Solvay S.A. of Belgium owning 80% of Solvay Minerals Inc.), the international competitive situation has begun to change. Approximately 38% of the Wyoming soda ash production capacity was European-owned in 1993 (Tg Soda Ash with 1.3 million short tons, Rhône-Poulenc with 1.17 million short tons, and Solvay with 1.6 million short tons). Highlighting this membership is Solvay S.A., the world's foremost leader in soda ash production and experience. With Solvay's announcement to close facilities in Belgium and Germany, other European producers followed with similar statements. Chemische Fabrik Kalk and Matthes und Weber closed their plants in Germany. Ironically, the Matthes and Weber plant was sold to the U.S. company North American Chemical Co. Indications of further closings in Europe continued at yearend. In addition, Solvay and Rhône-Poulenc have been negotiating for taking majority ownership of the two plants in Poland. Lastly, the French Government included Rhône-Poulenc and Elf Aquitaine in its list of 21 state-owned companies that it intends to sell in a privatization effort. The global restructuring of the world soda ash industry of the 21st century has begun.

In the first half of 1993, the major domestic issue was the proposed increase in the Federal royalty rate on Wyoming soda ash. The BLM announced that it intended to raise the rate from 5% to 8% on all new leases and those up for renewal. The increase was proposed because there has not been any change in the Federal royalty rate in more than 30 years; the increase would bring the Federal rate up to that of the Union Pacific Railroad, which is the other major land owner in the area; and the increase would generate additional Federal and State revenue. All five Wyoming soda ash producers opposed the proposal and submitted their comments to the BLM for review. The producers cited declining demand in the United States and in certain export markets, especially in Western Europe, as the major reason for opposing any increase at this time and felt a 3% increase in the rate was unjustified. The BLM conducted a thorough study of the issue and by August had recommended to follow through with the royalty rate increase.[3] The final decision was to be made by higher authority within the U.S. Department of the Interior; however, no decision had been made by yearend.

The important issue of the last half of 1993 pertained to the formal antidumping investigation by the European Commission. The complaint was submitted in June through the European Chemical Industry Council by five of the six European synthetic soda ash producers. The European producers claimed that they lost market share by price undercutting by U.S. exporters. Allegedly, the U.S. share of the EU market has risen from 1% in 1990 to 11.3% in 1992. Rumors of an impending investigation began earlier in the year caused a decrease in soda ash shipments from the United States. By yearend, the U.S. export market to Europe had declined by about 400,000 tons compared with 1992. A final decision by the Commission was expected by April 1994.[4]

Production

U.S. production of natural soda ash from California and Wyoming decreased 4% to 8,959,059 tons. The U.S. soda ash industry operated at 81% of total nameplate capacity in 1993. Most of the decrease in production was because of reduced export sales to Europe. A total of 96,336 tons of soda ash equivalent from soda liquors and mine waters was included in the total and used primarily for neutralizing powerplant process water. The liquors represent a growing market for soda ash producers and provide additional revenue. In addition, 134,863 tons of soda ash equivalent was used to manufacture chemical caustic soda by FMC, Solvay Minerals, and Tg Soda Ash. There was 14,491,288 tons of trona mined in Wyoming in 1993.

FMC Wyoming Corp.'s expansion of 545,000 tons (600,000 short tons) that it announced in 1992 was put on hold for 1 year pending final evaluation of other projects.[5] Owens Lake Soda Ash Co., the joint venture between Vulcan Materials Co. and Lake Minerals Corp., a subsidiary of Cominco American Inc., continued with its efforts to design and construct a 545,000-ton (600,000-short-ton) soda ash refinery at Owens Lake, CA. The company completed a draft environmental impact report on its project and applied for its permit applications with State and Federal agencies.[6] The Wold Trona Co. was formed in June 1993 with plans to construct a beneficiated trona facility with an annual capacity of 1.13 million tons (1.25 million short tons). An underground mine would provide the surface refinery with raw material that would be beneficiated using a dry process, resulting in a final product containing 96% to 98% sodium carbonate suitable for certain customers that do not require high-purity soda ash. The material also could be converted to chemical caustic soda to compete with chemical caustic soda produced by three of the Wyoming soda ash firms and electrolytic caustic soda manufactured as a coproduct from chlorine production. Construction of the project was planned to begin as early as mid-1995 with production scheduled for late 1997.[7]

About 480 mine workers of the United Steelworkers Union Local 15320 of General Chemical Corp.'s Green River mine went on strike on August 2 because of health care benefits. There also were disagreements with the company's retirement plan. The plant continued to operate using 160 salaried employees from some of General's other chemical plants and headquarters. The strike ended on November 22 with the ratification of a new 3-year contract. The effect of the strike had virtually no impact on the production of soda ash during this time period.[8]

Consumption and Uses

U.S. apparent consumption and reported consumption in 1993 remained virtually the same as that in 1992. The discrepancy between the two forms of consumption was attributed to disagreement between the sources of export data used to derive consumption statistics. The two sources were the Bureau of the Census, which reports exports upon departure from the U.S. port, and the soda ash producers, who consider a shipment as exported when their export association, the American Natural Soda Ash Corp. (ANSAC), takes charge at California or Wyoming plant sites. Transit times between the plant and port, which can take about 2 to 3 weeks before the cargo is actually exported, and carryover export inventories contribute to the discrepancy between reported and apparent consumption as well.

The recovery of the domestic economy in late 1993 was indicated by increased soda ash sales to the flat glass sector for the domestic construction and automobile manufacturing industries. The industrial building construction industry consumed about 57% of all flat glass made, whereas the automotive glass sector used 25%. Based on reported industry sales, the manufacture of flat glass products increased 3.8% in 1993 compared with 1992 and rose 10.8% from 1991, according to the Bureau of the Census. Glass container shipments increased 2.7% in 1993 from that of the previous year and rose 4.2% from 1991. Glass container production, however, rose only 1.8% in 1993 from that of 1992. Figure 1 shows the domestic production of glass containers and flat glass from 1989 through 1993. The economic recovery of the domestic construction and automotive industries is shown with the rise in the flat glass sector beginning in the third quarter of 1993. *(See figure 1.)*

Glass manufacture represented about 49% of domestic soda ash consumption, with the container sector comprising 28%; flat, 14%; fiber, 4%; and specialty, 3%. The other end uses include chemicals (primarily sodium bicarbonate, sodium chromates, sodium phosphates, and sodium silicates), 23%; soap and detergents, 13%; distributors, 5%; flue gas desulfurization and miscellaneous, 3%; and pulp and paper and water treatment, 2% each. *(See table 4.)*

Detergents are the third largest use of soda ash. Soda ash is used as a builder to emulsify oil stains, reduce the redeposition of dirt during washing and rinsing, provide alkalinity for cleaning, and soften laundry water. In addition, soda ash is a component of sodium tripolyphosphate (STPP), another major builder in detergent formulations, but soda ash consumption has been decreasing because phosphatic detergents can contribute to the environmental problems of eutrophication. Many regions of the Nation have adopted phosphate limitations or bans. These areas represent about 40% of the U.S. population. In response to the environmental issue, detergent manufacturers began reformulating their detergents to make compact and superconcentrated products. The reformulations require sodium silicates and synthetic zeolites, which are made from soda ash. Liquid detergents, which do not contain any soda ash, compete with powdered detergents and command 40% of the household laundry detergent market, up from only 15% in 1978.

Stocks

Yearend stocks of dense soda ash in domestic plant silos, warehouses, terminals, and on teamtracks amounted to 274,302 tons. Producers indicate that a potential supply problem could exist when inventories fall below 180,000 tons. Most consumers of soda ash do not have storage facilities to accommodate large quantities of soda ash and must rely on suppliers to provide the material on a timely basis. The majority of the U.S. soda ash producers that have been exporting to Europe have several foreign warehouses for product storage. These warehouses serve the needs of most foreign soda ash consumers that purchase U.S. soda ash.

Markets and Prices

About two-thirds of U.S. soda ash production is consumed domestically, with the remainder dedicated for export sales. In the domestic market, the large volume buyers of soda ash are primarily the major glass container manufacturers, whose purchases are seasonal (more beverage containers made in second and third quarters for summertime beverage consumption). Soda ash sales to the flat glass sector are usually dependent on the state of the economy because the largest use of flat glass is in automobile manufacture and residential housing and commercial building construction. These two major industrial sectors are especially sensitive to changing economic conditions. If construction starts and automobile sales are up, soda ash sales will proportionally follow.

The average annual value for dense natural soda ash, f.o.b. Green River, WY, and Searles Valley, CA, was $81.95 per ton ($74.34 per short ton), which was an 8% decrease from that of the previous year. The value is not a "price"; it is the value of the combined revenue of California and Wyoming bulk dense soda ash sold on an f.o.b. plant basis at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. The list price for Wyoming bulk, dense soda ash remained at $98 per short ton while the California price for the comparable product held at $123 per short ton. *(See table 5.)*

Foreign Trade

U.S. soda ash exports declined 5% in 1993 to 2.79 million tons. U.S. exports to 50 countries, on a regional basis, were as follows: Asia, 46%; South America, 18%; Europe, 16%; North America, 11%; Oceania, 3%; Africa and the Middle East, 2% each; and Central America and the Caribbean, 1% each. The biggest change was with Europe, which represented 23% of export shipments in 1992. The reason for the decline was primarily because of the antidumping investigation initiated by the European soda ash industry.

The six domestic members of ANSAC renewed their commitment to promoting U.S. export sales by signing a new 10-year agreement. ANSAC has been very successful in expanding the export market and will continue to increase sales to Africa, Asia, and the Middle East.[9] ANSAC negotiated with Saleh & Abdulaziz Abahsain Co., Ltd., to be the exclusive distributor for ANSAC in Saudi Arabia. A warehouse with a storage capacity of 10,000 tons will be located in Dammam, Saudi Arabia, for shipment within the Kingdom or to surrounding nations.

The U.S. soda ash industry was found guilty of dumping in the early 1980's by the EC Commission that resulted in the imposition of an antidumping duty of 67.5 European Currency Units (about $67.13 per ton). An investigation by the Commission in 1991 of the European soda ash producers found that the European industry conspired to restrict trade initiatives with the United States in the early 1980's. The producers were fined $64 million, and the antidumping tariffs on U.S. soda ash were removed in late 1990. Although soda ash export sales to all of Europe in 1992 rose to 689,348 tons; a 1,586% increase from that of 1980, exports in 1993 were 445,196 tons—a 35% decrease from that of the previous year. *(See tables 6, 7, and 8.)*

World Review

Industry Structure.—The largest consumers of soda ash tend to be the developed nations; however, these countries also usually have lower growth rates compared to developing countries that have greater demands for consumer products. 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 46% of nameplate capacity.

Ten countries have the capacity to produce more than 1 million tons annually. They are, in descending order, the United States, China, Russia, Germany, India, Japan, France, Romania, Bulgaria, and Ukraine. Most of these countries have large populations that require consumer products made with soda ash. The lesser developed nations tend to have greater soda ash demand and higher rates of growth as soda ash-consuming industries are developed. *(See table 9.)*

Capacity.—World soda ash production capacity is about 35 million tons divided among 36 countries. Approximately 70% of world capacity is synthetic soda ash and 30% is natural. The United States represents 30% of world capacity and 95% of the total natural capacity.

The largest soda ash company in the world, excluding state-owned facilities, is Solvay S.A. of Belgium. With its acquisition of Tenneco Minerals' natural facility in Wyoming in 1992, it operates 10 plants in 8 countries and has a combined annual capacity of about 6.07 million tons. With the announced closure of two of its plants by yearend 1993, Solvay's total will decrease by 600,000 tons. FMC Wyoming Corp. of the United States is the second largest company, with 2.59 million tons (2.85 million short tons) of capacity.

Albania.—Although there was no written confirmation of the action, the synthetic soda ash plant at Vlora reportedly closed during 1993. The plant had an annual production capacity of about 30,000 tons.

Australia.—Penrice Soda Products announced that it plans to expand capacity by 25% to 500,000 tons by 1996. The goal was to export 40% of total production to various Asian markets that are forecast to grow in the next decade. The project was expected to cost $20 to $30 million.[10]

Belgium.—On May 24, 1993, at 12:00 a.m., Solvay of Belgium issued a press release that formally stated that it would close its synthetic soda ash plant at Couillet during 1993. This announcement is of historical significance because this facility was the first Solvay plant built in the world. It was constructed in 1864 by Ernest Solvay, the founder of the company that bears his name. Competition from Bulgaria, Romania, and the United States was cited as the reason for the closure of this facility and Solvay's other plant in Heilbronn, Germany. The Belgian operation had a production capacity of about 350,000 tons per year. Workers went on strike at the Couillet plant after negotiations regarding the forthcoming layoffs of 185 workers broke off. About 270 employees were affected by the closure. Both facilities accounted for about 10% of Solvay's total capacity.[11]

China.—In a move to become more efficient, 18 soda ash manufacturers merged to form Suda Alkali Industrial Corp. The organization has a combined capacity of 4.46 million tons per year.[12]

Colombia.—Industry sources indicate that its last synthetic soda ash plant closed sometime during 1993. Colombia imported more than 74,000 tons from the United States in 1993, almost double from the 38,000 tons imported in 1992.

France.—Rhône-Poulenc stated that it planned to invest $7.1 million to convert almost all of the light soda ash to dense soda ash at its plant in Nancy. The improvement would provide the company the opportunity to serve the glass and detergent sectors that are growing in France and Germany.[13]

Germany.—Solvay announced the closure of its plant in Heilbronn by yearend that had an annual capacity of 250,000 tons. Problems with raw material sourcing and its relative small size contributed to the closure. The operation employed 270 workers.[14] In addition, Chemische Fabrik Kalk, which was owned by BASF subsidiary Kali und Salz, announced it would close its soda ash plant at Cologne by yearend. The facility had a capacity of 300,000 tons per year. The operation encountered similar problems like those at Heilbronn—small size and dependent on more expensive transported rock salt as feedstock. Increased use of cullet, glass imports, and rising environmental costs also were cited as reasons for the closure.[15] The company arranged to continue to supply its customers soda ash obtained from a long-term contract with Rhône-Poulenc, which would provide the material from either of its plants in Nancy, France, or Green River, WY. Rhône-Poulenc's natural soda ash from the United States would be available from the terminal at Zeebrugge in Belgium.[16]

In December, the soda ash plant operated by Matthes und Weber at Duisburg was sold to the Harris Chemical Group that owns North American Chemical Co. at Searles Lake in California. The facility has an annual soda ash capacity of 270,000 tons. The operation was to be closed by Matthes und Weber until the acquisition occurred. The Harris Chemical Group plans to modernize and consider expanding the product line. Most of the output is consumed by Matthes' parent company, Henkel, for detergent manufacture. About two-thirds of synthetic soda ash production is light ash with the remainder being dense soda ash. Chemische Fabrik Kalk's plant that closed is about 55 kilometers from Duisburg; therefore, there may be opportunities to sell into that surrounding market.[17]

India.—Nirma Chemical Works Pvt. Ltd., an Indian detergent manufacturer, was considering constructing a synthetic soda ash plant at Una in Gujarat. The project would have a capacity of 300,000 tons annually and would supply feedstock for the detergent plant. Humphreys and Glasgow Consultants in Bombay were selected as contractors in the proposed $210 million project that was planned to be on-stream by 1997.[18]

Iran.—Plans were announced to expand the dense soda ash facility at Shiraz. Alexanderwerk of Germany will be the primary contractor. The plant has a present production capacity of 60,000 tons per year.[19]

Mexico.—Production of natural soda ash from Lake Texcoco outside Mexico City ceased in August, according to reliable industry sources; however, the event was unrecorded by the trade publications. Production from this deposit, which was the only other commercial natural soda ash operation outside of the United States that operated in the Western Hemisphere, was estimated at about 160,000 tons annually.

United Kingdom.—Brunner Mond, which operates two synthetic soda ash plants at Lostock and Winnington, announced it would invest $7.5 million to construct a new dense soda ash plant at its Lostock facility. The expansion was to come on-stream by January 1995. More than $4.5 million was spent to install new process control equipment at Mond's Winnington plant.[20]

OUTLOOK

The antidumping investigation that began in mid-1993 resulted in reduced exports to Europe, causing an oversupply situation in the U.S. soda ash industry. In terms of operating efficiency, the domestic soda ash industry operated at 81% of nameplate capacity. A flat domestic market and reduced export sales contributed to the decline in the 1993 average value of soda ash. If the European Commission rules in favor of the U.S. producers (of which 38% of the Wyoming producers are European-based companies or European soda ash producers), it is anticipated that U.S. exports will rebound in the near future and exceed that of the alltime record of 2.96 million tons that was set in 1992. The U.S. industry is optimistic that both the domestic and foreign economies are recovering, signaling an improvement in general soda ash sales.

Exports

Despite the setback in exports to the European market, the outlook for U.S. soda ash exports remains optimistic. The two largest exporting organizations in the world are Solvay and ANSAC, which includes Solvay as a member. From its strategic location in Wyoming, Solvay is poised to penetrate markets in Asia, Central America, and South America that would be economically inaccessible from its European bases. Although ANSAC is prohibited from exporting to the European Union nations, the six individual U.S. soda ash producers will continue to strive to increase exports to that region pending a successful outcome to the antidumping investigation. Market conditions in Europe remained stagnant at yearend; however, economic recovery should begin in early 1994. The strength of the U.S. dollar relative to European currency and the decrease in the European soda ash sales price will probably lessen U.S. soda ash export sales for the short term. Because of the higher cost structure of manufacturing synthetic soda ash, it is doubtful that the European sales price can remain low for very long before it has an adverse economic affect on the producers. The gradual reduction in the import duties in the EU promulgated by the GATT negotiations will assist U.S. soda ash exporters by the end of the century.

Figure 2 shows a comparison of the top 18 countries the United States exported to during 1993. These nations represented 76% of the total export market. It is interesting to note that the bulk of the exports went to nations with some of the lowest import duties, ranging between 2% and 10%. Exports of less than 100,000 tons were to countries with import duties more than 10%. Using economic data from various Federal agencies, figure 3 lists the top 13 countries that imported U.S. soda ash and the respective nations' gross domestic product (GDP). The majority of the countries were emerging economies in Asia and South America. Of a total estimated world GDP of $19.746 trillion (foreign GDP converted to U.S. dollars), these nations represented 26% of the total world GDP. Most of these countries are targeted to expand their industries that produce consumer products such as glass, chemicals, and detergents. These developing nations have a greater demand for soda ash than many of the developed countries, such as the United States and several countries in Europe. Only Japan, with a GDP approaching $2.5 trillion, was the standout nation with a large GDP and a major soda ash importer. With no natural salt resources to supply feedstock to its soda ash refineries, Japan has started to change its position from being an exclusive soda ash producer to being a consumer supplying itself with product shipped from its U.S. partnerships in the Wyoming soda ash industry. It is foreseeable that Japan may choose to close at least one of its five facilities operating in Japan because of rising raw material costs and environmental considerations.

Because soda ash is considered to be a mature chemical commodity that tends to grow parallel population trends, future growth opportunities are favorable in areas with modest population growth rates, such as some of the countries shown in figure 4, which are the same ones previously discussed in terms of exports and GDP. Of these 13 nations, future growth in soda ash consumption appears favorable in Indonesia, Mexico, the Philippines, Thailand, and Venezuela. Many of the Southeast Asian markets are growing as a result of economic and technical outreach initiatives initiated by changes in the social and political institutions in those countries. These areas represent a tremendous export potential in the future for the U.S. soda ash industry. Some of the current import duties in these Asian countires that are in excess of 10% will decline as a result of the GATT treaty.

Export opportunities to the Middle East and South America also are very favorable. In addition, it is likely that some South American production capacity could be reduced as certain countries examine the operating economics of some facilities. Argentina, Brazil, Colombia, and Venezuela are probable areas for future growth in soda ash consumption. *(See figures 2, 3, and 4.)*

Glass

U.S. consumption of soda ash in the glass container sector declined for the sixth consecutive year because of (1) the increasing use of cullet; (2) the national interest in recycling; and (3) the continuing competition with polyethylene terephthalate (PET) plastic containers.

The United States is becoming more concerned about the environment than in previous years. The volume of waste accumulating in municipal landfills is a growing national problem. Glass reportedly accounts for 8.4% of disposable household waste. Glass recycling has been increasing with the average recycling rate approaching 38% nationally. Although the recycling of glass has had an adverse effect on soda ash consumption, industry sources indicate that the impact has leveled and that soda ash consumption should begin to stabilize in the glass container sector. In flat glass usage, the construction and automotive sectors are beginning to recover from the economic downturn that began earlier in the decade. Figure 5 shows the estimated quantity of glass used in U.S.-built automobiles since 1976. More glass was used per vehicle in 1993 than in the past 17 years—approximately 40.14 kilograms of glass per automobile. The quantity of glass as a function of total vehicle weight also has risen since 1976. In 1993, 2.8% of the automobile was glass, based on an average vehicle weight of 1,429 kg (3,149.5 pounds). In 1976, only 2.3% of the vehicle weight was glass, using an average vehicle weight of 1,706 kg (3,760.5 pounds). The increase in flat glass usage is reflected in the rise in soda ash sales, as shown in table 4. It is expected that this sector will remain strong throughout the next 2 years.

Although the outlook for the U.S. soda ash industry is very good, the structure of the industry continues to change as foreign participation increases. The United States will remain an important supply source of inexpensive natural soda ash for international consumption. However, a growing percentage will be shipped by the foreign partners of the U.S. resource—primarily Australia, Belgium, France, and Japan. More shares of the U.S. soda ash industry are available for joint venture at the present time. *(See figure 5.)*

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TABLE 1
SALIENT SODA ASH STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Production[1]	8,995	9,156	9,005	9,379	8,959
Value[1]	$764,146	$836,188	$835,577	$836,690	$734,157
Production, Wyoming trona	14,774	14,665	14,674	14,885	14,491
Exports	2,648	2,392	2,734	2,955	2,798
Value	$365,469	$346,693	$409,088	$433,606	$376,206
Imports for consumption	129	146	134	72	89
Value	$17,396	$20,495	$21,299	$12,772	$17,084
Stocks, Dec. 31: Producers'	221	287	234	371	274
Consumption:					
Apparent	6,516	6,844	6,458	6,359	6,348
Reported	6,469	6,527	6,278	[r]6,323	6,312
World: Production	[r]31,543	[r]32,029	[r]31,312	[r]31,712	[e]31,136

[e]Estimated. [r]Revised.

[1]Natural only, soda liquors and mine water converted to soda ash equivalent are as follows: 1989, 95,027 tons; 1990, 111,894 tons; 1991, 117,289 tons; 1992, 120,608 tons; and 1993, 85,084 tons.

TABLE 2
U.S. PRODUCERS OF SODA ASH IN 1993

(Million short tons, unless otherwise noted)

Company	Plant nameplate capacity	Plant location	Source of sodium carbonate
FMC Wyoming Corp.	2.85	Green River, WY	Underground trona.
General Chemical (Soda Ash) Partners[1]	2.40	do.	Do.
North American Chemical Co.[2]	1.30	Trona, CA	Dry lake brine.
Rhône Poulenc of Wyoming, L.P.[3]	2.30	Green River, WY	Underground trona.
Solvay Minerals Inc.[4]	2.00	do.	Do.
Tg Soda Ash Inc.[5]	1.30	Granger, WY	Do.
Total	12.15		
Total million metric tons	11.02		

[1]A joint venture between General Chemical Corp. (51%), Australian Consolidated Industries International (ACI—25%), and TOSOH Wyoming Inc. of Japan (24%), which purchased part of ACI's share June 1992.

[2]Acquired Dec. 1, 1990, from Kerr-McGee Chemical Corp., with Oriental Chemical Industries of Korea as partner (27%).

[3]Joint venture between Rhône-Poulenc Basic Chemicals Co. of France (51%) and Union Pacific Resources Co. (49%).

[4]Acquired mid-1992 from Tenneco Minerals Co. Operation is a joint venture with Solvay S.A. of Belgium (80%) and Asahi Glass Co. of Japan (20%), which became a partner in Feb. 1990. A 600,000-ton expansion was completed June 1992.

[5]Owned by Texasgulf Inc., subsidiary of Societe Nationale Elf Aquitaine of France (100%).

TABLE 3

SODA ASH SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WORLD PRODUCTION											
United States	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005	9,379	8,959
Rest of world	20,210	21,513	20,514	21,705	22,137	22,568	^{r}22,548	^{r}22,873	^{r}22,307	^{r}22,333	^{e}22,177
Total	27,891	29,234	28,235	29,360	30,203	31,306	^{r}31,543	^{r}32,029	^{r}31,312	^{r}31,712	^{e}31,136
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production capacity	10,124	10,124	10,124	9,580	9,580	9,512	9,580	9,950	9,950	10,710	11,020
Wyoming trona ore production	10,442	10,618	10,726	12,008	12,582	13,713	14,774	14,665	14,674	14,885	14,491
Domestic sources	7,681	7,721	7,721	7,655	8,066	8,738	8,995	9,156	9,005	9,379	8,959
Imports	18	15	51	96	136	121	129	146	134	72	89
Industry stocks, Jan. 1[2]	294	279	292	355	267	235	261	221	287	234	371
Total U.S. supply	7,993	8,015	8,064	8,106	8,469	9,094	9,385	9,523	9,426	9,685	9,419
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	279	292	355	267	235	261	221	287	234	371	274
Exports	1,484	1,495	1,584	1,859	2,017	2,238	2,648	2,392	2,734	2,955	2,799
Industrial demand[3]	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458	6,359	6,348
U.S. DEMAND PATTERN[4]											
Glass (total):	3,130	3,085	3,084	3,152	3,343	3,390	3,294	3,177	2,997	3,082	3,095
Container	2,177	2,087	1,996	1,951	2,107	2,128	1,961	1,909	1,823	1,812	1,790
Flat	522	544	635	680	821	852	907	851	767	837	869
Fiber	209	227	249	272	249	246	241	228	206	214	220
Other	222	227	204	249	166	164	185	189	201	219	216
Chemicals	1,270	1,406	1,361	1,179	1,238	1,445	1,412	1,573	1,510	^{r}1,537	1,476
Soaps and detergents	562	544	544	590	684	718	781	835	796	765	806
Pulp and paper	181	227	318	181	63	111	114	132	147	175	139
Water treatment	209	272	272	227	72	110	92	91	106	104	116
Flue gas desulfurization	NA	272	159	181	183	200	208	207	171	144	183
Distributors	NA	NA	NA	NA	349	373	380	376	403	387	337
Other[5]	878	422	387	470	168	148	188	136	148	129	159
Total U.S. consumption	6,230	6,228	6,125	5,980	6,100	6,495	6,469	6,527	6,278	^{r}6,323	6,312
Undistributed[6]	—	—	—	—	117	100	47	317	180	^{r}36	36
Total U.S. primary demand	6,230	6,228	6,125	5,980	6,217	6,595	6,516	6,844	6,458	6,359	6,348
VALUES[7]											
Average annual value:											
Dollars per short ton	76.95	67.00	67.82	65.29	66.78	66.96	77.07	82.85	84.18	80.93	74.34
Constant 1993 dollars	109.60	91.44	89.23	83.68	82.94	80.04	88.22	90.82	88.83	83.00	74.34
Dollars per metric ton	84.82	73.85	74.76	71.97	73.61	73.81	84.96	91.33	92.79	89.21	81.95
Constant 1993 dollars	120.81	100.79	98.36	92.25	91.42	88.23	97.25	100.12	97.91	91.49	81.95

^{e}Estimated. ^{r}Revised. NA Not available.

[1] Natural and synthetic except where noted.

[2] Natural soda ash only for 1987 and thereafter; natural and synthetic from yearend 1983-86.

[3] Also known as apparent consumption (production plus imports minus exports plus or minus stock changes) and is equal to "Total U.S. primary demand."

[4] Estimated consumption for 1983-86 was based on industry sources; reported consumption 1987 and thereafter were from quantitative and qualitative quarterly surveys of producers' sales. Other end-use categories were incorporated in the survey.

[5] Includes soda ash used in petroleum and metal refining, leather tanning, enamels, etc. Also includes data in categories indicated by "NA."

[6] Because end-use data prior to 1987 were estimated, industrial demand and U.S. primary demand calculations (both based on production, trade, and inventory data) were assumed to be equal to total U.S. consumption. Beginning with 1987, reported consumption data by end-use often disagreed with derived apparent consumption calculations that necessitated, including an "Undistributed" category account for the discrepancies. These discrepancies are because of the fluctuating balance of inventory in transit from plants to domestic or export destinations, and unsold foreign inventories of U.S. producers.

[7] Values are the combined total revenue of California and Wyoming natural, bulk, dense soda ash sold on an f.o.b. plant basis, at list prices, spot prices, discount, long-term contracts, and for export, divided by the quantity of soda ash sold. This value may or not be synonymous with the posted list prices of the commodity. Implicit price deflator for gross domestic product used to derive constant 1993 dollars, 1987=100.

Source: U.S. Bureau of Mines.

TABLE 4

REPORTED CONSUMPTION OF SODA ASH IN THE UNITED STATES, BY END USE

(Metric tons)

SIC code	End use	1989	1990	1991	1992	1993
32	Glass:					
3221	Container	1,961,039	1,908.983	1,822,631	1,811,613	1,789,893
3211	Flat	907,333	850,687	767,381	837,269	869,371
3296	Fiber	240,799	227,770	205.888	213,935	220,390
3229	Other	185,083	189,452	201,059	219,041	215,427
	Total	3,294,254	3,176,892	2,996,959	3,081,858	3,095,081
281	Chemicals	1,412,180	1,572,890	1,509,840	[r]1,536,828	1,475,847
284	Soaps and detergents	780,634	834,690	796,305	764,973	806,234
26	Pulp and paper	113,962	131,973	146,674	174,859	139,461
2899	Water treatment[1]	92,268	91,056	106,196	104,293	116,269
	Flue gas desulfurization	208,296	207,067	170,952	144,226	182,932
	Distributors	380,021	375,803	403,286	386,591	337,403
	Other	187,073	136,323	147,289	129,357	159,233
	Imports[2]	128,790	145,533	134,312	71,663	88,929
	Total domestic reported consumption[3]	6,468,688	6,526,694	6,277,502	[r]6,322,985	6,312,460
	Export[4]	[5]2,644,618	2,588,477	2,797,145	[r]2,864,152	2,838,768
	Total industry sales[6]	[7]9,113,306	9,115,171	[r]9,074,646	9,187,137	9,151,228
	Total production	8,994,717	9,156,036	9,004,790	9,378,883	8,959,059

[r] Revised.

[1] Includes soda ash equivalent from soda liquors, purge liquors, and mine water sold to powerplants for water treatment: 95,027 tons in 1989, 111,894 tons in 1990, 117,289 tons in 1991, 137,433 tons in 1992, and 85,084 tons in 1993.

[2] Data are from the Bureau of the Census and may vary from the quantity reported by the producer and/or importer. Actual imports are proprietary data but have been distributed into appropriate end-use categories and included in "Total domestic reported consumption."

[3] Reported consumption data do not agree with apparent consumption data shown in tables 1 and 3 because of dissimilar sources of export data. The data vary because of different reporting periods, overland transit time between plant and port, and carryover export inventory.

[4] As reported by producers. Includes Canada. Data may not necessarily agree with that reported by the Bureau of Census for the same periods.

[5] Revised from monthly Mineral Industry Surveys data because of 181 metric tons (200 short tons) of misreported exports data in first quarter 1989.

[6] Represents soda ash from domestic origin (production and inventory changes) and imports, and for exports.

[7] An extra 23,548 metric tons (25,957 short tons) of coproducer sales is included in total, but specific end-use breakout is unknown.

TABLE 5

SODA ASH YEAREND PRICES

		1992	1993
Sodium carbonate (soda ash):			
Dense, 58%, Na_2O 100-pounds, paper bags, carlot, works, f.o.b.	per short ton	$146.00	$146.00
Bulk, carlot, same basis tons	do.	98.00	98.00
Light 58%, 100-pounds, paper bags, carlot same basis	do.	151.00	151.00
Bulk, carlot, same basis tons	do.	103.00	103.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 242, No. 26, Dec. 25, 1992, p. 29; and V. 245. No. 1, Dec. 31, 1993, p. 30.

TABLE 6

REGIONAL DISTRIBUTION OF U.S. SODA ASH EXPORTS, BY CUSTOMS DISTRICTS, IN 1993

(Metric tons)

Customs districts	North America	Central America	South America	Caribbean	Europe	Middle East	Africa	Asia	Oceania	Total	Percent of total
Atlantic:											
Baltimore, MD	—	—	19	—	—	—	29	—	—	48	—
Miami, FL	25	39	95	40	—	—	—	—	—	199	—
New York, NY	—	—	—	18	69	1	—	([1])	—	88	—
Norfolk, VA	—	—	—	—	—	5	—	—	—	5	—
Philadelphia, PA	—	103	88	—	—	—	—	—	—	191	—
Savannah, GA	—	—	—	—	20	—	—	17	—	37	—
Gulf:											
Houston-Galveston, TX	—	—	—	18	—	—	1	—	—	19	—
New Orleans, LA	—	104	—	46	—	—	—	—	—	150	—
Port Arthur, TX	—	—	144,762	16,409	—	—	—	—	—	161,171	6
Pacific:											
Columbia-Snake River	—	18,795	165,266	—	370,697	52,618	41,982	1,230,963	72,153	1,952,474	70
Honolulu, HI	—	—	—	—	—	—	—	—	3	3	—
Los Angeles, CA	—	12,092	133,295	—	39,316	1	23,058	51,060	90	258,912	9
San Diego, CA	1,551	—	70,627	—	35,087	8,563	—	—	—	115,828	4
San Francisco, CA	—	—	—	—	—	—	—	8	456	464	—
Seattle, WA	8,474	—	—	—	—	—	—	199	—	8,673	—
North Central:											
Detroit, MI	57,365	—	—	—	6	—	—	—	—	57,371	2
Great Falls, MT	33,066	—	—	—	—	—	—	—	—	33,066	1
Pembina, ND	9,640	—	—	—	—	—	—	—	—	9,640	—
Northeast:											
Buffalo, NY	3,745	—	—	—	1	—	—	—	—	3,746	—
Ogdensburg, NY	393	—	—	—	—	—	—	—	—	393	—
Southwest:											
El Paso, TX	103	—	—	—	—	—	—	—	—	103	—
Laredo, TX	188,441	—	—	—	—	—	—	—	—	188,441	7
Nogales, AZ	17	—	—	—	—	—	—	—	—	17	—
Unknown:	7,409	—	—	—	—	—	—	—	—	7,409	—
Total[2]	310,229	31,133	514,152	16,531	445,196	61,188	65,070	1,282,247	72,702	2,798,446	100
Percent of total	11	1	18	1	16	2	2	46	3	100	—

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 7
U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1989	1990	1991	1992	1993
Algeria	(1)	4,057	18	37	—
Angola	—	(1)	—	—	—
Argentina	86,735	74,259	123,894	116,301	96,600
Australia	66,596	72,737	59,334	54,396	65,157
Bahamas, The	—	5	—	—	—
Belgium	—	—	44,400	181,039	149,092
Belize	34	8	—	—	—
Bermuda	33	1,075	18	13	—
Bolivia	1,449	554	900	3,320	1,650
Brazil	220,381	101,873	204,390	82,484	88,803
Canada	[2]252,741	151,480	151,455	135,835	120,092
Chile	72,680	39,425	58,901	75,029	59,153
China	317,086	56,159	58,092	64,258	59,066
Colombia	26,252	21,910	10,299	38,244	74,219
Costa Rica	5,577	8,479	7,935	8,047	8,096
Croatia[3]	—	—	—	35,699	51,943
Dominican Republic	5,219	2,722	2,724	3,152	—
Ecuador	11,281	10,634	4,475	5,954	9,552
El Salvador	3,146	—	2,986	3,252	3,077
France	4,874	11,474	28,131	38,814	19,050
Gabon	—	1	—	—	(1)
Germany	45	64	376	56	21
Guatemala	4,951	—	8,810	11,628	18,196
Guyana	—	8	5	(1)	—
Haiti	—	41	61	—	—
Honduras	14	7	—	6	—
Hong Kong	[4]189,571	40,734	2,898	1,996	909
Hungary	—	9,916	—	—	—
India	24	—	—	—	—
Indonesia	179,502	173,920	189,676	220,398	236,844
Iran	—	43,248	—	14,966	20,000
Ireland	—	(1)	—	—	—
Israel	—	9,757	10,450	6,179	8,563
Italy	—	—	—	32,689	37,833
Jamaica	3,998	6,059	3,561	4,128	8,000
Japan	289,781	337,207	273,729	262,411	353,145
Korea, Republic of	131,458	190,521	231,920	252,320	237,461
Kuwait	—	20	—	—	—
Malaysia	21,324	55,844	37,709	39,815	68,565
Marshall Islands	—	—	—	—	3
Mexico	141,731	191,820	236,957	161,723	190,137
Morocco	—	600	—	—	—
Netherlands	3	20,028	63,505	142,614	80,251
Netherlands Antilles	9	—	—	—	22
New Zealand	23,000	24,397	17,276	18,090	7,542
Nigeria	—	3	18	—	—
Panama	1,526	2,181	4,059	4,180	1,764
Peru	15,030	11,181	15,997	12,768	13,837
Philippines	90,324	86,095	71,245	114,106	85,643
Poland	—	—	32	3	50

See footnotes at end of table.

TABLE 7—Continued

U.S. EXPORTS OF SODA ASH, BY COUNTRY

(Metric tons)

Country	1989	1990	1991	1992	1993
Romania	—	—	—	—	20
Saint Lucia	—	5	—	—	—
Saudi Arabia	(1)	—	12	13	32,624
Sierra Leone	—	—	—	—	29
Senegal	17	—	—	18	—
Singapore	4,946	12,987	10,056	5,960	12,979
Slovenia[3]	—	—	—	14,804	13,720
South Africa, Republic of	186,952	170,370	135,331	110,236	65,040
Spain	—	9	71,568	146,028	70,505
Sudan	7	—	—	—	—
Suriname	152	—	—	—	—
Sweden	25,086	20,521	25,421	21,017	17,709
Switzerland	—	447	—	—	—
Taiwan	69,793	112,449	118,571	114,504	122,739
Thailand	69,167	103,635	111,476	148,624	104,896
Trinidad and Tobago	8,321	5,624	8,737	3,230	8,509
Turkey	—	58,530	—	—	—
United Kingdom	27,422	34,179	108,481	36,090	5,001
Uruguay	—	2,990	1,688	2,544	3,670
Venezuela	90,183	109,766	193,067	165,205	166,667
Yemen	—	—	—	—	1
Yugoslavia[5]	—	—	23,444	40,497	—
Total[6]	2,648,439	2,391,996	2,734,090	2,954,723	2,798,446

[1] Less than 1/2 unit.

[2] Data representing imports from the United States as reported by Statistics Canada, International Trade Division.

[3] Formerly part of Yugoslavia.

[4] The majority was bagged and transshipped to China.

[5] Dissolved in Apr. 1992.

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

Source: Bureau of the Census and Statistics Canada, as adjusted by the U.S. Bureau of Mines.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF SODA ASH

Year	Disodium carbonate[1]	
	Quantity (metric tons)	Value[2] (thousands)
1989[3]	128,790	17,396
1990	145,534	20,495
1991	134,312	21,299
1992	71,663	12,772
1993	88,930	17,084

[1] Beginning in 1989, import data were reclassified under the Harmonized Commodity Description and Coding System (HS Code No. 2836200000). Prior years were classified under the Tariff Schedule of the United States, Annotated, TSUSA No. 4208400 (calcined) and No. 4208600 (hydrated and sesquicarbonate).

[2] C.i.f. value at U.S. ports.

[3] Also contains sodium carbonate, hydrated and sesquicarbonate.

Source: Bureau of the Census.

TABLE 9

SODA ASH: WORLD PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Albania[e]	[2]27	27	[r]16	(3)	(3)
Australia[e]	300	300	300	300	300
Austria[e]	150	150	150	150	150
Belgium[e]	380	375	380	375	300
Bosnia and Herzegovina[4]	—	—	—	[r][e]25	20
Botswana	—	—	62	[r]124	180
Brazil[e]	[r]200	200	200	200	200
Bulgaria	[r]1,153	1,046	[r]893	[r][e]900	900
Canada[e]	325	315	310	305	305
China[e]	[r]2,983	[r]3,750	[r]3,940	[r]4,500	5,270
Colombia[e]	[r]115	[2]121	[r]121	[r]121	121
Czechoslovakia[e] [5]	110	[2]104	104	100	—
Egypt	[e]47	52	52	[e]51	51
France	[r]780	[r]1,180	[r]1,140	[r]1,100	1,000
Germany:					
Eastern states[e]	[r]917	[r]850	—	—	—
Western states	1,443	1,436	—	—	—
Total[e]	[r]2,360	[r]2,286	1,948	[r]1,639	1,600
India[e]	[2]1,344	1,400	1,500	1,500	1,500
Italy[e]	615	610	600	600	500
Japan	1,105	1,135	1,103	[r]1,057	1,100
Kenya[6]	241	244	[e]245	[e]245	245
Korea, Republic of[e]	280	280	300	300	310
Mexico[7]	[r]457	[r]449	[r][e]449	[r][e]440	390
Netherlands[e]	400	400	[r]400	[r]400	400
Pakistan[e]	135	135	147	[r]146	150
Poland	[r]1,005	[r]968	[r]962	[r]929	950
Portugal[e]	[r]155	150	150	150	150
Romania	889	[r]632	[r][e]600	[r][e]700	700
Russia	—	—	—	[e]3,000	2,500
Spain	[r]483	[r]527	[e]500	[e]500	500
Taiwan	116	[e]120	109	[r]91	100
Turkey[e]	381	385	385	385	385
U.S.S.R.[8]	4,809	4,359	[e]4,100	—	—
Ukraine	—	—	—	[e]1,000	900
United Kingdom[e]	1,000	1,000	1,000	1,000	1,000
United States[6]	8,995	9,156	9,005	9,379	[2]8,959
Yugoslavia[4] [9]	204	173	[e]140	—	—
Total	[r]31,543	[r]32,029	[r]31,312	[r]31,712	31,136

[e]Estimated. [r]Revised.

[1] Table includes data available through Apr. 29, 1994. Synthetic unless otherwise specified.

[2] Reported figure.

[3] Less than 1/2 unit.

[4] All production in Yugoslavia from 1989-91 came from Bosnia and Herzegovina.

[5] Dissolved on Dec. 31, 1992.

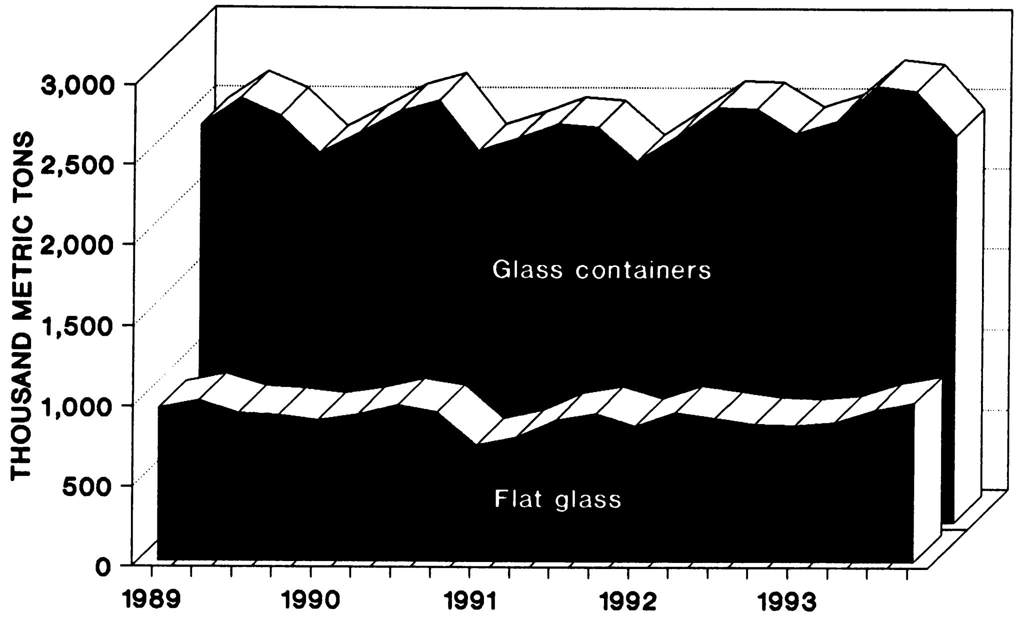
[6] Natural only.

[7] Includes natural and synthetic. Estimated production of natural soda ash, in metric tons, was as follows: 1989—190,000; 1990—190,000; 1991—190,000; 1992—160,000 (revised); and 1993—90,000.

[8] Dissolved in Dec. 1991.

[9] Dissolved in Apr. 1992.

FIGURE 1
U.S. PRODUCTION OF FLAT GLASS AND GLASS CONTAINERS, BY QUARTER



Source: U.S. Bureau of the Census.

FIGURE 2
RELATIONSHIP BETWEEN IMPORT DUTY AND IMPORTS FROM THE UNITED STATES IN 1993

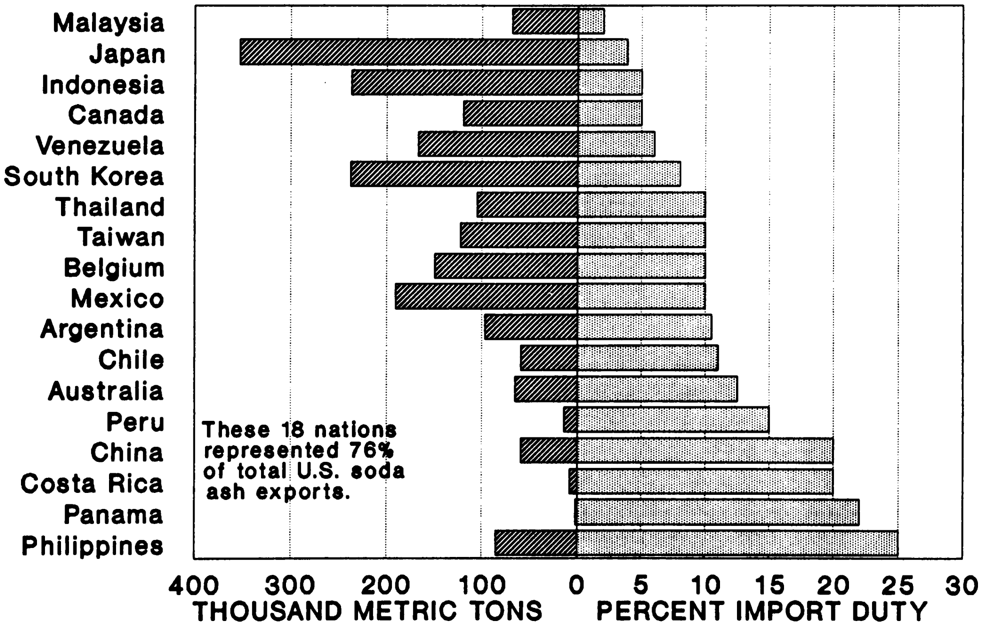


FIGURE 3
U.S. SODA ASH EXPORTS IN 1993 RELATIVE TO GROSS DOMESTIC PRODUCT

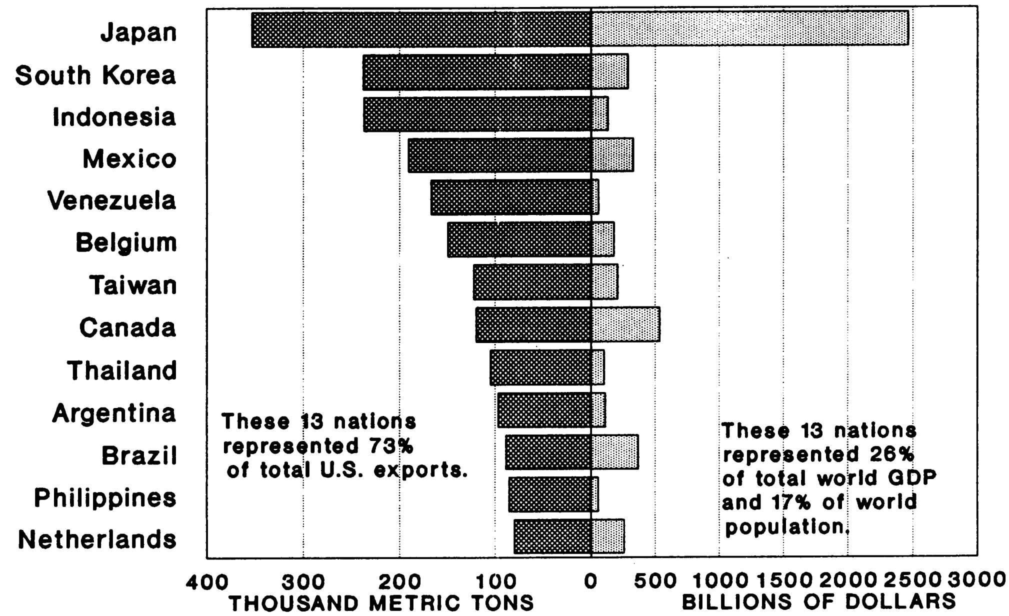


FIGURE 4
WORLD POPULATION IN 1993 RELATIVE TO POPULATION GROWTH RATES

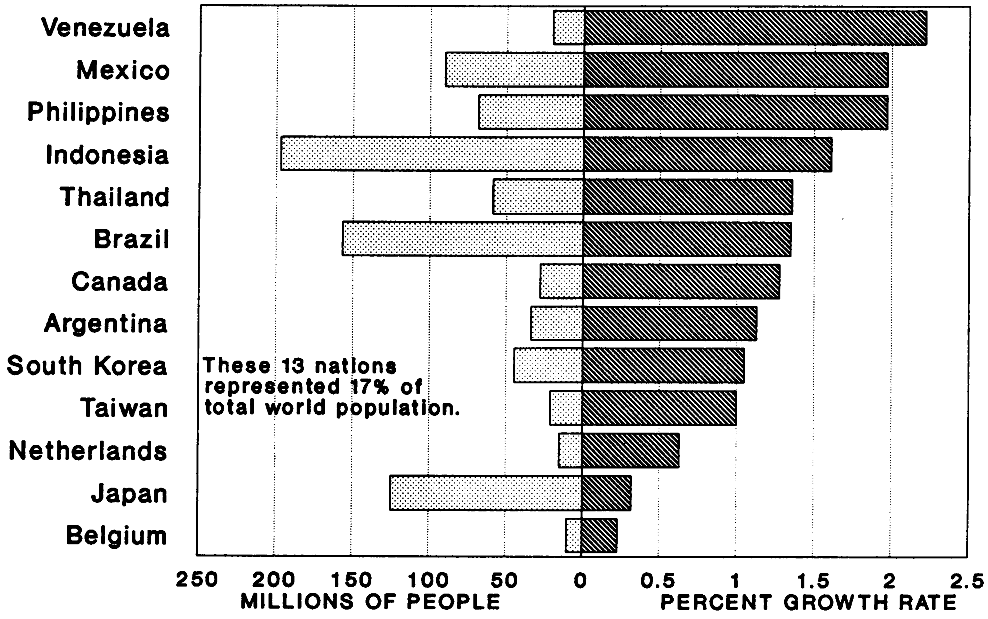
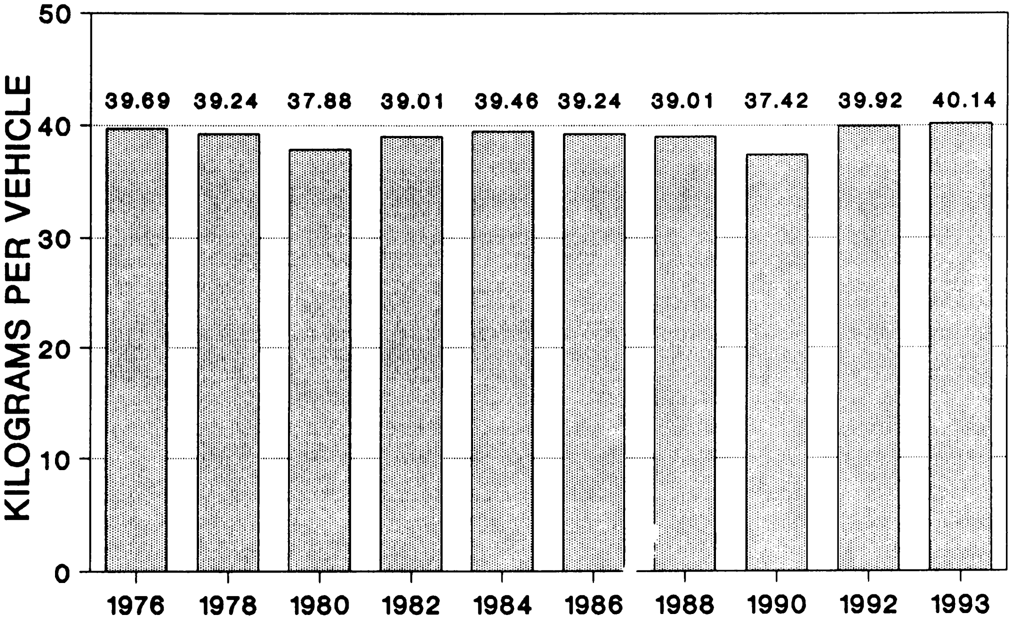


FIGURE 5
ESTIMATED AVERAGE GLASS CONSUMPTION IN U.S.-BUILT AUTOMOBILES, 1976-93



Source: American Metal Market.

SODIUM SULFATE

By Dennis S. Kostick

Mr. Kostick, a physical scientist with 15 years of U.S. Bureau of Mines experience, has been the commodity specialist for sodium sulfate since 1979. Domestic survey data were prepared by Maria Arguelles, statistical assistant; and international data tables were prepared by Doug Rhoten, international data coordinator.

Sodium sulfate ranked 47th of the 50 major nonfuel inorganic chemicals produced in the United States in 1993 according to a national survey.[1] Although it is an unfamiliar compound to most people, sodium sulfate is used to make several consumer products used by virtually everyone, such as detergents, brown paper bags, textiles, and glass. Sodium sulfate is produced from naturally occurring brines or crystalline mineral sources and as a byproduct from different chemical processes. Natural sodium sulfate is produced from mineral deposits found in California and Texas. It is also found as a constituent of saline lakes, such as the Great Salt Lake in Utah. Synthetic sodium sulfate is recovered as a byproduct from various manufacturing processes. Both types of sodium sulfate have several important and useful applications in various consumer products.

DOMESTIC DATA COVERAGE

Domestic production and inventory data for natural sodium sulfate are developed by the U.S. Bureau of Mines from monthly and annual surveys of U.S. operations. Of the three natural sodium sulfate operations to which a survey request was sent, all responded, representing 100% of the natural sodium sulfate data used in this report.

Synthetic sodium sulfate data were collected by the U.S. Department of Commerce, Bureau of the Census, from quarterly and annual surveys (aggregate data published in Current Industrial Reports, Inorganic Chemicals, MQ28A and MA28A) of companies engaged in recovering and selling byproduct sodium sulfate. Any revised Census Bureau data have been included using most recent Census Bureau statistics. These data are aggregated with U.S. Bureau of Mines natural sodium sulfate data and included in several tables. *(See table 1.)*

BACKGROUND

Natural sodium sulfate was known to have been used as a medicine as early as the 16th century. It was first accurately described in 1658 by Johann Rudolf Glauber, a German chemist whose name is still associated with the hydrated crystal, Glauber's salt ($Na_2SO_4 \cdot 10H_2O$), and the anhydrous mixed sulfate, Glauberite ($Na_2SO_4 \cdot CaSO_4$).

Glauber and other researchers prepared sodium sulfate by reacting common salt with sulfuric acid. The invention of the Kraft process for making pulp and paper in 1880 provided the first major industrial market for sodium sulfate.

Definitions, Grades, and Specifications

The following terms are used in the sodium sulfate industry:

Anhydrous Sodium Sulfate.—Refined sodium sulfate or the mineral thenardite (Na_2SO_4). Named for the French chemist, Louis Jacques Thenard, thenardite is a colorless to white mineral with a specific gravity of 2.67 and a hardness of 2.5 to 3. Because of its whiteness and purity, it is used in detergents, pharmaceuticals, dyestuffs, glass, and ceramic glazes. Commercial-grade material has a bulk density of about 1.23 grams per cubic centimeter (77 pounds per cubic foot).

Byproduct Sodium Sulfate.—Synonymous with synthetic sodium sulfate. It is recovered as a byproduct from various chemical and textile manufacturing processes.

Glauber's Salt.—Same as the mineral mirabilite (Latin "sal mirabile" or "wonderful salt"), sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$). The mineral contains 55.9% water of crystallization and forms opaque to colorless needlelike crystals.

High Purity.—Refers to anhydrous sodium sulfate with a purity of 99% or greater. Usually sold to detergent, glass, and textile industries.

Low Purity.—Some processes occasionally produce sodium sulfate that does not meet certain physical or color specifications required by certain consumers despite being a chemically pure product. This grade of sodium sulfate is generally sold to sectors that are not as concerned about whiteness or particle size, such as the pulp and paper industry, at reduced prices.

Natural Sodium Sulfate.—Sodium sulfate obtained from mining crystalline sodium sulfate-bearing minerals or from sodium sulfate-bearing brines.

Salt Cake.—Normally refers to impure sodium sulfate containing 90% to 99% Na_2SO_4. Because of its impurity or possible discoloration, it usually is sold only to the pulp and paper industry.

Synthetic Sodium Sulfate.—Same as byproduct sodium sulfate.

Sodium sulfate made from natural brine usually contains less than 0.5% total impurities, but that produced as a byproduct of other manufacturing may contain much larger quantities. The material meeting U.S. Pharmacopeia (U.S.P.) specifications and that intended for glassmaking must contain at least 99% sodium sulfate. In addition, glassmakers' grade must be low in iron and heavy metals. Technical grades of sodium sulfate may have from 2% to 6% impurities. Purchases of detergent- or rayon-grade sodium sulfate are based primarily on whiteness. Its sodium chloride content may be between 1.5% and 2.0%, and its iron content between 60 and 100 parts per million.

Industry Structure

Three companies produced natural sodium sulfate from a total of three plants in California, Texas, and Utah. The domestic natural sodium sulfate industry supplied about one-half of the total output of U.S. sodium sulfate. Because of the location of these plants, most natural sodium sulfate is marketed in the West and southern Gulf coast areas of the Nation. Byproduct material was supplied by 14 companies operating 15 plants primarily in the Midwest and Mid-Atlantic regions. Total rated production capacity in 1993 was 780,000 tons, and the industry operated at 85% of this capacity. *(See table 2.)*

Geology-Resources

Sodium is the sixth most abundant element in the Earth's crust. Sodium sulfate-bearing mineral deposits are geologically young, mainly of postglacial age. Sodium sulfate is widespread in occurrence and is a common component of seawater and many saline or alkaline lakes. Economic reserves of natural sodium sulfate are estimated at 3.3 billion metric tons worldwide. With world production of natural sodium sulfate averaging about 1.8 million tons per year, supplies are sufficient to meet anticipated demand for several centuries. The quantity of synthetic sodium sulfate is dependent on the longevity of the manufacturing firms recovering byproduct sulfate.

Surface depressions or lakes that have no outlets and are fed by spring waters flowing over volcanic rocks containing sulfide minerals commonly yield soluble sulfide salts that are oxidized by contact with the air to produce sulfates. Some minerals over which the spring water may flow contain the sulfates directly, such as bentonite or gypsum. When an inland lake of this type evaporates and becomes highly concentrated in salts, one of the first salts to precipitate would be mirabilite, also known as Glauber's salt, which has very poor solubility at low temperatures. During seasonal temperature variations, the sulfate will precipitate preferentially to the lake bottom.

Thenardite and mirabilite are the only sodium sulfate minerals that are commercially important. Many economic deposits of sodium sulfate are in the form of crystalline beds of mirabilite such as those found in Canada and the former U.S.S.R., which has the world's largest sodium sulfate resource in the Kara-Bogaz-Gol Gulf. Because mirabilite converts to thenardite when exposed to air, its outer surface may develop a thenardite crust. Some buried sedimentary formations contain very large deposits of thenardite and glauberite, such as the deposit in Villarrubia de Santiago in Spain.

Sodium sulfate is also found dissolved in underground brines in California, Texas, and other parts of the world. The sulfate is usually converted to mirabilite when extracted from the brine by mechanical refrigeration techniques. *(See table 3.)*

Technology

The technology to mine and process natural sodium sulfate involves mechanical refrigeration or natural chilling to induce crystallization followed by dissolution, filtration, evaporation, and drying. Recovery of byproduct sodium sulfate from chemical processes involves various techniques.

Mining.—Sodium sulfate is extracted from the upper level of the Searles Lake brine in California and is treated separately from the carbonate-rich lower level and mixed layer brines. The subterranean sodium sulfate-bearing brines in western Texas are the simplest of the domestic brine deposits. Mechanical refrigeration is used to extract Glauber's salt crystals from the brine. The Great Salt Lake in Utah also contains valuable quantities of sodium sulfate. Brine from the most concentrated northwest segment of the lake is pumped into solar evaporation ponds on the eastern shore of the lake where sodium chloride first precipitates as the water evaporates. Sodium sulfate crystals precipitate in a fairly pure state when winter weather cools the brine to -1° to 4° C (30° to 40° F). The crystals are picked up by large earth-moving machinery and stored outdoors until further processing to anhydrous sodium sulfate can take place.

Processing.—At Searles Lake, the brine is first cooled at about 16° C (60° F) to precipitate borax crystals, which are removed from the system for subsequent further processing and sale. A second cooling to about 4° C (40° F) precipitates the sodium sulfate in the form of Glauber's salt. These crystals are separated from the brine on a rotating drum filter. They are then redissolved in fresh water in a vacuum crystallizer. After the second separation and drying, the crystals are about 98.2% sodium sulfate. Additional treatment can obtain a 99.3% purity. Major impurities remaining are sodium chloride, sodium carbonate, and boron.

In Texas, after the crystals are processed in rotary drum vacuum filters and washed, they are melted and dehydrated using mechanical vapor recompression evaporators, which are more energy efficient than triple-effect evaporators or submerged gas burners. Final classifying, centrifuging, drying in rotary kilns, and screening converts the Glauber's salt to marketable anhydrous sodium sulfate of 99.7% purity.

Purification and dehydration procedures at the facility on the Great Salt Lake are similar to those of other sodium sulfate plants. The purity of the final product is between 99.5% to 99.7%.

Sodium sulfate also is produced as a byproduct of the production of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments. It also is recovered from certain flue gas desulfurization operations. The Mannheim and Hargreaves furnace processes also produce byproduct sodium sulfate. In the Mannheim furnace, salt and sulfuric acid are reacted to form hydrogen chloride (HCl) and sodium sulfate. The Hargreaves furnace produces HCl and sodium sulfate by the reaction of sulfur dioxide, sodium chloride, air, and water. The Mannheim process is the major method used in Europe, but its use in the United States has decreased considerably since less expensive methods to produce HCl became available.

Recycling.—Because of environmental concerns regarding sulfur emissions from pulp and paper mills, many Kraft pulpers were installing pollution abatement equipment to reduce sulfur losses in the pulping process. This will result in more sodium sulfate being recycled and less used in batch makeup solutions.

Byproducts and Coproducts

The brines of Searles Lake in California contain sodium sulfate as well as coproduct borax, potassium chloride, sodium chloride, and soda ash. The Great Salt Lake in Utah is a source of magnesium compounds, potassium sulfate, sodium chloride, as well as sodium sulfate. There are no secondary products produced from the brines in Texas.

Some manufacturers of ascorbic acid, boric acid, cellulose, chromium chemicals, lithium carbonate, rayon, resorcinol, and silica pigments produce sodium sulfate as a byproduct of the process. The sodium sulfate is considered a waste product but has marketability.

Economic Factors

Prices.—Producers of natural sodium sulfate tend to market and sell most of their own product, but most synthetic producers use major chemical distributors or chemical supply companies as sales agents. The principal product made and sold by the synthetic sodium sulfate producer is the primary economic factor. Because sodium sulfate is considered a waste product, it will be sold at a price that ensures prompt sales. This practice tends to set the rates at which the natural product can be sold.

The list prices quoted in trade journals or by producers of all grades of sodium sulfate differ from the annual average values reported by the U.S. Bureau of Mines. The value represents the combined amount of total revenue of domestic natural sodium sulfate sold at list prices, spot prices, long-term contracts, discounts, and export divided by the aggregated quantity of sodium sulfate sold. The published value does not necessarily correspond to the posted list price. *(See table 4.)*

Tariffs.—Import tariffs serve to protect the interests of domestic producers for particular products. For sodium sulfate, a 32.5-cents-per-ton tariff is imposed on imported anhydrous sodium sulfate from countries having most-favored-nation (MFN) status and $2.95 per ton from those with non-MFN status. There are no import tariffs on imported salt cake, regardless of the country of origin. The non-MFN countries in 1993 were Afghanistan, Albania, Azerbaijan, Belarus, Cuba, Georgia, Kampuchea, Kazakhstan, Laos, North Korea, Romania, Tajikistan, Turkmenistan, Uzebekistan, and Vietnam.

Royalties.—Sodium sulfate mined on Federal lands is subject to the Mineral Leasing Act of 1920, which provides for royalty payments to the U.S. Government. The royalty is 5% of the quantity or gross value of the output of the product at the point of shipment to market. Each Federal lease also has other costs, such as bonds, acreage rental fees, sodium prospecting permit application fees, and permit bonds. The Searles Lake sodium sulfate deposit is the only resource with active operations that has any Federal leases. Because of the variety of the brine constituents, the operator has a commingling agreement with the U.S. Government to compute royalties.

Depletion Provisions.—Legislation passed by the U.S. Government provides an allowance for the depletion of natural resources, notably timber and minerals. The depletion allowance is an important inducement for companies willing to accept the risk and high cost of mining development. The concept of depletion allowances for minerals is similar to the depreciation of other assets. Although cost depletion and percentage depletion are two methods used to compute depletion deductions, most companies prefer to use the latter. About 100 mineral categories are entitled to percentage depletion. The rates range between 5% and 22% of the gross income from the mineral property, depending on the mineral and location (foreign or domestic), and are subject to a limitation of 50% of the net income of the property. The mineral depletion allowance for natural sodium sulfate is 14% for U.S. companies mining from domestic or foreign sources.

Operating Factors

Operating factors are different for mining companies producing natural sodium sulfate compared with manufacturing facilities recovering byproduct sodium sulfate. The quantity of synthetic sodium sulfate recovered is directly associated with the production capabilities of the primary industry (e.g., rayon, lithium carbonate, etc.) and the sulfate recovery rates.

Environmental Requirements.—Land usage may become a problem when sodium sulfate is obtained by solar evaporation, as in the case of the Great Salt Lake brines. Large areas of relatively flat land are required to allow for adequate concentration and evaporation. When land values are high, the capital required for land acquisition may increase operating costs. Disposal of the waste liquors from which sodium sulfate was extracted may develop into a major ground water discharge problem in some areas. Reinjection of spent solutions into underground source strata is expensive but often is the only acceptable method of disposal.

Because sodium sulfate is water-soluble, most releases of sodium sulfate to the environment affect water quality rather than air or land quality. These releases are mainly from Kraft pulp mills, which typically discharge between 5,000 to 15,000 tons (5,500 to 16,500 short tons) 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 also have caused environmental concerns not attributed to sodium sulfate. The second largest byproduct sodium sulfate facility in the United States at Front Royal, VA, owned by Avtex Fibers Inc., was closed in late 1989 by Federal and State regulatory agencies because of contaminated water discharges containing carbon disulfide and polychlorinated biphenyls (PCB's). These toxic chemicals were produced from rayon manufacture, not sodium sulfate recovery.

Toxicity.—Sodium sulfate was deleted in early 1989 from the list of toxic chemicals under section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986. The U.S. Environmental Protection Agency determined that there was no evidence that sodium sulfate caused, or could reasonably be anticipated to cause, adverse human health or environmental effects as specified in the act.

Employment.—According to the Bureau of Labor Statistics and industry sources, approximately 300 persons are employed in mining and processing natural sodium sulfate in the United States. No data are available on the number of personnel employed in recovering byproduct sodium sulfate.

Energy Requirements.—The energy requirements to mine natural sodium sulfate are minimal compared with the amount of energy required to process it. An early U.S. Bureau of Mines energy survey reported that 4.5 million British thermal units (Btu's) was required to produce 1 ton of natural sodium sulfate. With the interest in conserving energy, some technical improvements, such as the installation of mechanical vapor recompression crystallizers, have reduced the overall energy requirement to slightly less than 2 million Btu's per ton of sulfate produced.

Transportation.—All natural sodium sulfate is shipped in bulk or in bags by either rail or truck. The mode of transportation depends on the location of the customer, quantity purchased, and difference in freight rates. Because of the location of the natural producers in the West and Southwest, very little natural sodium sulfate is shipped to the East because transportation rates reduce its competitiveness with synthetic sodium sulfate. Consumers in the Midwest and East tend to rely on synthetic sodium sulfate produced in various Midwest and Southern locations.

ANNUAL REVIEW

U.S. sodium sulfate production increased 6% in 1993 to 651,000 tons according to preliminary statistics from the Bureau of the Census. Production of natural sodium sulfate from three domestic locations declined 5% to 327,000 tons, which was the lowest level since 1958 when production was 315,000 tons. Output from byproduct sources increased 21% compared with that of the previous year. The increase in production was attributed to the improved national economic conditions that affected some of the industries that recover byproduct sodium sulfate. Although the United States is one of the largest producers in the world of natural and synthetic sodium sulfate, its share has decreased from 23% of world production total in 1980 to 15% in 1993.

Issues

Although there was excess supply of sodium sulfate during the first half of 1993, the situation changed in the last half of the year as inventories were reduced because of greater demand in the domestic textile industry and increased consumption by the domestic detergent manufacturers.

The U.S. Environmental Protection Agency issued a proposal that would reduce and prevent future discharges of dioxin and other toxic compounds from pulp and paper mills into rivers and other surface waters. About 350 pulp and paper mills would be affected, costing the industry $4 billion in capital expenses and $600 million to implement.[2] The proposal is to restrict chlorine-based bleaching chemicals and use oxygen-base bleaching chemicals for pulp delignification. Sodium chlorate and oxygen are the two preferred chemicals to use. The Rapson R8 process, which is the most widely used system in the pulp industry, uses sodium chlorate, sulfuric acid, and methanol to produce chlorine dioxide and byproduct sodium sulfate. The sodium chlorate can be produced on-site at various pulp mills. By producing their own sodium sulfate, certain pulp mills would not have to purchase any sodium sulfate, thereby reducing the demand for saltcake sold by the natural or byproduct sodium sulfate industry. In addition, sodium sulfite mills often sell their waste effluent that contains sodium sulfate to Kraft pulp mills for makeup saltcake.

Production

U.S. total sodium sulfate production increased 6% in 1993 primarily because of increased demand for detergent-grade sodium sulfate for powdered home laundry detergents and carpet freshener products, and increased demand by the textile industry.

Lenzing A.G. of Austria, which operates a rayon plant in Lowland, TN, and recovers byproduct sodium sulfate, announced plans at midyear to increase rayon production capacity by 25% in 1994. This would increase sodium sulfate recovery by about 8,000 tons annually.[3] *(See tables 5 and 6.)*

Consumption and Uses

Domestic sodium sulfate apparent consumption increased 22% from that of the previous year. Despite early concerns about potential supply shortages, the majority of the consuming sectors had sufficient quantities available. Most of the same economic conditions that affected demand in 1992 still remained in 1993. Imports for consumption of sodium sulfate, primarily from Canada, rose slightly to meet domestic demand requirements.

Sodium sulfate consumption by the soap and detergent industry, which has been the largest consumer of sodium sulfate, grew slightly in 1993. Sodium sulfate is used as an inert filler to provide bulk in powdered laundry detergents. Typical laundry detergent formulations historically had consisted of about 35% sodium sulfate but the quantity recently has shrunk to about 15%. The emergence of superconcentrated liquid detergents may erode some of the market held by powdered products. Dishwasher detergents, which contain about 28% sodium sulfate, are being challenged by concentrated dishwasher products. Another use of sodium sulfate in the detergent sector is the carpet deodorizer market. Approximately 10% of the North American detergent industry is represented by this market. About 40% of U.S. sodium sulfate demand is for detergents.

Sodium sulfate consumption remained stagnant in the Kraft pulping industry because of the economic recession affecting the paper industry, and recycling of paper products. 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 25% of the total demand for sodium sulfate. As more pulp mills convert to sodium chlorate bleaching technology that produces byproduct sodium sulfate, less make up sodium sulfate will be sold by natural or other byproduct producers.

The use of sodium sulfate in textiles is increasing, especially in the Southeast. Salt traditionally has been used in the dyeing process to separate organic contaminants, promote "salting out" of dyestuff precipitates, and blending with dyes to standardize concentrated dyes. The equipment used in this process used stainless steel, which was susceptible to corrosion because of the salt. The textile industry began substituting the salt with sodium sulfate, which is not corrosive to the manufacturing equipment. Approximately 140,000 tons of sodium sulfate was consumed by the textile industry in 1993, accounting for about 19% of domestic sodium sulfate consumption. This sector is estimated to grow about 2% annually.

Stocks

Inventories of natural sodium sulfate stored at yearend 1993 by the three producers were 41,863 tons, which was a 11% decrease over that of the previous year. The material stockpiled was anhydrous sodium sulfate. Synthetic sodium sulfate was marketed mainly through major chemical distributors, which have separate storage facilities from the producers.

Markets and Prices

The average value declined to $76.53 per metric ton ($69.39 per short ton) in 1993 from $77.97 per metric ton ($70.73 per short ton) in 1992 for bulk sodium sulfate, f.o.b. mine or plant.

Giles Chemical Industries Inc., which acquired Ashland Chemical Inc.'s sodium sulfate business, announced a $5 per ton increase in its off-list price for bagged product, effective November 1, 1993. Its prices were $182 per short ton for 50-pound bags and $172 per ton for 100-pound bags, f.o.b. Atlanta, GA; $185 per ton for 50-pound bags, $180 for 100-pound bags, and $190 per ton for 2,000-pound supersacks, f.o.b. Baltimore, MD; and $171 per ton for 50-pound bags and $161 per ton for 100-pound bags, f.o.b. Lowland, TN.[4] *(See table 7.)*

Foreign Trade

U.S. exports of 89,000 tons were 43% lower in 1993 when compared with those of the previous year. Of the eight countries that crude sodium sulfate was exported to, Colombia received 31%, followed by Australia, 24%; Republic of Korea, 19%; and New Zealand, 9%. Eighteen nations imported anhydrous sodium sulfate from the United States. The major ones were Guatemala, 27%; Venezuela, 27%; Mexico, 18%; and Australia, 17%.

Total imports amounted to more than 163,000 tons in 1993; an increase of 3% compared with those of the previous year. Canada supplied virtually all of the U.S. imports of crude sodium sulfate. Canada also was the primary source of anhydrous sodium sulfate entering the United States through the Great Falls, MT, Pembina, ND, and Duluth, MN, customs districts. Some imports were received from Germany and the United Kingdom. *(See tables 8 and 9.)*

World Review

Industry Structure.—About 55% of the world sodium sulfate production in 1993 was from natural sources; the balance was represented by synthetic sodium sulfate recovered from various chemical and manufacturing processes. Although the U.S. Bureau of Mines collects or estimates data from 31 sodium sulfate-producing countries, other countries are known or assumed to have produced synthetic sodium sulfate, but production statistics are not reported, and available information is inadequate to make reliable estimates of output. *(See table 10.)*

Spain and the United States were the largest producers of total sodium sulfate, representing 18% and 15%, respectively, of the world total. Mexico produced 11%, followed by Canada, 7%; Japan, 6%; the former U.S.S.R., 5%; and Germany, 3%. These seven countries accounted for approximately 62% of the world's output of total sodium sulfate, based on obtainable production data.

Capacity.—The data in table 2 are rated capacities for domestic natural operations and byproduct recovering facilities in 1993. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for natural sodium sulfate is derived from available company data on ore throughput to the refinery. The ore refers to mined crystalline sodium sulfate, harvested precipitate, or sodium sulfate-bearing brines. Refinery capacity for natural sodium sulfate pertains to the total amount of anhydrous sodium sulfate that the plant is capable of processing from the ore. Synthetic sodium sulfate-refining capacity is dependent on the production capabilities of the primary industry and the sodium sulfate recovery rates.

Canada.—Ormiston Mining and Smelting began small-scale production of soda ash at its Ormiston, Saskatchewan, natural sodium sulfate facility. The plant will use a new process to convert its surplus sodium sulfate into commercial-grade soda ash for use in Canada or in the United States.[5]

OUTLOOK

Sodium sulfate is a mature commodity that tends to follow the domestic economic trends. Supply of product in the short term will probably not be a problem for consumers as new capacity is scheduled to be online in 1994. For example, GNB Inc.'s new battery recycling center in Waynesboro, GA, will generate about 27,000 tons of byproduct sodium sulfate annually beginning in 1994. In addition, Lenzing A.G. will add another 8,000 tons of byproduct capacity when an expansion at its Lowland, TN, plant is completed, also in 1994.

U.S. consumption of sodium sulfate is expected to decline in the pulp and paper sector with the emergence of replacement technology to replace chlorine-based bleaching agents in pulp and paper production. Although sales to the textile industry have been favorable, this sector alone cannot compensate for overall declining sodium sulfate consumption.

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[1] Chemical and Engineering News. Top 50 Chemicals Production Rose Modestly Last Year. V. 72, No. 15, p. 13.

[2] Chemical Marketing Reporter. EPA Seeks Increase in Chlorate, O_2 Use. V. 244, No. 19, p. 5.

[3] ———. Sulfate Supply Finds Home in Textiles, Exports. V. 244, No. 1, p. 22.

[4] ———. Sulfate Supply Tightening Brings Rising Market Prices. V. 244, No. 15, p. 24.

[5] European Chemical News. In Brief. V. 59, No. 1570, p. 11.

TABLE 1

SALIENT SODIUM SULFATE STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
United States:					
Production[1]	685	713	720	609	651
Value[2]	$62,703	$64,244	$62,885	$55,900	$49,821
Exports	62	62	103	155	89
Value	$6,241	$6,704	$11,495	$11,865	$8,540
Imports for consumption	173	162	157	158	163
Value	$13,990	$13,155	$13,807	$13,444	$13,637
Stocks, Dec. 31: Producers	24	39	35	47	42
Apparent consumption	826	798	778	600	730
World: Production	[r]4,868	[r]5,057	[r]4,742	[r]4,405	[e]4,356

[e]Estimated. [r]Revised.

[1] Includes natural and synthetic. Total production data for synthetic sodium sulfate, obtained from the Bureau of the Census, were revised in Feb. 1994 MQ28A Inorganic Chemicals, Current Industrial Report.

[2] The value for synthetic sodium sulfate is based upon the average value for natural sodium sulfate.

TABLE 2

U.S. PRODUCERS OF NATURAL AND SYNTHETIC SODIUM SULFATE IN 1993

Product and company	Plant nameplate capacity (thousand metric tons)	Plant location	Source
Sodium sulfate, natural:			
Great Salt Lake Minerals & Chemicals Corp.	45	Ogden, UT	Salt lake brine.
North American Chemical Co., Westend plant	218	Trona, CA	Dry lake brine.
Ozark-Mahoning Co.[1]	141	Seagraves, TX	Do.
Total	404		
Sodium sulfate, synthetic:			
Lenzing A.G.[2]	34	Lowland, TN	Rayon manufacture.
Courtaulds North American Inc.	45	La Moyne, AL	Do.
Flour Corp., Doe Run Co.	9	Boss, MO	Battery recycling.
4M Paper Corp.	6	Ft. Madison, IA	Pulping process.
FMC Corp.	41	Bessemer City, NC	Lithium carbonate.
Hoffman-La Roche Inc.	14	Belvidere, NJ	Ascorbic acid.
W. R. Grace & Co. Organic Chemicals Div.	8	Nashua, NH	Chelating agents.
J. M. Huber	32	Etowah, TN	Silica pigment.
Do.	14	Havre de Grace, MD	Do.
Indspec Chemical Corp.	35	Petrolia, PA	Resorcinol manufacture.
North American Rayon Corp.	14	Elizabethton, TN	Rayon manufacture.
Occidental Chemical Corp.	109	Castle Hayne, NC	Sodium dichromate manufacture.
Public Service of New Mexico	6	Waterflow, NM	Flue gas desulfurization.
Teepak, Inc.	6	Danville, IL	Cellulose manufacture.
Star Enterprise[3]	3	Delaware City, DE	Flue gas desulfurization.
Total	376		
Grand total	780		

[1] Ozark's Brownfield plant, owned by Atochem North America (formerly Pennwalt), was placed on standby in Sept. 1987; 64,000 tons of capacity is not included in total industry capacity.

[2] Acquired from BASF July 1992.

[3] Owned by Saudi Refining Inc. (50%) and Texaco Inc. (50%).

NOTE.—Climax Chemicals Co.'s Hobbs, NM, plant closed in 1992, and Cyprus Mineral Co.'s facility at Kings Mountain, NC, reportedly has been closed.

TABLE 3

WORLD NATURAL SODIUM SULFATE RESERVES AND RESERVE BASE

(Million metric tons)

	Reserves	Reserve base[1]
North America:		
Canada	84	272
Mexico	165	227
United States	857	1,361
Total	1,106	1,860
Europe:		
Russia	1,814	2,268
Spain	180	272
Total	1,994	2,540
Africa:		
Botswana	188	227
World total[2]	3,300	4,600

[1] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources). These definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification for Minerals."

[2] Rounded.

NOTE.—Resources of sodium sulfate are known to also exist in Antarctica, Argentina, Chile, India, Iran, Italy, Mongolia, Romania, the Republic of South Africa, and Turkey. Production of synthetic sodium sulfate is dependent on the supply and demand of the primary product.

TABLE 4

TIME-VALUE RELATIONSHIPS FOR SODIUM SULFATE

Year	Average annual value,[1] dollars per ton			
	Natural sodium sulfate			
	Actual value		Based on constant 1993 dollars[2]	
	Short ton	Metric ton	Short ton	Metric ton
1971	16.00	17.64	52.28	57.64
1972	16.26	17.92	50.67	55.84
1973	17.26	19.03	50.53	55.71
1974	23.99	26.44	64.60	71.19
1975	41.48	45.72	101.93	112.35
1976	49.25	54.29	113.85	125.50
1977	46.09	50.81	99.68	109.89
1978	46.06	50.77	92.35	101.79
1979	55.69	61.39	102.79	113.31
1980	62.42	68.81	105.25	116.03
1981	71.03	78.30	108.84	119.98
1982	83.00	91.49	119.75	131.99
1983	93.30	102.85	132.89	146.49
1984	92.16	101.59	125.78	138.65
1985	92.19	101.62	121.29	133.70
1986	86.11	94.92	110.37	121.53
1987	86.72	95.59	107.71	118.72
1988	78.81	86.87	94.21	103.84
1989	83.05	91.55	95.07	104.80
1990	87.66	96.63	96.09	105.93
1991	79.23	87.34	83.61	92.16
1992	70.73	77.97	72.54	79.92
1993	69.39	76.53	69.39	76.53

[1] Based on the average valuation by producers of their annual total production and reported sales. The values incorporate the price differences change by producers for the finished product sold in bulk at the plant.

[2] Final implicit price deflators for 1993 are based on gross domestic product and not gross national product, which was used previously. Based on 1987=100.

TABLE 5
SODIUM SULFATE SUPPLY-DEMAND RELATIONSHIPS[1]

(Thousand metric tons)

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WORLD PRODUCTION											
United States	776	791	736	763	725	743	685	713	720	609	651
Rest of world	3,306	3,611	3,773	3,846	4,170	4,119	[r]3,783	[r]4,372	[r]4,029	[r]3,796	[e]3,705
Total	4,082	4,402	4,509	4,609	4,895	4,862	[r]4,468	[r]5,057	[r]4,742	[r]4,405	[e]4,356
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
Domestic sources	776	791	736	763	725	743	685	713	720	609	651
Imports	311	240	177	171	125	136	173	162	157	158	163
Industry stocks, Jan. 1[2]	27	44	54	28	65	50	54	24	39	35	47
Total U.S. supply	1,114	1,075	967	962	915	929	912	899	916	802	861
Distribution of U.S. supply:											
Industry stocks, Dec. 31[2]	44	54	28	65	50	54	24	39	35	47	42
Exports	83	69	108	101	111	77	62	62	103	155	89
Industrial demand	987	952	831	796	754	798	826	798	778	600	730
U.S. DEMAND PATTERN[3]											
Glass	50	49	48	48	45	48	33	32	36	36	50
Pulp and paper	464	454	445	239	226	239	231	223	200	144	180
Soaps and detergents	425	363	318	414	392	415	495	479	400	264	290
Textiles	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	126	140
Other[5]	48	86	20	95	91	96	67	64	142	30	70
Total U.S. primary demand	987	952	831	796	754	798	826	798	778	600	730
VALUES[6]											
Average annual value per short ton[7]	93.30	92.16	92.19	86.11	86.72	78.81	83.05	87.66	79.23	70.73	69.39
Constant dollars per short ton[8]	132.89	125.78	121.29	110.37	107.71	94.21	95.07	96.09	83.61	72.54	69.39
Average annual value per metric ton	102.85	101.59	101.62	94.92	95.59	86.87	91.55	96.63	87.34	77.97	76.53
Constant dollars per metric ton[8]	146.49	138.65	133.70	121.53	118.72	103.84	104.80	105.93	92.16	79.92	76.53

[e]Estimated. [r]Revised.

[1] Natural and synthetic except where noted. Synthetic sodium sulfate data obtained from the Bureau of the Census are revised periodically and may differ from previous published reports by the U.S. Bureau of Mines. World production data also are periodically revised on receipt of updated information.

[2] Natural sodium sulfate only.

[3] Estimated using data from "Chemical Profile" issues on sodium sulfate by Chemical Marketing Reporter for 1983, 1986, and 1989.

[4] Included with "Other" prior to 1992.

[5] Includes ceramics, chemicals (potassium sulfate, sodium hyposulfite, sodium sulfide, sodium silicate, and sodium aluminum sulfate), feed supplements, printing inks, sulfonated oils, textile dyeing, veterinary medicines, and viscose sponges.

[6] Dollars per ton for natural sodium sulfate, f.o.b. mine or plant.

[7] Although data from 1990 and thereafter will be published in metric units, historical values based on short tons will continue to be published for reference.

[8] Final implicit price deflators for 1993 are based on gross domestic product and not gross national product, which was used previously. Based on 1987=100.

TABLE 6
SYNTHETIC AND NATURAL SODIUM SULFATE[1] PRODUCED IN THE UNITED STATES

(Thousand metric tons and thousand dollars)

Year	Synthetic and natural[2] (quantity)			Synthetic	Natural	
	Lower purity[3] (99% or less)	High purity	Total	Quantity	Quantity	Value
1971	466	765	1,231	607	624	11,008
1972	477	727	1,204	568	636	11,396
1973	481	824	1,305	695	610	11,597
1974	513	710	1,223	602	621	16,411
1975	391	722	1,113	508	605	27,667
1976	422	695	1,117	516	601	32,655
1977	614	474	1,088	511	577	29,313
1978	599	461	1,060	511	549	27,865
1979	555	462	1,017	533	484	29,689
1980	613	421	[4]1,033	504	529	36,389
1981	604	404	1,008	456	552	43,186
1982	420	364	784	W	W	W
1983	388	388	776	392	384	39,425
1984	388	403	791	396	395	40,125
1985	340	396	736	383	353	35,860
1986	328	435	763	404	359	34,102
1987	312	413	725	379	346	33,086
1988	312	431	743	382	361	31,377
1989	291	394	685	345	340	31,104
1990	345	368	713	364	349	33,748
1991	367	353	720	366	354	30,904
1992	341	268	609	272	337	26,262
1993	NA	NA	651	329	322	24,643

NA Not available. W Withheld to avoid disclosing company proprietary data.

[1] All quantities converted to 100% Na_2SO_4 basis.

[2] Current Industrial Reports, Inorganic Chemicals, Bureau of the Census. MQ28A, Feb. 1994.

[3] Includes Glauber's salt.

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

TABLE 7
SODIUM SULFATE YEAREND PRICES

		1992	1993
Sodium sulfate (100% Na_2SO_4):			
East, bulk, carlot, works, freight equalized	per ton	$113.00-$114.00	$113.00-$114.00
Gulf, bulk, carlot, same basis	do.	110.00	110.00
West, bulk, carlot, same basis	do.	127.00	127.00
Salt cake (100% Na_2SO_4):			
East, bulk, f.o.b. works	do.	72.00	72.00

Sources: Chemical Marketing Reporter. Current Prices of Chemicals and Related Materials. V. 242, No. 26, Dec. 28, 1992, p. 29, and V. 245, No. 1, Jan. 3, 1994, p. 31.

TABLE 8
U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake		Disodium sulfate, other		Total	
	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)
1992:						
Argentina	1,000	103,000	2	3,627	1,002	106,627
Australia	71,917	1,795,235	—	—	71,917	1,795,235
Bahamas, The	40	4,095	—	—	40	4,095
Bahrain	—	—	22	41,856	22	41,856
Belize	20	3,837	—	—	20	3,837
Brazil	—	—	2	2,762	2	2,762
Canada	286	37,715	—	—	286	37,715
Chile	15,827	1,844,556	4,008	388,752	19,835	2,233,308
China	—	—	19	20,975	19	20,975
Colombia	10,822	440,966	5,890	588,985	16,712	1,029,951
Dominican Republic	14	2,596	—	—	14	2,596
El Salvador	500	61,500	—	—	500	61,500
Germany	—	—	3	9,654	3	9,654
Guatemala	4,687	576,539	2,909	307,848	7,596	884,387
Hong Kong	—	—	64	63,284	64	63,284
Japan	—	—	46	22,372	46	22,372
Korea, Republic of	10,761	1,272,175	115	888,536	10,876	2,160,711
Mexico	339	27,342	1,079	294,721	1,418	322,063
New Zealand	13,480	1,379,723	—	—	13,480	1,379,723
Panama	—	—	(2)	5,250	(2)	5,250
Portugal	—	—	94	60,264	94	60,264
Singapore	—	—	15	16,380	15	16,380
Spain	—	—	2	4,941	2	4,941
Switzerland	—	—	(2)	4,295	(2)	4,295
Taiwan	—	—	28	53,808	28	53,808
United Kingdom	—	—	14	3,783	14	3,783
Venezuela	3,945	473,992	6,792	597,427	10,737	1,071,419
Total	133,638	8,023,271	21,104	3,379,520	154,742	11,402,791
1993:						
Argentina	9,570	957,095	1	5,280	9,571	962,375
Australia	17,933	1,787,585	2,545	563,671	20,478	2,351,256
Bermuda	—	—	16	5,434	16	5,434
Brazil	—	—	19	26,417	19	26,417
Canada	1,615	160,939	—	—	1,615	160,939
China	—	—	16	18,810	16	18,810
Colombia	22,933	1,117,275	445	154,908	23,378	1,272,183
El Salvador	—	—	968	115,000	968	115,000
Germany	—	—	18	50,372	18	50,372
Guatemala	—	—	4,000	460,000	4,000	460,000
Honduras	—	—	18	3,547	18	3,547
Hong Kong	—	—	1	3,900	1	3,900
Italy	798	86,888	—	—	798	86,888
Japan	—	—	172	83,188	172	83,188
Korea, Republic of	14,051	799,708	—	—	14,051	799,708
Mexico	472	57,614	2,646	801,582	3,118	859,196

See footnotes at end of table.

TABLE 8—Continued

U.S. EXPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake		Disodium sulfate, other		Total	
	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)	Quantity (metric tons)	Value[1] (dollars)
1993—Continued:						
Netherlands	—	—	1	3,801	1	3,801
New Zealand	6,657	618,476	—	—	6,657	618,476
Panama	—	—	44	179,940	44	179,940
Taiwan	—	—	115	53,809	115	53,809
Thailand	—	—	1	5,754	1	5,754
Venezuela	—	—	3,986	418,546	3,986	418,546
Total	74,029	5,585,580	[3]15,013	2,953,959	89,041	8,539,539

[1] F.a.s. value at U.S. ports.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9

U.S. IMPORTS OF SODIUM SULFATE, BY COUNTRY

Country	Disodium sulfate, salt cake[1] [2]		Disodium sulfate, other		Total	
	Quantity (metric tons)	Value[3] (dollars)	Quantity (metric tons)	Value[3] (dollars)	Quantity (metric tons)	Value[3] (dollars)
1992:						
Canada	83,931	7,831,881	73,957	5,560,087	157,888	13,391,968
Germany	125	12,344	—	—	125	12,344
Japan	138	1,326	—	—	138	1,326
Mexico	12	7,796	191	29,441	203	37,237
United Kingdom	1	1,326	—	—	1	1,326
Total	84,207	7,854,673	74,148	5,589,528	158,355	13,444,201
1993:						
Canada	88,269	8,480,964	73,004	4,958,387	161,273	13,439,351
Germany	33	71,531	6	3,084	39	74,615
Japan	1,147	52,519	—	—	1,147	52,519
Mexico	51	38,278	—	—	51	38,278
United Kingdom	41	31,224	—	—	41	31,224
Total	89,541	8,674,516	73,010	4,961,471	162,551	13,635,987

[1] Salt cake is HTS No. 2833.11.1000.

[2] Includes Glauber's salt, HTS No. 2833.11.5050.

[3] C.i.f. value at U.S. ports.

Source: Bureau of the Census.

TABLE 10
SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993•
Natural:					
Argentina (mirabilite)	10,281	[r]12,677	[r]13,520	[r]9,788	10,000
Canada	[r]323,000	[r]345,000	332,000	[r]282,000	315,000
Chile[3]	10,245	13,497	•13,000	•13,200	13,200
China• [4]	27,000	27,000	28,000	28,000	29,000
Egypt	45,677	41,418	41,110	•41,000	41,000
Iran	184,848	176,951	144,204	[r]237,459	250,000
Mexico[5] (bloedite)	478,000	545,157	517,600	[r]534,445	500,000
Netherlands•	22,000	22,000	22,000	22,000	20,000
South Africa, Republic of	15	•20	[r]—	[r]37,169	26,000
Spain[6]	[r]538,605	[r]716,440	[r] •700,000	[r] •675,000	650,000
Turkey (concentrates)	68,183	[r]110,273	[r] •115,000	[r]75,058	80,000
Turkmenistan•	—	—	—	[r]100,000	70,000
U.S.S.R.• [7]	365,000	340,000	320,000	70,000	60,000
United States	339,761	349,256	353,836	336,829	[8]327,249
Total	[r]2,412,615	[r]2,699,689	[r]2,600,270	[r]2,461,948	2,391,449
Synthetic:					
Austria•	120,000	120,000	120,000	120,000	120,000
Belgium•	255,000	250,000	[r]260,000	250,000	250,000
Bosnia and Herzegovina•	—	—	—	5,000	1,000
Brazil•	9,000	9,000	9,000	9,000	9,000
Chile[9]	56,245	59,509	•60,000	•61,800	61,800
Finland•	33,000	33,000	33,000	[r]30,000	30,000
France•	120,000	120,000	[r] [8]93,000	[r] [8]77,000	75,000
Germany:					
Eastern states	•175,000	•170,000	—	—	—
Western states	172,178	167,120	—	—	—
Total	•347,178	•337,120	[r]145,943	[r]113,660	110,000
Greece•	6,000	6,000	6,000	6,000	6,000
Hungary•	9,000	8,000	[r]6,000	[r]6,000	6,000
Italy•	130,000	[r]125,000	125,000	125,000	125,000
Japan	256,393	253,131	249,817	[r]242,771	245,000
Macedonia•	—	—	—	3,000	1,000
Netherlands•	15,000	15,000	15,000	15,000	15,000
Pakistan•	1,000	1,000	1,000	1,000	1,000
Portugal•	55,000	[r]50,000	50,000	50,000	50,000
Serbia and Montenegro•	—	—	—	[r]5,000	5,000
Spain•	[r]160,000	[r]150,000	150,000	150,000	150,000
Sweden•	100,000	100,000	100,000	100,000	100,000
Turkey•	27,000	27,000	30,000	30,000	30,000
U.S.S.R.• [7]	270,000	250,000	220,000	180,000	160,000
United Kingdom•	90,000	90,000	90,000	90,000	90,000

See footnotes at end of table.

TABLE 10—Continued

SODIUM SULFATE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country[2]	1989	1990	1991	1992	1993[e]
Synthetic—Continued:					
United States[10]	345,555	315,604	342,576	272,484	[e]323,751
Yugoslavia[11]	50,333	37,953	[e]35,000	—	—
Total	[r]2,455,704	[r]2,357,317	[r]2,141,336	[r]1,942,715	1,964,551
Grand total	[r]4,868,319	[r]5,057,006	[r]4,741,606	[r]4,404,663	4,356,000

[e] Estimated. [r] Revised.

[1] Table includes data available through May 31, 1994.

[2] In addition to the countries listed, 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 inadequate for the formulation of reliable estimates of output levels.

[3] Natural mine output, excluding byproduct output from the nitrate industry, which is reported separately under "Synthetic" in this table.

[4] Byproduct sodium sulfate is known to be recovered but reliable data are not available; not included under "Synthetic."

[5] Series reflects output reported by Industrias Penoles plus an additional 22,000 tons estimated production by Sulfato de Viesca.

[6] Na_2SO_4 content of glauberite and thenardite.

[7] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries, other than listed in this table.

[8] Reported figure.

[9] Byproduct of nitrate industry.

[10] 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).

[11] Dissolved in Apr. 1992.

CRUSHED STONE

By Valentin V. Tepordei

Mr. Tepordei, a geological engineer with more than 20 years of industry experience, has been the crushed stone commodity specialist with the U.S. Bureau of Mines since 1981. Domestic survey data were prepared by the crushed and broken stone survey staff of the Branch of Data Collection and Coordination.

Crushed stone is one of the most accessible natural resources and a major basic raw material used by a wide range of industries from construction to agriculture, chemicals, and complex industrial processes. Despite the relative low-value of its basic products, the crushed stone industry is a major contributor to and an indicator of the economic well-being of the Nation.

Beginning with this issue, the statistical information included in the Annual Report for Crushed Stone is published in metric units in compliance with the provisions of the Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418). The information that was published in prior years in short tons was converted to metric tons in this issue of the Annual Report. During 1994, only the totals in each table are published in dual units: metric tons and short tons.

A total of 1.1 billion metric tons (1.23 billion short tons) of crushed stone was produced for consumption in the United States in 1993, a 5.9% increase compared with the total production of 1992. This tonnage represents the second highest production level ever recorded, indicating a continued increase in the demand for construction aggregates in the United States in 1993. *(See table 1.)*

About three-quarters of the crushed stone production continued to be limestone and dolomite, followed by granite, traprock, sandstone and quartzite, miscellaneous stone, calcareous marl, marble, volcanic cinder and scoria, shell, and slate, in order of volume. *(See table 2.)*

Foreign trade of crushed stone continued to remain relatively minor in 1993. Exports increased 31.9% to 4.8 million metric tons (5.3 million short tons), while value decreased 9.5% to $39.3 million compared with that of 1992. Imports of crushed stone, including calcium carbonate, increased 20% to 8.4 million metric tons (9.3 million short tons), while the value increased 22.4% to $74.3 million. Domestic apparent consumption of crushed stone was 1.1 billion metric tons. *(See tables 1, 22, and 23.)*

The major issues of concern to the crushed stone industry continue to be: the implementation of the Clean Air Act Amendments of 1990 and its complex legal and technical provisions; the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the associated "no net loss of wetlands" policy; the Storm Water Pollution Prevention Program; the Occupational Safety and Health Administration's (OSHA) Hazard Communication Standards regulating the use of products containing more than 0.1% crystalline silica; and the provisions of the Federal Endangered Species Act.

DOMESTIC DATA COVERAGE

Domestic production data for crushed stone are developed by the U.S. Bureau of Mines (USBM) from voluntary surveys of U.S. producers. Full surveys of crushed stone producers are conducted for odd-numbered years only. For even-numbered years, only annual estimates for each State are generated based on information provided by the quarterly sample survey of crushed stone and sand and gravel producers. This survey, implemented by the USBM in 1989, provides production estimates by quarters for each State and the nine geographic regions. The sample surveys canvass most of the large companies in each State, accounting for most of each State's production. The results of this survey are published each quarter in the Quarterly Mineral Industry Survey of Crushed Stone and Sand and Gravel Producers.

Of the 5,371 crushed stone operations surveyed, 3,213 operations with 3,915 quarries were active. Of these, 2,748 operations with 3,335 quarries representing 85.5% of the total number of operations reported to the USBM survey, and their total production represented 91.8% of the total U.S. crushed stone output. The nonrespondent's production was estimated using employment data and/or adjusted prior years' production reports. Of the 2,748 reporting operations, 519 operations with 602 quarries did not report a breakdown by end use. Their production represented 21.6% of the U.S. total and is included in table 13 under "Unspecified uses, actual." The estimated production of 465 nonresponding operations represented 8.2% of the U.S. total and is included in table 13 under "Unspecified uses, estimated." A total of 1,210 quarries were either idle or presumed to have been idle in 1993 because no information was available to estimate their production. A total of 677 operations were closed down since 1991, the last year when a full survey of crushed stone producers was conducted.

BACKGROUND

Crushed stone is a term applied to rock that has been broken and/or crushed after quarrying. It is a low-value product characterized by its "place value," a term that describes the importance of the location of the geologic deposit in reference to the market. Stone in its multitude of forms represents a very significant part of the Earth's crust. As one of the most accessible natural resources, it has been used since the earliest days of our civilization. First used as a tool or weapon, it was then used as a construction material, and later, in its crushed form, as one of the basic raw materials for a wide variety of uses, ranging from agriculture and chemicals to complex industrial processes.

The beginnings of the crushed stone industry are difficult to trace, but it is known that the Greeks, and later the Romans, the first great road builders, used limestone and lime extensively.[1] In the 19th century, the mining of crushed stone was labor intensive. Men with sledge hammers and shovels used their muscles to work the quarries and produce crushed stone that was used mostly for road and railroad construction.[2] The modern crushed stone industry began in England in about 1815 and expanded rapidly after the invention of the mechanical rock crusher in 1858.[3] Today's crushed stone industry is vastly different. It evolved from a labor-intensive to a capital-intensive industry where the work force mostly directs and controls sophisticated and powerful equipment operating in the quarries.

In the United States, railroad ballast was the principal market for the crushed stone industry during the last half of the 19th century. Passage of the Federal Aid Highway Act in 1916 acknowledged the national importance of highways, and subsequent highway construction created a new and significantly larger market. The crushed stone industry grew tremendously, especially in the second half of this century. Production increased from 130 million tons in 1928 to a high of 1.25 billion tons in 1988, mainly owing to rapidly increasing demand for highway, railroad, and other construction work. Today the volume of crushed and broken stone produced is greater than that of any other mineral mined in the United States. The United States is, in general, self-sufficient in crushed stone, producing enough to meet most of the domestic needs. Small quantities of crushed stone, used mostly as construction aggregates, are being imported by water from the Bahamas, Canada, and Mexico.

Most of crushed stone is used for construction purposes, mainly as aggregate with or without a binder. Road base or road surfacing material, macadam, riprap, and railroad ballast are the major uses without a binder. Aggregate for cement and bituminous concrete in highway and road construction and repair and in residential and nonresidential construction are the major uses for aggregates with a binder. Other uses include cement and lime manufacture, agriculture, metallurgical flux, and fillers and extenders.

Although crushed stone resources are widespread and in adequate supply in most parts of the United States, local shortages exist. Land use conflicts and environmental problems associated with rapid urban expansion are major factors contributing to these shortages. Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future.

Definitions, Grades, and Specifications

Crushed and broken stone is a term applied to rock that has been broken and/or crushed into smaller, irregular fragments or ground to specified particle sizes. Crushed stone is also classified by kind of stone, including limestone, dolomite, marble, shell, granite, traprock, sandstone, quartzite, slate, volcanic cinder and scoria, and miscellaneous stone. The terminology used by the crushed stone industry is not always consistent with mineralogical definitions. Limestone and dolomite are rocks composed, respectively, of the minerals calcite, $CaCO_3$, and dolomite, $CaMg(CO_3)_2$; however, they are usually called limestone by the industry, and intermediate varieties are seldom distinguished. Some deposits of limestone consist chiefly of the mineral aragonite, which has the same composition as calcite, but has a different crystal structure. Marble may include any calcareous rock that will accept a polish. Marl is calcitic and contains varying amounts of shale or clay. Granite includes the coarser grained igneous rocks such as true granite and syenite. Gneisses, although metamorphic rocks, are usually included with granite. Quartzite is a well cemented sandstone that is indurated to the extent that, when fractured, it breaks across the grain. Traprock includes all dense, dark, and fine-grained igneous rocks such as basalt, diabase, and gabbro.

Crushed stone in its different rock types and particle sizes is used in a wide variety of applications in many industries, including construction, chemical, metallurgical, and agriculture. For the purpose of collecting and disseminating production information, the USBM generally accepts the rock type classification and the principal end uses and their definitions as reported by the crushed stone producers.

Specifications for crushed stone are numerous because of the large number and the variety of uses, the diversity of stone types, and the variations in physical and chemical requirements for different uses. Various national specifications and tests exist for crushed stone products, but the most active organizations in preparing and reviewing them are the American Society for Testing and Materials (ASTM)[4] and American Association of State Highway and Transportation Officials (AASTO). For construction aggregates, these are regarded by industry as guide or reference specifications. State specifications are often much more stringent and vary from State to State. The most common specifications and tests relate primarily to gradation, but soundness, shape, abrasion resistance, porosity, chemical compatibility, and content of soft particles are also important.[5] Specifications for construction aggregates are written by commercial users; government agencies, including Federal, State, county, and city construction and highway departments, and the ASTM. Problems arise for the producers of construction aggregates when their product is sold or used in several different cities, counties, or States, many of which may have different specifications. Some progress is being made toward the standardization of aggregate sizes for similar requirements. A need exists for a more active interchange of data and experience among aggregate consumers and producers.

Specifications for limestone used in portland cement manufacture require a content of more than 75% calcium carbonate ($CaCO_3$) and less than 3% magnesium carbonate ($MgCO_3$). For white portland cement, the iron content of the raw materials should be very low, less than 0.01%. Because raw materials are finely ground for processing, chert nodules or coarse quartz grains are undesirable. Limestone for lime manufacture should contain more than 90% calcium carbonate, often more than 97% or 98%, less than 5% magnesium carbonate, and less than 3% of other impurities. For lime produced in vertical kilns, 12.7 to 20.3 centimeters stone is recommended, while in rotary kilns 0.95 to 6.35 centimeters 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 2.5 to 10 centimeters, 5 to 10 centimeters, and 7.6 to 15 centimeters. The limestone or dolomite used for glassmaking should contain at least 98% $CaCO_3$ or $MgCO_3$, respectively, and less than 0.05% to 0.02% iron oxide. Size specifications vary with the manufacturer and the kind of glass being produced, but uniformity is a major requirement; usually 100% of the material should pass a No. 10 sieve (2 millimeter) and 96% to 100% should be retained on a No. 100 sieve (0.15 millimeter).

Requirements for agricultural limestone are not very rigid and depend on the specific use: as direct application to soil, as filler and conditioner for fertilizers, in animal mineral feeds, or as poultry grit. In all of these applications, $CaCO_3$ or $MgCO_3$ equivalent or content is of major significance. Many individualized specifications exist for a wide variety of industrial applications, mostly pulverized limestone for rock dusting, or as asphalt, plastic, rubber, paper, or paint fillers or extenders.[6]

Uses and Products for Trade and Industry

The ultimate use of crushed stone determines the specification for particle size and gradation, shape, rock type, and chemical composition. Crushed stone can be used without any binder, for a variety of construction or industrial applications, or it may be mixed with a matrix binding material such as bituminous or portland cement. The most common use of crushed stone for construction purposes is as aggregate without a binder, including road base or road surfacing material, macadam, riprap, railroad ballast, filter stone, etc. The second largest use of crushed stone is as aggregate for cement and bituminous concrete in a variety of forms and applications in residential and nonresidential construction, highway and road construction and repair, airports, dams, sewers, and foundations. Sized crushed stone is used to make asphaltic concrete aggregate and road bases. Broken surfaces adhere to the hot asphaltic mixture better than rounded surfaces do and provide interlocking surfaces that tend to strengthen the asphaltic concrete. Broken particles pack better and tend to move less under load than rounded particles do and, therefore, make better road bases for highway and road construction. This is essential because bases and asphaltic concrete tend to flow when placed under great or long duration stresses. Other uses include limestone for cement and lime manufacturing and as agricultural limestone used as direct application to soil, as filler and conditioner for fertilizers, in animal mineral feeds, or as poultry grit. Smaller amounts of crushed stone are used for a wide variety of applications ranging from metallurgical fluxing of antimony, copper, iron, lead, and zinc to the manufacture of glass, ceramic pottery, paper, and as fillers and extenders in asphalt, paint, rubber, and plastics.

A growing amount of limestone is being used in the removal of sulfur oxides from stack gases, primarily from coal burning electric generating stations, and for mine dusting to enhance mine safety by reducing the explosion risk of highly combustible coal dust.

Industry Structure

Because of the low unit value, crushed stone is usually produced near the point of use; therefore, the industry is concentrated mostly in or nearby large, rapidly expanding urban areas. Crushed stone is produced in every State except Delaware, with more than 75% of the national total coming from two major geographic regions, the South and Midwest. The largest quarries tend to be concentrated in the States with the largest population and largest productions of crushed stone.[7]

Although limestone is produced in all States except Alaska, Delaware, Louisiana, New Hampshire, and North Dakota, the major producing States are east of the Rockies. Crushed marble is produced mostly in the eastern part of the United States in Alabama, Georgia, and Pennsylvania. Crushed granite is produced primarily in Appalachia, with Georgia, North Carolina, South Carolina, and Virginia being the largest producing States. Crushed traprock is produced mainly in the northeast and the Pacific

Coast States, with California, Connecticut, Massachusetts, New Jersey, Oregon, and Washington the largest producing States. Crushed sandstone and quartzite are produced in 27 States led by Arkansas, California, and Pennsylvania. Most crushed slate is produced in the eastern part of the United States, mainly in Arkansas, Georgia, and Virginia. Shell, primarily oyster residue, is produced by dredging along the gulf coast. Volcanic cinder is produced in the West, mainly in Arizona, California, and New Mexico.

On the basis of tonnage, the crushed stone industry is the largest nonfuel mineral industry in the United States. The industry is widespread and has a large variation in operation size, kind of stone, and size of material produced. The individual companies range in size from small, independent producers with one quarry to large, diversified corporations with 50 or more crushed stone operations.

In 1993, 1,566 companies produced crushed stone from 3,213 operations with 3,915 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 1993, for example, 71 operations each reporting production of more than 2 million tons per year represented only 2.2% of the total number of operations, but accounted for 19.6% of total crushed stone production. *(See table 7.)* The large operations are owned or operated by a small number of companies. In 1993, the combined production of the top 10 producers operating 509 quarries accounted for 31% of the total output of crushed stone in the United States.

The 10 leading producers were Vulcan Materials Co., Beazer USA Inc./Hanson PLC, Martin-Marietta Aggregates, CSR America, Inc., Rogers Group Inc., Lafarge Construction Materials, Florida Rock Industries Inc., Tarmac America, Inc., Dravo Basic Materials Co., and Lone Star Industries Inc.

In the past several years, significant changes in the structure of the crushed stone industry have occurred, caused primarily by mergers and acquisitions. An established and well-managed company with significant reserves in the ground becomes a potential target of larger companies trying to lock up sufficient reserves or expand into the aggregate business. Some of the recent acquisitions were made by foreign companies or were associated with the influx of foreign capital. Four of the top 10 crushed stone-producing companies in 1993 are subsidiaries of foreign companies.

The United States is the largest producer of crushed and broken stone among the market economy countries. Other major producing countries are Australia, Canada, France, Germany, Japan, and the United Kingdom. Some information about the production of crushed stone in foreign countries may be found in the USBM Minerals Yearbook Volume III, Area Reports: International. For nonreporting countries, estimates of crushed stone outputs can be based on indirect sources such as the level of cement consumption.

Geology-Resources

Bedrock deposits are classified on the basis of their origin into sedimentary, igneous, and metamorphic rocks. Sedimentary rocks were produced from the consolidation of loose sediments through chemical or mechanical sedimentation. Limestone, which is primarily calcium carbonate ($CaCO_3$), and dolomite, which is calcium-magnesium carbonate ($CaMg(CO_3)_2$), are the most common sedimentary rocks produced through chemical or biochemical sedimentation. Limestone and dolomite formations are widespread in the United States, with most of the deposits being of Paleozoic age, with a few of Mesozoic and Tertiary age. Most States have adequate reserves for use in construction and other applications that do not require chemically pure stone.[8] High-calcium limestone and high-purity dolomite make up only a small fraction of all limestone and dolomite formations, and they occur in restricted areas, mostly in the eastern part of the United States, with some formations in the Western States as well.[9] High-purity dolomite deposits are more limited in occurrence than the high-calcium limestone. Of the clastic sedimentary rocks that are produced through mechanical sedimentation, only sandstones, rocks consisting predominantly of cemented sand-size particles, are, to a limited extent, used as crushed stone.

Igneous rocks, rocks that solidify from molten volcanic magma, are classified as intrusive and extrusive rocks. Intrusive or plutonic rocks are those that were formed deep beneath the ground surface, are coarse grained, and include granite, diorite, and gabbro as rock types. Extrusive or volcanic rocks are igneous rocks that were formed from molten volcanic magma at the Earth's surface, are fine-grained, and include andesite, rhyolite, and basalt. Plutonic and volcanic rocks are further subdivided on the basis of mineralogy in light-colored igneous rocks with high-silica content that includes granite, diorite, rhyolite, and andesite, and dark-colored igneous rocks low in silica content that include gabbro, diabase, and basalt, commonly called traprock. Granite and traprock are the most common igneous rock types used as crushed stone. Granite occurs primarily in the eastern part of the United States from Maine to Georgia, along the Appalachian Range where major producing States are located. It also occurs in Arkansas, Minnesota, Missouri, Oklahoma, Texas, and Wisconsin and in all Western States except Utah. Most of the traprock occurs in California, Hawaii, Idaho, Oregon, and Washington in the West; in Connecticut, Maryland, Massachusetts, New Jersey, New York, North Carolina, Pennsylvania, and Virginia in the East; and to a smaller extent in Minnesota and Texas.

Metamorphic rocks are formed from preexisting rocks through mineralogical, chemical, and structural changes produced by high heat and pressure. The metamorphic rocks include gneisses, marbles, quartzite, slates, and schists. Marble, quartzite, and slate are the major types of metamorphic rocks used to some extent as crushed stone. Marble occurs primarily in Alabama, Georgia, New York, Vermont, and Virginia in the East and in California and Texas in the West.

A comprehensive report showing geologic occurrences of potential sources of crushed stone and sand and gravel of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.[10]

On the basis of geologic evidence, stone resources of the United States and the world are sufficient to meet demands, although not always precisely at the locations where needed. Reserves, which are measurable amounts of crushed stone that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of stone available is so vast as to preclude the necessity of measurement on a large scale. The local shortages that occasionally exist are caused less by a lack of stone than by urban encroachment or zoning regulations that force closure of operating quarries or prevent the development of new ones.

Technology

Major technological developments have been instrumental in maintaining adequate production at relatively stable real costs in the crushed stone industry. Equipment manufacturers usually conduct most of the research related to improvements in the mining and processing of crushed stone operations. Larger, more efficient equipment is being developed and improved constantly. The use of computerized control systems in plant operation and quality control has increased significantly in recent years. Automatic controls, along with monitoring by closed-circuit television coordinated with automated counting and recording and radio communications systems, have been installed in many of the larger and newer operations. Automated plants have significantly improved operating efficiency and produce the optimal product mixture to fit market requirements at lower cost.

As part of the national drive to reduce air pollution, significant progress is being made toward the desulfurization of stack gases resulting from coal burning electric generating stations and some industrial installations.[11] Limestone and lime are used as chemically reactive agents in most of the dry or wet scrubbing processes as well as in the treatment of acidified waters, specifically lakes and streams.

Exploration.—A large number of geologic formations that have economic potential as a source of crushed stone have been mapped and described in the literature over the years. Consequently, detailed exploration and development work for any new crushed stone operation will most probably be done on one of these formations. However, in the event that a new stone deposit is discovered, more exploration and evaluation work would be required before development. Preliminary examination can establish the extent and nature of the deposit. This is followed by a detailed exploration program aimed at obtaining reasonably accurate information about the quality of the available material, including the kind of stone, its chemical composition and degree of cementation, and the degree of uniformity throughout the deposit. Also, the nature and the amount of waste material and the economic feasibility of its removal, processing, and marketing must be studied. In most cases, an environmental impact study is required by local or State agencies.

If the raw material cost and quality are proven to be adequate and sufficient reserves are demonstrated, the development stage of the operation can be started. Economic feasibility and marketing studies include: analysis of the availability of power and water supply; mining and processing costs and requirements; the condition of nearby roads and highways and the proximity of rail haulage; the cost of compliance with local, State, and Federal regulations; and the proximity and density of local population, as well as its attitude toward such a project.

Mining.—Most crushed and broken stone is mined from open quarries; however, in many areas, factors favoring large-scale production by underground mining are becoming more frequent and more prominent.

Surface mining equipment varies with the kind of stone mined, the production capacity needed, the size and shape of the deposit, estimated life of the operation, location of the deposit with respect to urban centers, and other important factors. Ordinarily, drilling is done with tricone rotary drills, long-hole percussion drills, and churn drills. Blasting in smaller operations may still be done with dynamite, but in most medium- to large-size operations ammonium nitrate-fuel oil mixtures (AN-FO), which are much lower in cost, are used.

Underground operations are becoming more common, especially for limestone mining in the central and eastern parts of the United States, as the advantages of such operations are increasingly recognized by the producers. By operating underground, a variety of problems usually connected with surface mining such as environmental impacts and community acceptance are significantly reduced. Underground room-and-pillar mines can be operated on a year-round basis, do not require extensive removal of overburden, and produce a minimum of environmental disturbance. The need for less surface space is also an important factor in areas of high land costs. Subsidence has not been a problem in areas mined, and the conventional practice has been to leave 12% to 15% of pillar areas and 2 to 2.5 meters of stone in the mined roof. A specific advantage of underground quarries is the creation of valuable storage facilities. In many cases, the value of the sale or rental of the storage space may exceed the value of the stone mine. Thus, the incentives for producing stone from underground mines can be enhanced by the economic advantages of subsequent use of the excavated areas.

Loading and hauling equipment has grown larger as increased demand for stone has made higher production capacities necessary. Track-mounted equipment is still used extensively, but hydraulic, tire-mounted hauling equipment is predominant.

Processing.—Processing plants have become larger and more efficient, in part because of an increase in the use of computerized control systems. Programmable controllers and/or computers are viewed today as valuable tools that improve operating efficiency and product quality. Primary crushing is often done at or near the pit, usually by jaw or gyratory crushers, but impact and other special types of crushers are also used for nonabrasive stone or stone that tends to clog conventional crushers. The cost effectiveness of permanent crushing installations can be limited because the raw material moves away from the primary stage. It becomes increasingly expensive to haul material from the production face to the crushing plant. Improved crusher technology and increased capacity toward greater equipment mobility are accelerating the use of in-pit movable primary crushers. There is an increased interest in the use of portable crushers ranging in size from 500 tons per hour up to 5,000 tons per hour. For secondary crushing, a variety of comminution equipment is used, depending on plant size, rock type, and kind of material being produced. Cone crushers and gyratory crushers are the most common types used, but impact crushers, including hammer mills, and roll crushers are often used. Belt conveyors are being used extensively to haul material within the quarry because they provide continuous operation, low maintenance costs, low work force requirements, and reduced noise levels. Conveying systems are often associated with in-pit crushers and consist of several portable units and a stationary field conveyor. The portable conveyors, usually in 30- to 60-meter lengths, make the connection between the portable crusher and the field conveyor and provide a good range of motion. The increased use of conveyors reduces significantly the use of haul trucks in quarries.

Screening is the single most important part of the processing cycle of crushed stone particles. A wide variety of screen types exists, and their selection is a function of the material processed as well as the final product required. Inclined vibratory screens are most commonly used in stationary installations, while horizontal screens are used extensively in portable plants. For screening large sizes of crushed stone, grizzly bars, rod decks, and heavy punched steel or plastic plates are used; for smaller sizes, woven wire, welded wire cloth, rubber, or plastic screens are used.

Processed crushed stone is usually stored in open areas except for relatively small quantities that go to the loadout bins. In the more efficient plants, the crushed stone is transported from the storage piles on belt conveyors through tunnels installed under the piles, thus facilitating the blending of any desired mixture of sizes from different piles.

Recycling.—As the Nation moves into an age of increased environmental consciousness, recycling of old concrete and asphalt, used mostly in pavements, is increasing. Waste disposal problems as well as local scarcity or high cost of construction aggregates in some areas are making recycling more attractive economically. In some States, limited recycling, especially in road construction, is either encouraged or required by law. The best utilization for recycled cement concrete is as road base material, because the matrix of concrete cannot be converted back to cement, and also because of the lower strength of concrete compared with that of natural aggregates. Sound crushed concrete can make good coarse aggregate, but the fines produced in crushing the concrete have a higher absorption, are more friable, and will require a higher amount of asphalt in asphaltic concrete and a higher amount of mixing water in portland cement.[12]

The amount of asphalt roads recycled is significantly larger than that of concrete roads, mainly because asphalt can be rejuvenated with oil additives and used in pavements, significantly reducing the cost of the finished road. Experience has shown that about 35% of crushed asphalt pavement can be recycled into new asphalt mixtures. Proper testing under engineering supervision in all construction projects using recycled materials as aggregates should be performed to ensure that the technical specifications are met.

Byproducts and Coproducts

Clay of good quality is sometimes encountered in limestone overburden and is mined as a coproduct. Gypsum is often encountered beneath beds of limestone and is mined as a coproduct. Amphibolite rock often occurs as formations paralleling spodumene-bearing pegmatitic dikes and is mined concurrently with these, notably in North Carolina. This coproduct of lithium mining is marketed primarily as roadstone. Stone is also mined in conjunction with many metallic ores and nonmetallic minerals, but seldom does a market exist for it.

Economic Factors

Crushed stone is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets, largely because stone is an abundant mineral. Production costs are determined mainly by the cost of labor, equipment, energy, and water, in addition to the costs of compliance with environmental and safety regulations. These costs vary depending on geographic location, the nature of the deposit, and the number and type of products produced. Despite having one of the lowest average per ton values of all mineral commodities, the constant dollar price of crushed stone has changed relatively little over the past 20 years. Increased productivity achieved through increased use of automation and more efficient equipment was mainly responsible for maintaining the prices at an almost constant level.

The delivered price of the product, in addition to quality, is a particularly important element in any major transaction because of the low unit value of crushed stone, and therefore, producers that are closest to markets have a significant advantage. Sophisticated equipment backed by technical knowledge combined with solid sales expertise are becoming very important. For this reason, large companies are better able to compete in the crushed stone business, especially when there is a need for a wide variety of products. Smaller, less efficient operations become less economical as operating costs, as well as costs associated with meeting various Federal, State, and local regulations, continue to increase. The only alternatives these producers have are to supply local markets with a limited number of products. The gradual trend toward larger operations has continued, mostly because the stone industry is capital intensive, and it is becoming less economical to operate small quarries. The viability of small operations is dependent on the demand in the local markets, mining costs, and the degree of processing required to supply the final product.

A 5% depletion allowance based on gross income is allowed for crushed stone used in construction, including aggregates. The depletion allowance for chemical and metallurgical crushed stone is 14%.

Operating Factors

Many States, counties, and cities in the United States have zoning laws, and land within each governmental unit is usually zoned to indicate acceptable land uses. If mining is permitted in a zone and a crushed stone company owns or leases land within that zone, the company may apply for a use permit or its equivalent to begin an operation. If the parcels to be quarried are on lands under both city and county jurisdiction, permits usually must be obtained from each. An acceptable reclamation plan that meets the guidelines or regulations of the appropriate governmental agency also must 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 also must 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 also may be required, with considerable overlap of subject matter with the EIS. A complete EIS may cover all the problem areas at once and facilitate acceptance.

Environmental Requirements.—Many of the environmental problems facing crushed stone producers arise because a great number of stone quarries and processing plants are in suburban areas near the major crushed stone markets. Major environmental considerations that must be dealt with in mining and processing of crushed stone are emission of particulate matter into the air, discharge of processing water, noise abatement, and employee and public health and safety. Air pollution constitutes a major problem in processing plants, especially in the drying and packaging stages of fine particle products such as limestone used as fillers or extenders. Both wet and dry methods of dust control are used. The most important water pollutant is clay in suspension that results from washing and screening crushed stone. Because of the large quantities of water used to process stone and the need for compliance with often stringent regulations, the treatment of discharge water by crushed stone producers is becoming a necessity that may require sophisticated and expensive processing methods. Significant progress has been made in reducing noise pollution both inside and outside of the quarries, including noise and vibration produced by blasting and movement of heavy trucks. Therefore, the industry must be concerned first about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards. Because crushed stone is a local industry, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of crushed stone into the marketplace. Also, stringent controls by the local governments that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of crushed stone into the marketplace.

Although much progress is being made through premining planning, the crushed stone industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas.

Transportation.—Transportation is a major factor in the delivered price of crushed stone. The cost of moving crushed stone from the plant to the market often equals or exceeds the sale price of the product at the plant. Because of the high cost of transportation and the large quantities of bulk material that have to be shipped, crushed stone is usually marketed locally. The high cost of transportation is responsible for the wide dispersion of quarries around the country, usually near highly populated areas.

However, increasing land values combined with local environmental concerns are moving crushed stone quarries farther from the end-use locations, increasing the price of delivered material. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the crushed stone industry, despite the fact that it is the most expensive mode of transportation on a cost-per-ton/per-kilometer basis. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of crushed stone, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable. Rail and water transportation combined account for about 8% of total crushed stone shipments. In recent years, an increased amount of crushed stone is being shipped into the United States by water from Bermuda, Canada, and Mexico using large ocean going vessels. Some of these are self-unloading vessels.

ANNUAL REVIEW

In 1993, a total of 1.1 billion metric tons (1.23 billion short tons) of crushed stone was produced for consumption in the United States, a 5.9% increase compared with that of 1992. This tonnage represents the second highest production level ever recorded in the United States.

Legislation

Department of Transportation and Related Agencies Appropriation Act of 1994 (Public Law 103-122) was signed by the President on October 27, 1994. The act appropriates $20.6 billion for new highway spending, a $2 billion increase from the fiscal year 1993 total. The act also includes a $2.2 billion appropriation in grants for airport construction and provision for a 1-year delay in the imposition of the "crumb rubber" use in highway construction as required by the Intermodal Surface Transportation Efficiency Act of 1991.

Issues

The implementation of the provisions of the amended Federal Water Pollution Control Act of 1977, the Clean Water Act, Section 404, dealing with "wetlands" and the establishment of a "no net loss of wetlands" policy constitutes one of the major areas of concern to the crushed stone industry. There is a significant amount of uncertainty regarding the process of designating some lands as wetlands and whether the current exemptions to the Clean Water Act, Section 404, permit program will be maintained in the future. On August 24, 1993, the administration's wetland policy was announced. The new policy endorses an interim goal of "no overall net loss" of wetlands and a long-term goal of increasing wetlands quantity and quality; provides for administrative appeals of permitting process decisions; establishes deadlines for the Army Corps of Engineers decisions on permit applications, generally within 90 days; mandates the use of the 1987 Wetlands Delineation Manual by the Army Corps of Engineers, Environmental Protection Agency (EPA), Soil Conservation Service, and Fish and Wildlife Service to identify wetland; encourages the development of wetland mitigation banks; and promotes the long-term restoration of wetlands through voluntary, nonregulatory programs.

Several bills were reintroduced in the 103d U.S. Congress to replace the current Section 404 of the Federal Water Pollution Control Act. The new proposed bills plan to provide a concise and structured program for the delineation of wetlands based on their functions and values and will balance the need for effective protection of the Nation's important wetlands with the need for essential community growth and the constitutional rights of landowners.

The complex legal and technical provisions of the comprehensive amendments of 1990 to the Clean Air Act and the implementing regulations for these provisions continues to constitute a major area of concern to the crushed stone industry. One major emphasis of the amendments is expanded authority given to EPA and the States to enforce the new law and assess increased penalties. EPA is now authorized to issue administrative orders with penalties of up to $200,000 for noncompliance, and its field inspectors can issue citations for minor violations with penalties of up to $5,000 per day for each violation. The law also includes provisions for new Federal permits to be issued by the State agencies that include source-specific emission limitations and related monitoring, recordkeeping, and reporting requirements. Complying with the new provisions of the Clean Air Act Amendments will constitute a major challenge to all crushed stone producers.

Another issue of concern to the construction aggregates industries is the classification of crystalline silica as a probable human carcinogen by the International Agency for Research on Cancer, an agency of the World Health Organization. OSHA-regulated sites that receive and/or use products containing more than 0.1% crystalline silica must comply with OSHA's Hazard Communication Standard. Both the classification of crystalline silica as a probable human carcinogen and the requirement to quantitatively analyze for crystalline silica at the 0.1% level are controversial.

Production

A total of 1.1 billion metric tons (1.23 billion short tons) of crushed stone was produced for consumption in the United States in 1993, a 5.9% increase compared with that of 1992. *(See table 1.)* Of this total, 793 million metric tons or 71% was limestone and dolomite, 169 million tons or 15.1% was granite, and 84 million tons or 7.6% was traprock. The remaining 6.3% was shared, in descending order of quantity, by sandstone and quartzite, miscellaneous stone, calcareous marl, marble, volcanic cinder and scoria, shell, and slate. *(See table 2.)*

A comparison of the four major geographic regions indicates that in 1993 the South continued to lead the Nation in the production of crushed stone with 516.5 million metric tons or 46.3% of the total, followed by the Midwest with 332.5 million metric tons or 29.8%, and the Northeast with 148.1 million metric tons or 13.3%. Approximately 76% of the total U.S. crushed stone output was produced in two major geographic regions, the South and the Midwest. *(See table 3.)*

Of the nine geographic regions, the South Atlantic led the Nation in the production of crushed stone with 271 million metric tons or 24.3% of the U.S. total. Next was the East North Central region with 208 million metric tons or 18.6% of the total, followed by the Middle Atlantic with 126 million metric tons or 11.3%.

A comparison of the estimated 1992 and reported 1993 production data by regions indicates that the output of crushed stone increased in all regions except the East South Central. The largest increases were recorded in the Pacific, +26.5%; the South Atlantic, +18.6%; and the Middle Atlantic, +10.9%.

Crushed stone was produced in every State except Delaware. The 10 leading States in the production of crushed stone, in order of volume, were Texas, Pennsylvania, Florida, Illinois, Missouri, Ohio, Virginia, Georgia, Kentucky, and North Carolina. Their combined production represented 51% of the national total.

In the second half of 1993, Beazer USA, Inc./Hanson Industries of Walnut Creek, CA, a subsidiary of Hanson PLC of London, United Kingdom, reorganized its U.S. operations to provide more local operational and financial control and to capitalize on the company's more recognizable names in regional markets. Beazer Northeast became General Materials & Construction Co. of Easton, PA; Beazer Southeast became Benchmark Materials Co. of Research Triangle Park, NC; Beazer Northwest became Kaiser Materials Corp. of Pleasanton, CA; and Beazer Southwest became Southwest Construction Materials and Services, Co. of Long Beach, CA; Gifford-Hill & Co. of Dallas, TX, and Spectrum Construction Co. of Virginia Beach, VA, that were also part of the Beazer Group will retain their original names.

On November 12, 1993, Martin Marietta Corp. announced that its construction materials division, Martin Marietta Aggregates, will become a separate company, Martin Marietta Materials Inc., located in Raleigh, NC. The new company that was incorporated in North Carolina will be a wholly owned subsidiary of Martin Marietta Corp. On December 8, 1993, a registration statement was filed with the Security and Exchange Commission for an underwritten public offering of about 19% of the company common stocks.

In December 1993, Lafarge Corp. of Reston, VA, announced the restructuring of its North American operations by consolidating 11 cement and construction materials regional operating units into 6 units. Effective January 1, 1994, Lafarge's new North American organization will include three regional centers for construction materials: Western, based in Calgary, Alberta, Canada; Eastern, based in Toronto, Ontario, Canada; and the United States, based in Canfield, OH; and three regional offices for cement's group located in Calgary, Alberta, Canada; Montreal, Quebec, Canada; and the United States in Southfield. MI.

Limestone.—The 1993 output of crushed limestone, including some dolomite, increased 13.1% to 724 million metric tons valued at $3.5 billion, compared with the 1991 totals. *(See table 2.)* In addition to the quarries reporting only limestone, 35 operations with 40 quarries reported producing limestone and dolomite, without making a distinction between the two kinds of stone. Their production, 15.6 million metric tons, was included with the limestone, and therefore, the limestone totals shown in this chapter include an undetermined amount of dolomite, in addition to the dolomite reported separately.

Limestone was produced by 940 companies at 1,959 operations with 2,109 quarries in 47 States. Leading States, in order of tonnage, were Texas, Florida, Missouri, Kentucky, and Pennsylvania; these five States accounted for 37% of the total U.S. output. *(See table 8.)* Leading U.S. producers were, in order of volume, Vulcan Materials Co., Beazer USA/Hanson, CSR America, Inc., Martin Marietta Aggregates, and Rogers Group, Inc. These five companies accounted for 21.7% of total U.S. output of limestone.

Dolomite.—Production of dolomite increased 7.9% to 69 million metric tons valued at $382 million, compared with the 1991 reported totals. *(See table 2.)* Crushed dolomite was reportedly produced by 92 companies at 142 operations with 148 quarries in 28 States. An additional undetermined amount of dolomite is included in the total crushed limestone. Leading States in the production of dolomite, in order of tonnage, were Pennsylvania, New York, Ohio, Virginia, and Indiana; these five States accounted for 42.9% of the total U.S. output. *(See table 8.)* Leading U.S. producers were Vulcan Materials Co., Asarco-American Limestone Inc., Lone Star Industries, Evered Bardon PLC, and Stabler Co.-Eastern Industries Inc. Their combined production represented 43.5% of the total U.S. dolomite production.

Marble.—Production of crushed marble increased only 2.5% to 3.5 million metric tons valued at $74 million. *(See table 2.)* Crushed marble was produced by 11 companies with 21 operations and 38 quarries in 8 States. Leading producers of crushed marble, in order of tonnage, were Georgia Marble Co., ECC Construction Materials Ltd., and Onoda Cement Co.; their combined production represented 86% of the total U.S. output.

Calcareous Marl.—Output of marl decreased slightly to 5.2 million metric tons valued at $26 million. *(See table 2.)* Marl was produced by 12 companies at 12 quarries in 7 States. South Carolina accounted for 55.6% of total U.S. output. *(See table 9.)* Leading producers, in order of tonnage, were Holnam Inc., Capital Aggregates Inc., and Giant Group Ltd.; their combined production represented 60.1% of the total U.S. output.

Shell.—Shell is mainly derived from fossil reefs or oyster shell. The output of crushed shell decreased 60.8% to 1.9 million metric tons valued at $12.3 million. *(See table 2.)* The decrease is mostly due to the restrictions imposed on the industry in Louisiana as a result of concerns that shell dredging produces irreversible damage to the environment. Crushed shell was produced by 14 companies from 14 operations in 5 States.

The major producing States were Florida and Louisiana, and the leading producers, in order of tonnage, were Dravo Basic Materials Co., Quality Aggregates Inc., and Highlands Co.; their combined production represented 67.9% of the U.S. output.

Granite.—Compared with that of 1991, the 1993 output of crushed granite increased 14.3% to 169 million metric tons valued at $1 billion. *(See table 2.)* Crushed granite was produced by 162 companies at 344 operations with 468 quarries in 34 States. Leading States, in order of tonnage, were Georgia, North Carolina, Virginia, South Carolina, and New Jersey; these five States accounted for 73.8% of the U.S. output. *(See table 10.)*

Leading U.S. producers, in order of tonnage, were Vulcan Materials Co., Martin Marietta Aggregates, Beazer USA/Hanson, Florida Rock Industries, Inc., and Tarmac America, Inc.; their combined production represented 56.3% of the U.S. total.

Traprock.—Production of crushed traprock increased 7.6% to 84.3 million metric tons valued at $525 million. *(See table 2.)* Traprock was produced by 256 companies at 373 operations with 593 quarries in 26 States. Leading States, in order of tonnage, were Oregon, Virginia, Washington, New Jersey, and California; these five States accounted for 62.1% of U.S. output. *(See table 10.)* Leading U.S. producers, in order of tonnage, were Evered Bardon PLC, Luck Stone Corp., Vulcan Materials Co., Beazer USA/Hanson, and Seubert Excavators, Inc.; their combined production accounted for 23% of the total U.S. output.

Sandstone and Quartzite.—The combined output of crushed sandstone and quartzite increased 7.2% to 30 million metric tons valued at $182.1 million. *(See table 2.)* Crushed sandstone was produced by 106 companies at 130 operations with 187 quarries in 33 States, while crushed quartzite was produced by 26 companies at 27 operations with 34 quarries in 16 States. Leading States in the production of sandstone and quartzite, in order of tonnage, were Pennsylvania, Arkansas, and South Dakota; their combined production represented 47.1% of the U.S. output. *(See table 10.)* Leading producers of sandstone and quartzite, in order of tonnage, were Western Mobile Inc., Arkola Sand and Gravel Co., Eucon Co., Martin-Marietta Aggregates, and Latrobe Construction Co. The combined production of the top five producers represented 26.8% of the total U.S. output.

Slate.—Compared with that of 1991, the 1993 output of crushed slate increased 29% to 1.9 million metric tons valued at $12.6 million. *(See table 2.)* Crushed slate was produced by 9 companies at 10 quarries in 6 States. Most of the crushed slate is produced in North Carolina. Leading producers, in order of tonnage, were Martin Marietta, Mariposa Aggregates Co., and Lesuer-Richmond Slate Corp.

Volcanic Cinder and Scoria.—Production of volcanic cinder and scoria remained practically unchanged at 2 million metric tons valued at $13.4 million. *(See table 2.)* Volcanic cinder and scoria were produced by 30 companies from 45 operations with 124 quarries in 14 States. Leading States, in order of volume, were California, New Mexico, and Hawaii; their combined production accounted for 39.3% of the total U.S. output. *(See table 11.)* Leading producers, in order of tonnage, were Martin Marietta, the Bishop Red Rock Inc., and Stoney Point Rock Quarry Inc; their combined production accounted for 43.9% of U.S. output.

Miscellaneous Stone.—Output of other kinds of crushed stone increased 16.6% to 24.9 million metric tons valued at $134.8 million. *(See table 2.)* Miscella-neous stone was produced by 108 companies from 133 operations with 175 quarries in 29 States. Leading States, in order of volume, were Pennsylvania, California, and Texas; their combined production accounted for 39.1% of the total U.S. output. *(See table 11.)* Leading producers, in order of tonnage, were Evered Bardon PLC, Anchorage Sand & Gravel Co., and Herzog Stone Products, Inc.

Consumption and Uses

Crushed stone production reported to the USBM is actually material that was either sold or used by producers. Stockpiled production is not reported. Therefore, the "sold or used" tonnage represents the amount of production released for domestic consumption or export in a given year. Because some of the crushed stone producers did not report a breakdown by end use, their total production is reported under "Other unspecified uses, actual." The estimated production of nonrespondents is reported under "Other unspecified uses, estimated."

In 1993, U.S. consumption of crushed stone was 1.1 billion metric tons valued at $5.9 billion, a 5.9% increase from the estimated consumption of 1992 and a 12% increase from the reported consumption of 1991. Of the 1.1 billion metric tons of crushed stone consumed in 1993, 332 million metric tons or 29.7% of the total was unspecified uses—actual and estimated. Of the remaining 784 million metric tons, about 82.7% was used as construction aggregates, mostly for highway and road construction and maintenance; 13.6% for chemical and metallurgical uses, including cement and lime manufacture; 2% for agricultural purposes; 1.4% for special uses and products; and 31% for other unspecified uses. *(See table 13.)* To provide a more accurate estimation of the consumption patterns for crushed stone, the "Unspecified uses" are not included in the aforementioned percentages. It is recommended that in any use pattern or marketing analysis the quantities included in "Unspecified uses" be distributed among the reported uses by applying the aforementioned percentages.

Limestone.—Of the 724 million metric tons of crushed limestone consumed, 213 million metric tons or 29.5% was reported as "Other unspecified uses." Of the remaining 510 million metric tons of crushed limestone reported by uses by the producers; 75.9% was used as construction aggregates; 19.7% for chemical and metallurgical uses, including cement and lime manufacturing; 2.7% for agricultural purposes; and 1.4% for special uses and products. *(See table 14.)*

Dolomite.—Of the 69 million metric tons of crushed dolomite consumed, 9.1 million metric tons or 13.2% was reported as "Other unspecified uses." Of the remaining 59.9 million metric tons of crushed dolomite reported by uses by the producers, 91.8% was used as construction aggregates, 3.7% for chemical and metallurgical uses, and 2.7% for agricultural purposes. An additional undefined amount of dolomite consumed in a variety of uses, mostly construction aggregates, is reported with the limestone. *(See table 14.)*

Marble.—Of the 3.5 million metric tons of crushed marble consumed, 1.8 million metric tons or 51.4% was reported as "Other unspecified uses." Of the remaining 1.7 million metric tons of crushed marble reported by uses by the producers, 65.3% was used as miscellaneous uses, including fillers and extenders, 26.5% for cement manufacture, and 7.7% as construction aggregates. *(See table 16.)*

Calcareous Marl.—Of the 5.2 million metric tons of crushed calcareous marl consumed, 2.2 million metric tons or 42.5% was reported as "Other unspecified uses." Of the remaining 3 million metric tons of crushed marl reported by uses by the producers, 80.8% was used for cement manufacturing, and the remaining 19.2% as construction aggregates and for agricultural purposes.

Shell.—Of the 1.9 million metric tons of crushed shell consumed, 774,000 metric tons or 39.7% was reported as "Other unspecified uses." Of the remaining 1.2 million metric tons of crushed shell reported by uses by the producers, 97.8% was used as construction aggregates.

Granite.—Of the 169 million metric tons of crushed granite consumed, 53.3 million metric tons or 31.5% was reported as "Other unspecified uses." Most of the remaining 116 million metric tons of crushed granite reported by uses by the producers was used as construction aggregates. *(See table 17.)*

Traprock.—Of the 84 million metric tons of crushed traprock consumed, 22.5 million metric tons or 26.7% was reported as "Other unspecified uses." Most of the remaining 62 million metric tons of crushed traprock reported by uses by the producers was used as construction aggregates. *(See table 17.)*

Sandstone and Quartzite.—Of the 24 million metric tons of crushed sandstone consumed, 10.3 million metric tons or 42.3% was reported as "Other unspecified uses." Most of the remaining 14 million metric tons of crushed sandstone reported by uses by the producers were used as construction aggregates. *(See table 18.)*

Of the 6 million metric tons of crushed quartzite consumed, 2.6 million metric tons or 44% was reported as "Other unspecified uses." Most of the remaining 3.4 million metric tons of crushed quartzite reported by uses by the producers was used as construction aggregates. *(See table 18.)*

Volcanic Cinder and Scoria.—Of the 2.1 million metric tons of volcanic cinder and scoria consumed, 821,000 metric tons or 39.1% was reported as "Other unspecified uses." Most of the remaining 1.3 million metric tons of crushed volcanic cinder and scoria reported by uses by the producers was used as construction aggregates. *(See table 19.)*

Miscellaneous Stone.—Of the 34 million metric tons of miscellaneous crushed stone consumed, 18.2 million metric tons or 53.7% was reported as "Other unspecified uses." Of the remaining 15.8 million metric tons reported by uses by the producers, 83.3% was used as construction aggregates and 15.5% was used for cement manufacturing. *(See table 19.)*

Prices

Prices in this chapter are f.o.b. plant, usually at the first point of sale or captive use. This value does not include transportation from the plant or yard to the consumer. It does, however, include all costs of mining, processing, in-plant transportation, overhead costs, and profit.

The 1993 average unit price per metric ton of crushed stone increased 2.9% to $5.30, compared with that of 1991, the last time when an annual survey of the crushed stone producers was conducted. By kind of stone, the average unit prices showed increases of 62.4% for calcareous marl, 10.9% for sandstone and quartzite, 4.7% for limestone, 3.8% for granite, 3.6% for slate, and 2.2% for volcanic cinder and scoria. At the same time, the average unit prices for shell decreased 29.3%, for marble 13.3%, and for traprock 3.6%, while the prices for dolomite and miscellaneous stone remained unchanged.

Transportation

For 369 million metric tons or 33.1% of the total 1.1 billion metric tons of crushed stone produced in 1993, no means of transportation was reported by the producers. Of the remaining 747 million metric tons of crushed stone, 73.1% was reported as transported by truck from the processing plant or quarry to the first point of sale or use, 6.5% was transported by rail, and 6.2% by waterway. About 11.8% of the total production was reported as not transported and therefore used on-site. Information regarding means of transportation used by the producers to ship crushed stone in each geographic regions is also provided. *(See table 20.)*

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 especially Mexico are increasing.

Exports.—Exports of crushed stone increased 31.9% to 4.8 million metric tons compared with that of 1992, while value decreased 9.5% to $39.3 million. About 83% of the exported crushed stone was limestone, Canada being the major destination with 86.8% of the total crushed stone. *(See table 22.)*

Imports.—Imports of crushed stone increased 20% to 8.4 million metric tons compared with that of 1992, while the value increased 15.1% to $69 million. About 95.8% of the imported crushed stone was limestone.

Imports of natural calcium carbonate fines increased from 2,000 to 44,000 metric tons. *(See table 23.)*

Shipments of crushed stone from the Bahamas, Canada, and Mexico into the United States continued in 1993. The imported crushed stone was used mostly as construction aggregates or for cement manufacturing. This trend is expected to continue and the volume of imports, especially from Mexico, to increase.

Current Research

The Center for Aggregates Research (CAR) established by the National Aggregates Association and the National Stone Association and managed through the Aggregates Foundation for Technology, Research, and Education (AFTRE), is the first organization dedicated wholly to aggregates research. A technical advisory committee overviewing the center's activity identified six priority areas of research that include: fine aggregates properties and their influence on end products; uses for fines resulting from the processing of aggregates; performance-related tests for aggregates; proper use of aggregates in asphaltic concrete to minimize rutting; prevention of alkali-silica and alkali-carbonate reactivity of aggregates in portland cement concrete; and nature and effects of coatings on aggregates. CAR will concentrate its efforts into these areas.

The University of Texas at Austin and Texas A&M University, the two institutions jointly operating CAR, have already considerable research in progress related to aggregates. Some of the projects underway are as follows:

- Evaluation of the performance of pavements made with different coarse aggregates, including those with different thermal coefficients and the development of design procedures;

- Evaluation of the effectiveness of large stone mixtures in resisting plastic deformation—rutting—in asphalt pavements, and recommended design procedures and quality assurance testing and constructability;

- Study of the alkali-silica reaction in concrete containing fly ash. The objectives of the study are to identify the most relevant components of fly ash, portland cement, and aggregates affecting the alkali-silica reaction and to determine the type and amount of a given component to be used in producing high-quality concrete;

- Study of surface friction of seal coat pavements to identify the best methods for determining aggregates properties and characteristics that will accurately predict surface friction performance of seal coats; and

- Potential engineering and environmental uses of quarry fines.[13]

The Intermodal Surface Transportation Efficiency Act of 1991 authorized about $108 million for Strategic Highway Research Program (SHRP) implementation and Long Term Pavement Performance (LTPP) projects. With the completion of SHRP's 5-year research program, the Federal Highway Administration (FHWA) was assigned the responsibility of implementing the research results, products, and techniques through an FHWA Technology Applications program. A series of implementation actions also are being undertaken by AASHTO and the Transportation Research Board (TRB). AASHTO's Subcommittee on Materials amended its procedures to accept new product standards on a provisional basis for a maximum of 4 years, during which time hands-on testing will be conducted. At the end of 2 years, the product standards can be balloted for acceptance as regular standards, or the provisional status can be extended for an additional 2 years. The Subcommittee on Materials is also developing information about the specific resources needed to implement SHRP products. TRB has created the TRB/SHRP committee, which will provide industry, highway agencies, and research specialists with a continuing forum to coordinate activities related to implementation of SHRP products and continuation of the LTPP program.

Technology

A new mobile conveyor system designed to load or unload bulk commodity rail cars was introduced by Granite Rock Co. of Watsonville, CA, at the Rock by Rail Third Conference that was held in April 1993 in League City, TX. TransloadXpress conveyor system was engineered by Granite Rock Co. to provide a cost-effective, efficient, and fast method of loading and unloading rail cars. TransloadXpress can convey bulk materials at rates of up to 800 tons/hour, and can unload rail-to-truck systems at rates averaging 300 tons/hour. TransloadXpress can unload materials into waiting trucks for short hauls to the job site or can convey materials directly into portable ready-mix concrete and asphalt plants. TransloadXpress helps the aggregates producer take advantage of the economies of scale offered by rail shipments and also provides significant environmental advantages. According to a study conducted by the Department of Energy, rail delivers more than eight times the energy efficiency of trucking when measured by the required BTU's per ton-mile of transportation.[14]

Quarry blasting usually requires considerably greater control than most mining or public works rock blasting. Maximizing the breakage of rock during primary blasting reduces significantly the need for secondary breakage of oversize rock and therefore of energy consumption required to produce the final product. Efficient and cost-effective blasting requires proper selection of blasthole pattern, explosive selection, delay timing, and initiation sequence, as well as a thorough understanding of the impact the blasting will have on nearby structures. A comprehensive review of the technology, including blasting fragmentation, drilling accuracy, explosive performance, ground vibration, blast size, and delay timing, and how the technology can be used to reduce blasting costs was published by Quarry Management magazine and was reprinted by Rock Products magazine.[15]

A comprehensive review of the available microcomputer software for use in aggregate-producing industry was published by Rock Products magazine. The review includes software for mine planning, geographic information systems, plant design, mining cost analysis, blasting design, scale management, financial modeling, and accounting. Available information on environmental and occupational health and safety standards, State and Federal regulatory requirements, and legal and engineering codes and standards affecting the aggregates industry is also included in the review.[16]

OUTLOOK

The demand for crushed stone in 1994 is expected to be about 1.17 billion metric tons (1.29 billion short tons), a 5% increase compared with that of 1993. Gradual increases in demand for construction aggregates are anticipated after 1994 as well, based on increased volume of work on the infrastructure that is being financed by the Intermodal Surface Transportation Efficiency Act of 1991 and the recovery of the U.S. economy. The law authorized $151 billion to be spent in the next 6 years on transportation projects, of which $119.5 billion on highway work and $32.5 billion on mass transit.

It is estimated that the demand for crushed stone will reach 1.3 billion tons in 1995. The projected increases will be influenced by construction activity primarily in the public as well as the private construction sector.

Crushed stone f.o.b. prices are not expected to increase significantly, even if the demand for construction aggregates will rise over the forecasts. However, the delivered prices of crushed stone are expected to increase, especially in and near metropolitan areas, mainly because more aggregates are transported from distant sources.

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TABLE 1
SALIENT U.S. CRUSHED STONE STATISTICS

		1989	1990	1991[r]	1992	1993
Sold or used by producers:						
Quantity[1]	thousand metric tons	1,100,800	[e]1,108,600	996,800	[e]1,053,700	1,116,000
Quantity[2]	thousand short tons	1,213,400	[e]1,222,000	1,098,800	[e]1,161,500	1,230,200
Value[1]	thousand dollars	$5,325,800	[e]$5,591,300	$5,136,600	[e]$5,593,700	$5,915,500
Exports	value, thousand dollars	$23,345	$41,400	$33,000	$43,400	$39,300
Imports[3]	do.	$36,870	$35,310	$38,600	$60,700	$74,300

[e]Estimated. [r]Revised.

[1]Does not include American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands.

[2]One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3]Excludes precipitated calcium carbonate.

TABLE 2
CRUSHED STONE SOLD OR USED IN THE UNITED STATES, BY KIND

Kind	1991[r]				1993			
	Number of quarries	Quantity (thousand metric tons)	Value (thousands)	Unit value	Number of quarries	Quantity (thousand metric tons)	Value (thousands)	Unit value
Limestone[1]	2,183	639,564	$2,988,483	$4.67	2,110	723,540	$3,540,336	$4.89
Dolomite	138	64,251	354,979	5.52	148	69,355	381,998	5.51
Marble	45	3,423	83,400	24.36	38	3,507	74,035	21.11
Calcareous marl	16	5,329	16,291	3.06	12	5,239	26,017	4.97
Shell	15	4,968	44,431	8.94	14	1,949	12,327	6.32
Granite	477	147,777	852,094	5.77	468	168,924	1,012,440	5.99
Traprock	583	78,369	505,997	6.46	593	84,292	525,494	6.23
Sandstone and quartzite	238	28,278	153,239	5.42	224	30,303	182,084	6.01
Slate	7	1,464	9,443	6.45	10	1,889	12,625	6.68
Volcanic cinder and scoria	124	2,039	12,828	6.29	124	2,088	13,435	6.43
Miscellaneous stone	177	21,386	115,377	5.39	175	24,935	134,753	5.40
Total[2]	XX	996,800	5,136,600	5.15	XX	1,116,000	5,915,500	5.30
Total[3] [4]	XX	1,098,800	5,136,600	4.67	XX	1,230,200	5,915,500	4.81

[r]Revised. XX Not applicable.

[1]Includes "Limestone-dolomite," reported with no distinction between the two.

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

[3]One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[4]Total shown in thousand short tons and thousand dollars.

TABLE 3

CRUSHED STONE[1] SOLD OR USED IN THE UNITED STATES, BY REGION

(Thousand metric tons and thousand dollars)

Region	1992[e]		1993	
	Quantity	Value	Quantity	Value
Northeast:				
New England	21,682	175,800	21,814	168,592
Middle Atlantic	113,852	718,900	126,298	787,656
Midwest:				
East North Central	207,110	910,100	208,112	922,803
West North Central	116,130	530,700	124,350	602,284
South:				
South Atlantic	228,792	1,356,800	271,329	1,567,079
East South Central	123,921	680,900	123,623	637,140
West South Central	112,491	477,300	121,535	519,010
West:				
Mountain	34,201	175,500	37,389	210,725
Pacific	[2]64,501	[2]336,400	81,568	500,256
Total[3]	[4]1,053,700	[4]5,593,700	1,116,000	5,915,500
Total[5] [6]	1,161,500	5,593,700	1,230,200	5,915,500

[e] Estimated.

[1] Includes volcanic cinder and scoria.

[2] Does not include Alaska and Hawaii.

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

[4] Includes Alaska, Hawaii, and "Other" totals; see table 5 for totals.

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[6] Total shown in thousand short tons and thousand dollars.

TABLE 4

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY QUARTER AND REGION[1]

Region	Quantity 1st quarter (thousand short tons)	Percent change[2]	Quantity 2d quarter (thousand short tons)	Percent change[2]	Quantity 3d quarter (thousand short tons)	Percent change[2]	Quantity 4th quarter (thousand short tons)	Percent change[2]	Total[3] (thousand short tons)	Value total (thousands)
Northeast:										
New England	1,200	-2.9	7,600	9.4	9,600	9.5	8,000	15.6	26,400	$185,200
Middle Atlantic	14,300	4.3	38,800	9.8	44,600	.4	34,000	6.2	131,700	766,000
Midwest:										
East North Central	27,300	5.1	67,400	2.3	78,900	6.4	70,000	12.4	243,600	981,600
West North Central	20,100	-12.3	35,700	1.0	42,100	4.6	37,000	25.8	135,000	530,700
South:										
South Atlantic	54,700	15.6	81,000	20.6	82,600	12.3	74,000	15.5	292,400	1,570,800
East South Central	24,700	-3.4	37,900	4.6	41,900	6.2	36,900	4.6	141,500	699,300
West South Central	28,000	7.5	34,300	11.3	37,300	3.0	31,500	2.0	131,200	522,000
West:										
Mountain	8,200	37.1	11,700	8.0	13,600	10.5	9,300	8.5	42,800	207,500
Pacific[4]	14,400	-4.4	19,600	.7	22,700	16.3	22,000	29.2	78,700	351,300
Total[2]	192,900	4.9	334,100	8.4	373,300	7.1	322,900	12.6	[5]1,254,200	[5]6,021,300
Total[6] [7]	175,000	4.9	303,100	8.4	338,700	7.1	292,900	12.6	[5]1,137,800	[5]6,021,300

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[1] As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1993 Mineral Industry Survey."

[2] All percentage changes are calculated using unrounded totals.

[3] Data may not add to totals shown because of independent rounding, and differences between projected totals by States and by regions.

[4] Does not include Alaska and Hawaii.

[5] Includes Alaska, Hawaii, and "Other" totals.

[6] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[7] Total shown in thousand metric tons and thousand dollars.

TABLE 5

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1992[e]			1993		
	Quantity (thousand metric tons)	Value (thousands)	Unit value	Quantity (thousand metric tons)	Value (thousands)	Unit value
Alabama	25,945	$175,600	$6.77	28,863	$175,607	$6.08
Alaska	2,722	13,400	4.92	2,425	[2]11,294	4.66
Arizona	4,990	26,300	5.27	6,430	36,823	5.73
Arkansas	22,861	118,900	5.20	[3]21,706	[3 4 5]102,555	4.72
California	37,013	198,300	5.36	38,167	249,740	6.54
Colorado	10,886	60,400	5.55	10,338	61,950	5.99
Connecticut	5,352	54,500	10.18	[3 6]4,599	[3 6]39,525	8.59
Florida	53,796	266,900	4.96	64,926	[7]313,270	4.83
Georgia	39,916	244,200	6.12	49,353	292,144	5.92
Hawaii	9,525	93,500	9.82	[6]8,456	[6]81,412	9.63
Idaho	3,629	19,200	5.29	4,602	20,770	4.51
Illinois	65,952	322,800	4.89	[2]61,487	[2]315,149	5.13
Indiana	39,009	178,000	4.56	36,862	165,861	4.50
Iowa	34,473	186,200	5.40	30,500	168,597	5.53
Kansas	15,331	69,600	4.54	[2]18,847	[2]90,663	4.81
Kentucky	53,342	251,100	4.71	[2]49,028	[2]226,058	4.61
Louisiana	W	W	9.34	[6 8 9]W	[6 8 9]W	10.91
Maine	1,724	11,400	6.61	1,832	10,359	5.65
Maryland	21,591	180,400	8.36	23,051	152,273	6.61
Massachusetts	9,435	77,200	8.18	[3 6] 9,455	[3 6] 76,267	8.07
Michigan	35,017	125,500	3.58	31,019	111,763	3.60
Minnesota	9,525	39,500	4.15	9,423	37,736	4.00
Mississippi	2,268	10,400	4.59	2,102	8,122	3.86
Missouri	47,355	187,400	3.96	53,368	239,297	4.48
Montana	1,996	6,200	3.11	2,816	10,375	3.68
Nebraska	5,352	29,100	5.44	6,763	38,871	5.75
Nevada	1,089	6,700	6.15	1,607	12,529	7.80
New Hampshire	1,542	11,000	7.13	1,390	7,794	5.61
New Jersey	15,513	126,000	8.12.	[2 8] 16,702	[2 8] 137,872	8.25
New Mexico	2,722	14,400	5.29	[10]3,503	[10]18,411	5.26
New York	33,384	212,700	6.37	38,448	[5]223,293	5.81
North Carolina	44,089	262,400	5.95	[10 11 12]47,787	[10 11 12]297,657	6.23
North Dakota	9	W	W	[12]W	[12]W	[12]W
Ohio	43,998	194,500	4.42	52,167	228,364	4.38
Oklahoma	24,948	105,300	4.22	27,055	113,958	4.21
Oregon	15,241	74,900	4.91	18,891	84,655	4.48
Pennsylvania	64,954	380,200	5.85	[10]69,361	[10]405,346	5.84
Rhode Island	1,361	9,500	6.98	1,291	9,251	7.17
South Carolina	15,966	83,800	5.25	19,765	120,939	6.12
South Dakota	4,082	18,900	4.63	[2 6]4,227	[2 6]18,684	4.42
Tennessee	42,366	243,800	5.75	43,534	226,521	5.20
Texas	64,682	253,100	3.91	70,772	279,245	3.95
Utah	4,808	22,400	4.66	4,555	29,400	6.45
Vermont	2,268	12,200	5.38	2,520	12,899	5.12
Virginia	43,091	261,300	6.06	50,998	292,345	5.73

See footnotes at end of table.

TABLE 5—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE[1]

State	1992[e]			1993		
	Quantity (thousand metric tons)	Value (thousands)	Unit value	Quantity (thousand metric tons)	Value (thousands)	Unit value
Washington	12,247	$63,200	$5.16	13,204	$68,648	$5.20
West Virginia	10,342	57,800	5.59	[3]10,313	79,661	7.72
Wisconsin	23,133	89,300	3.86	26,248	98,026	3.73
Wyoming	4,082	19,900	4.87	3,456	19,837	5.74
Other	18,779	124,400	6.62	11,806	93,726	7.94
Total[12]	1,053,700	5,593,700	5.31	1,116,000	5,915,500	5.30
Total[13] [14]	1,161,500	5,593,700	4.82	1,230,200	5,915,500	4.81

[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 sandstone.

[3]Excludes dolomite.

[4]Excludes quartzite.

[5]Excludes traprock.

[6]Excludes other.

[7]Excludes limestone-dolomite.

[8]Excludes limestone.

[9]Excludes shell.

[10]Excludes slate.

[11]Excludes volcanic cinder.

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

[13]One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons into short tons, divide metric tons by 0.907185.

[14]Total shown in thousand short tons and thousand dollars.

TABLE 6

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY QUARTER AND STATE[1]

State	Quantity 1st quarter (thousand short tons)	Percent change[2]	Quantity 2d quarter (thousand short tons)	Percent change[2]	Quantity 3d quarter (thousand short tons)	Percent change[2]	Quantity 4th quarter (thousand short tons)	Percent change[2]	Total[3] (thousand short tons)	Value total (thousands)
Alabama[4]	5,900	-4.5	8,100	5.0	8,400	10.5	7,400	3.9	29,800	$184,800
Alaska[5]	—	—	—	—	—	—	—	—	3,100	14,000
Arizona	1,800	34.3	1,400	9.7	1,200	-19.3	1,300	-7.5	5,700	28,600
Arkansas[4]	5,800	27.5	7,500	26.4	8,400	13.0	7,300	0.6	29,000	134,400
California	8,100	-5.4	11,500	3.6	12,400	11.3	12,500	24.5	44,500	207,800
Colorado[4]	2,400	35.2	4,000	21.1	4,900	16.1	3,100	14.4	14,400	75,900
Connecticut[4]	100	-47.0	1,600	-18.8	2,000	-2.2	1,900	15.5	5,600	46,800
Delaware	—	—	—	—	—	—	—	—	—	—
Florida	17,700	20.4	18,300	23.1	17,500	26.0	17,600	15.0	71,100	323,200
Georgia	10,100	35.8	14,500	20.0	15,000	13.0	12,900	14.9	52,500	291,000
Hawaii[5]	—	—	—	—	—	—	—	—	10,200	89,300
Idaho[5]	—	—	—	—	—	—	—	—	5,100	25,000
Illinois[4]	8,600	-8.3	20,500	1.8	24,900	4.1	21,800	12.8	75,800	338,100
Indiana[4]	6,600	12.4	12,800	11.0	15,400	10.5	13,600	16.8	48,400	205,500
Iowa	4,700	-33.0	11,300	2.4	12,000	3.5	10,300	24.9	38,300	180,700
Kansas[4]	3,500	3.2	4,900	7.0	5,300	8.8	4,900	20.2	18,600	76,500

See footnotes at end of table.

TABLE 6—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY QUARTER AND STATE[1]

State	Quantity 1st quarter (thousand short tons)	Percent change[2]	Quantity 2d quarter (thousand short tons)	Percent change[2]	Quantity 3d quarter (thousand short tons)	Percent change[2]	Quantity 4th quarter (thousand short tons)	Percent change[2]	Total[3] (thousand short tons)	Value total (thousands)
Kentucky[4]	10,700	-3.4	15,500	6.4	17,700	3.7	15,800	-2.0	59,700	$252,000
Louisiana[5]	—	—	—	—	—	—	—	—	—	—
Maine	200	83.6	500	6.3	700	-9.0	600	-1.6	2,000	12,000
Maryland	3,400	-7.4	7,700	14.0	8,300	11.4	8,100	36.4	27,500	198,900
Massachusetts	400	-18.0	3,900	31.6	5,000	31.4	3,900	26.7	13,200	93,500
Michigan	2,400	-2.1	11,600	-9.2	12,300	-.4	11,200	.6	37,500	123,800
Minnesota	400	-38.0	2,900	-4.0	4,700	7.0	2,900	23.3	10,900	39,500
Mississippi[5]	—	—	—	—	—	—	—	—	2,900	12,300
Missouri	9,500	-8.7	13,300	-5.0	14,300	-7.8	15,800	27.6	52,900	177,000
Montana	400	14.5	600	-21.4	700	3.4	500	5.1	2,200	5,900
Nebraska	1,100	1.0	1,600	6.0	2,600	23.9	1,700	37.7	7,000	33,500
Nevada	300	6.4	300	3.1	300	-3.8	300	4.7	1,200	7,400
New Hampshire	100	-12.3	400	-23.6	600	—	500	2.4	1,600	9,600
New Jersey	2,400	29.8	5,200	10.3	5,300	1.4	5,400	2.4	18,300	138,800
New Mexico	600	15.4	800	-1.3	1,100	25.4	1,100	56.8	3,600	16,200
New York	3,300	.7	11,900	25.3	14,000	-4.0	9,800	3.2	39,000	229,900
North Carolina	9,500	5.9	15,300	17.8	15,700	6.7	13,400	12.6	53,900	295,400
North Dakota[5]	—	—	—	—	—	—	—	—	—	—
Ohio	7,000	13.1	15,300	15.7	17,400	12.8	15,900	16.4	55,600	225,300
Oklahoma[4]	6,000	-1.4	7,300	14.6	7,400	-5.9	7,100	-1.3	27,800	110,600
Oregon[4]	3,900	12.4	5,100	8.9	6,100	34.2	6,400	56.5	21,500	86,500
Pennsylvania[4]	8,500	-1.4	21,800	1.7	25,300	3.1	18,700	9.7	74,300	397,300
Rhode Island[4] [5]	—	—	—	—	—	—	—	—	2,000	13,000
South Carolina[4]	4,300	15.9	5,900	31.1	5,600	14.0	5,100	13.0	20,900	98,000
South Dakota	700	20.7	1,600	17.2	2,000	44.4	1,500	25.7	5,800	23,500
Tennessee	7,200	-4.5	13,400	1.4	14,900	4.0	13,200	13.5	48,700	250,200
Texas	16,400	8.1	19,700	6.7	22,100	4.9	17,400	4.2	75,600	277,000
Utah	1,800	118.1	1,800	33.0	2,000	17.1	1,700	18.2	7,300	30,000
Vermont[5]	—	—	—	—	—	—	—	—	2,100	10,300
Virginia	8,900	12.7	15,600	23.2	16,700	18.2	14,500	14.1	55,700	310,800
Washington	2,400	-23.7	2,700	-25.2	4,400	10.5	3,000	4.7	12,500	57,000
West Virginia[4]	1,700	-6.5	3,100	7.9	3,400	-18.0	2,500	-6.2	10,700	53,500
Wisconsin	2,800	21.4	6,800	-16.3	9,000	2.6	7,500	18.7	26,100	88,900
Wyoming	600	-18.3	1,500	-9.0	1,300	-3.3	700	-24.1	4,100	18,500
Other[5]	—	—	—	—	—	—	—	—	17,600	103,600
Total	XX	XX	XX	XX	XX	XX	XX	XX	1,254,200	6,021,300
Total[6] [7]	XX	XX	XX	XX	XX	XX	XX	XX	1,137,800	6,021,300

XX Not applicable.

[1] As published in the "Crushed Stone and Sand and Gravel in the Fourth Quarter of 1993 Mineral Industry Survey."

[2] All percentage changes are calculated using unrounded totals.

[3] Data may not add to totals shown because of independent rounding, and differences between projected totals by States and regions.

[4] To avoid disclosing proprietary data, certain state totals do not include all kinds of stone produced within the State; the portion not shown has been included with "Other."

[5] Due to a low number of reporting companies, no production estimates by quarters were generated.

[6] One metric ton is equal to 1,000 kilograms or 2,204.62 pounds. To convert short tons to metric tons, multiply short tons by 0.907185.

[7] Total shown in thousand metric tons and thousand dollars.

TABLE 7

CRUSHED STONE SOLD OR USED IN THE UNITED STATES IN 1993, BY REGION AND SIZE OF OPERATION

Size range (metric tons)	Northeast				Midwest			
	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total
Less than 25,000	51	12.6	367	0.2	216	19.0	1,724	0.5
25,000 to 49,999	9	2.2	290	.1	130	11.4	4,280	1.3
50,000 to 99,999	47	11.6	3,136	2.1	160	14.1	10,632	3.2
100,000 to 199,999	61	15.1	8,211	5.5	175	15.4	23,059	6.9
200,000 to 299,999	52	12.8	11,657	7.8	127	11.2	28,860	8.7
300,000 to 399,999	44	10.9	13,629	9.2	80	7.0	25,000	7.5
400,000 to 499,999	32	7.9	12,992	8.7	40	3.5	16,298	4.9
500,000 to 599,999	24	5.9	12,223	8.2	45	4.0	22,321	6.7
600,000 to 699,999	17	4.2	9,883	6.6	23	2.0	13,538	4.1
700,000 to 799,999	15	3.7	10,238	6.9	28	2.5	18,948	5.7
800,000 to 899,999	10	2.5	7,608	5.1	16	1.4	12,271	3.7
900,000 to 999,999	15	3.7	12,973	8.7	12	1.1	10,340	3.1
1,000,000 to 1,499,999	16	4.0	16,787	11.3	50	4.4	53,831	16.2
1,500,000 to 1,999,999	3	0.7	4,553	3.0	15	1.3	22,522	6.8
2,000,000 to 2,499,999	4	1.0	7,946	5.3	7	.6	13,708	4.1
2,500,000 to 4,999,999	5	1.2	15,619	10.5	11	1.0	35,270	10.6
5,000,000 and over	—	—	—	—	3	—	19,859	6.0
Total[1]	405	100.0	148,100	100.0	1,138	100.0	332,500	100.0
Total[2] [3]	XX	XX	163,300	XX	XX	XX	366,500	XX

See footnotes at end of table.

TABLE 7—Continued

CRUSHED STONE SOLD OR USED IN THE UNITED STATES IN 1993, BY REGION AND SIZE OF OPERATION

Size range (metric tons)	South				West				U.S. total[1]			
	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total
Less than 25,000	77	7.9	763	0.1	242	35.0	1,855	1.6	586	18.2	4,709	0.4
25,000 to 49,999	50	5.1	1,678	.3	80	11.6	2,683	2.3	269	8.3	8,931	.8
50,000 to 99,999	84	8.6	5,997	1.2	109	15.8	7,328	6.2	400	12.4	27,095	2.4
100,000 to 199,999	115	11.7	14,910	2.9	95	13.7	12,562	10.6	446	13.8	58,743	5.3
200,000 to 299,999	98	10.0	22,068	4.3	53	7.7	11,868	10.0	330	10.2	74,454	6.7
300,000 to 399,999	84	8.6	26,587	5.1	27	3.9	8,673	7.3	235	7.3	73,889	6.6
400,000 to 499,999	86	8.8	35,246	6.8	18	2.6	7,540	6.3	176	5.4	72,075	6.5
500,000 to 599,999	60	6.1	29,728	5.8	15	2.2	7,651	6.4	144	4.4	71,923	6.4
600,000 to 699,999	53	5.4	31,235	6.0	8	1.2	4,776	4.0	101	3.1	59,432	5.3
700,000 to 799,999	49	5.0	33,439	6.5	8	1.2	5,568	4.7	100	3.1	68,195	6.1
800,000 to 899,999	38	3.9	29,161	5.6	8	1.2	6,202	5.2	72	2.2	55,241	4.9
900,000 to 999,999	32	3.3	27,528	5.3	2	.3	1,740	1.5	61	1.9	52,580	4.7
1,000,000 to 1,499,999	79	8.1	87,569	17.0	11	1.6	10,961	9.2	156	4.8	169,146	15.2
1,500,000 to 1,999,999	41	4.2	63,039	12.2	7	1.0	10,751	9.0	66	2.0	100,866	9.0
2,000,000 to 2,499,999	11	1.1	22,111	4.3	2	.3	4,094	3.4	24	.7	47,858	4.3
2,500,000 to 4,999,999	16	1.6	44,560	8.6	6	.9	14,705	12.4	38	1.1	110,155	9.9
5,000,000 and over	6	.6	40,867	7.9	—	—	—	—	9	.2	60,726	5.4
Total[1]	979	100.0	516,500	100.0	691	100.0	118,900	100.0	3,213	100.0	1,116,000	100.0
Total[2] [3]	XX	XX	569,300	XX	XX	XX	131,100	XX	XX	XX	1,230,200	XX

XX Not applicable.

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

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3] Total shown in thousand short tons and thousand dollars.

TABLE 8

CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Alabama	[1]24,937	[1]107,217	W	W
Arizona	4,161	23,183	—	—
Arkansas	5,999	30,471	W	W
California	17,944	119,247	164	1,438
Colorado	[1]2,819	[1]15,012	—	—
Connecticut	W	W	W	W
Florida	[1]62,492	[1]307,414	W	W
Georgia	4,875	29,451	W	W
Hawaii	1,416	14,416	—	—
Idaho	W	W	—	—
Illinois	[1]46,948	[1]242,544	W	W
Indiana	[1]34,144	[1]151,578	2,718	14,283
Iowa	[1]30,300	[1]167,888	W	W
Kansas	18,848	90,662	—	—
Kentucky	49,020	226,048	—	—
Louisiana	W	W	—	—
Maine	1,425	8,577	—	—
Maryland	15,382	101,824	—	—
Massachusetts	W	W	W	W
Michigan	26,722	96,241	W	W
Minnesota	7,209	27,134	W	W
Mississippi	W	W	—	—
Missouri	[1]49,921	[1]223,022	2,198	9,069
Montana	1,816	7,066	—	—
Nebraska	6,763	38,871	—	—
Nevada	W	W	379	4,396
New Hampshire	W	W	—	—
New Jersey	W	W	—	—
New Mexico	1,238	5,234	—	—
New York	[1]27,784	[1]150,234	7,489	56,069
North Carolina	W	W	179	1,254
Ohio	[1]47,705	[1]210,707	3,906	15,208
Oklahoma	23,386	97,861	—	—
Oregon	W	W	—	—
Pennsylvania	[1]40,970	[1]238,762	12,253	70,977
Rhode Island	W	W	—	—
South Carolina	W	W	W	W
South Dakota	2,580	9,017	—	—
Tennessee	[1]38,754	[1]203,671	W	W
Texas	65,265	254,082	W	W
Utah	3,187	24,103	W	W
Vermont	1,726	9,349	—	—
Virginia	[1]14,692	[1]85,572	3,428	27,081

See footnotes at end of table.

TABLE 8—Continued

CRUSHED LIMESTONE AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Washington	[1]530	[1]9,631	W	W
West Virginia	9,352	57,567	W	16,745
Wisconsin	[1]19,756	[1]73,020	W	W
Wyoming	[1]925	[1]3,987	—	—
Other	12,549	79,674	36,640	165,477
Total[2]	723,500	3,540,300	69,400	382,000
Total[3] [4]	797,600	3,540,300	76,500	382,000

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.

[3] One short ton is equal 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[4] Total shown in thousand short tons and thousand dollars.

TABLE 9

CRUSHED CALCAREOUS MARL AND MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Calcareous marl		Marble	
	Quantity	Value	Quantity	Value
Alabama	—	—	W	W
Arizona	—	—	W	W
California	—	—	467	2,626
Florida	W	3,188	—	—
Georgia	W	W	W	W
Maine	W	W	—	—
Michigan	W	W	—	—
New York	—	—	75	2,423
North Carolina	W	W	—	—
South Carolina	2,889	W	—	—
Texas	W	W	W	W
Vermont	—	—	W	W
Wyoming	—	—	74	2,446
Other	2,350	22,829	2,891	66,540
Total[1]	5,200	26,000	3,500	74,000
Total[2] [3]	5,700	26,000	3,900	74,000

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

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

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3] Total shown in thousand short tons and thousand dollars.

TABLE 10

CRUSHED GRANITE, TRAPROCK, AND SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Granite		Traprock		Sandstone and quartzite	
	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	W	W	—	—	—	—
Alaska	W	W	528	2,607	W	W
Arizona	1,764	9,861	W	W	55	782
Arkansas	7,888	41,472	760	W	5,461	24,768
California	6,695	43,737	7,567	54,206	735	3,866
Colorado	3,432	16,935	—	—	W	W
Connecticut	129	1,485	3,317	28,641	—	—
Georgia	41,583	245,179	—	—	W	W
Hawaii	—	—	6,848	65,244	—	—
Idaho	382	1,834	2,845	10,866	W	W
Illinois	—	—	—	—	W	W
Kansas	—	—	—	—	W	W
Kentucky	8	11	—	—	W	W
Maine	W	W	W	W	—	—
Maryland	4,795	28,622	W	W	187	1,395
Massachusetts	W	W	7,719	55,902	—	—
Michigan	—	—	W	W	W	W
Minnesota	W	W	W	W	W	W
Missouri	W	W	—	—	W	W
Montana	W	W	W	W	417	1,758
Nevada	W	W	W	W	—	—
New Hampshire	W	W	937	4,665	—	—
New Jersey	7,966	66,943	8,737	70,929	W	W
New Mexico	1,511	9,865	168	371	W	W
New York	1,435	9,102	W	W	623	4,518
North Carolina	40,090	246,229	2,212	14,921	W	W
Ohio	—	—	—	—	555	2,449
Oklahoma	3,081	13,262	—	—	588	2,835
Oregon	91	482	15,878	71,318	W	W
Pennsylvania	1,642	9,917	3,202	19,651	6,143	39,139
Rhode Island	W	W	W	W	—	—
South Carolina	14,287	90,604	—	—	—	—
South Dakota	—	—	—	—	2,656	17,078
Tennessee	W	W	—	—	W	W
Texas	25	186	W	W	1,033	7,032
Utah	—	—	—	—	W	W
Vermont	495	1,507	—	—	W	W
Virginia	20,690	115,536	10,554	55,477	1,219	6,630
Washington	631	3,397	9,589	44,925	W	W
West Virginia	—	—	—	—	960	5,349
Wisconsin	1,346	2,529	W	W	1,125	4,748
Wyoming	2,383	W	—	—	W	W
Other	6,578	53,747	3,431	25,771	8,545	59,737
Total[1]	168,900	1,012,400	84,300	525,500	30,300	182,100
Total[2] [3]	186,200	1,012,400	92,900	525,500	33,400	182,100

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

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

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[3] Total shown in thousand short tons and thousand dollars.

TABLE 11

CRUSHED VOLCANIC CINDER AND SCORIA AND CRUSHED MISCELLANEOUS STONE[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

(Thousand metric tons and thousand dollars)

State	Volcanic cinder and scoria		Miscellaneous stone	
	Quantity	Value	Quantity	Value
Alabama	—	—	W	W
Alaska	—	—	W	W
Arizona	112	405	W	W
Arkansas	—	—	W	W
California	356	1,762	4,240	22,858
Colorado	W	W	W	W
Connecticut	—	—	W	W
Florida	—	—	1,592	7,427
Georgia	—	—	W	W
Hawaii	192	W	441	1,700
Idaho	W	W	W	W
Iowa	—	—	W	W
Louisiana	—	—	W	W
Maine	—	—	W	W
Maryland	—	—	W	W
Massachusetts	—	—	W	W
Michigan	—	—	W	W
Montana	3	7	17	51
Nevada	W	W	W	W
New Hampshire	—	—	W	W
New Mexico	277	1,852	207	977
New York	—	—	W	947
North Carolina	W	W	3,123	20,428
North Dakota	W	W	—	—
Oregon	116	682	1,613	7,597
Pennsylvania	—	—	5,851	30,296
South Carolina	—	—	3,004	16,677
South Dakota	—	—	W	W
Tennessee	—	—	W	W
Texas	—	—	3,206	10,310
Utah	13	105	—	—
Vermont	—	—	W	W
Virginia	—	—	W	W
Washington	W	W	609	2,342
Wyoming	W	W	W	W
Other	1,019	8,344	10,107	64,110
Total[2]	2,100	13,400	34,000	185,700
Total[3] [4]	2,300	13,400	37,200	185,700

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

[1] Includes marl, shell, slate, and other stone.

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

[3] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[4] Total shown in thousand short tons and thousand dollars.

TABLE 12

KIND OF CRUSHED STONE PRODUCED IN THE UNITED STATES IN 1993, BY STATE

State	Limestone	Dolomite	Marble	Marl	Shell	Granite	Traprock	Sandstone	Quartzite	Slate	Volcanic cinder and scoria	Miscellaneous
Alabama	X	X	X			X				X		
Alaska						X	X	X		X		X
Arizona	X		X			X	X	X			X	X
Arkansas	X	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	X					X
Florida	X	X		X	X							
Georgia	X	X	X	X		X			X			
Hawaii	X						X				X	X
Idaho	X				X	X	X		X		X	X
Illinois	X	X						X				
Indiana	X	X										
Iowa	X	X										X
Kansas	X							X				
Kentucky	X					X		X				
Louisiana	X				X							X
Maine	X			X		X	X					X
Maryland	X					X	X	X				X
Massachusetts	X	X				X	X					X
Michigan	X	X		X			X	X				X
Minnesota	X	X				X	X	X	X			
Mississippi	X											
Missouri	X	X				X		X				
Montana	X					X	X	X	X		X	X
Nebraska	X											
Nevada	X	X				X	X				X	X
New Hampshire	X					X	X					X
New Jersey	X					X	X	X				
New Mexico	X					X	X	X	X		X	X
New York	X	X	X			X	X	X				X
North Carolina	X	X		X		X	X		X	X	X	X
North Dakota											X	
Ohio	X	X						X	X			
Oklahoma	X					X		X				
Oregon	X					X	X	X		X	X	X
Pennsylvania	X	X				X	X	X	X			X
Rhode Island	X					X	X					
South Carolina	X	X		X	X	X						
South Dakota	X							X	X			X
Tennessee	X	X				X		X				X
Texas	X	X	X	X		X	X	X	X			X
Utah	X	X						X			X	
Vermont	X		X			X			X			X
Virginia	X	X				X	X	X	X	X		X
Washington	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

TABLE 13

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (thousand metric tons)	Value (thousands)	Unit value
Coarse aggregate (+1 1/2 inch):			
Macadam	4,878	$22,929	$4.70
Riprap and jetty stone	20,365	109,597	5.38
Filter stone	8,344	46,424	5.56
Other coarse aggregate	6,154	42,400	6.89
Coarse aggregate, graded:			
Concrete aggregate, coarse	100,766	564,289	5.60
Bituminous aggregate, coarse	78,656	442,089	5.62
Bituminous surface-treatment aggregate	20,531	125,735	6.12
Railroad ballast	14,581	80,997	5.55
Other graded coarse aggregate	20,941	121,382	5.80
Fine aggregate (-3/8 inch):			
Stone sand, concrete	19,679	123,448	6.27
Stone sand, bituminous mix or seal	22,237	109,845	4.94
Screening, undesignated	30,624	148,269	4.84
Other fine aggregate	2,904	16,790	5.78
Coarse and fine aggregates:			
Graded road base or subbase	185,925	794,557	4.27
Unpaved road surfacing	31,661	144,358	4.56
Terrazzo and exposed aggregate	1,947	15,623	8.02
Crusher run or fill or waste	41,482	189,425	4.57
Other coarse and fine aggregates	19,566	102,405	5.23
Other construction materials[1]	15,788	91,353	5.79
Roofing granules	1,334	12,748	9.56
Agricultural:			
Agricultural limestone	12,521	72,962	5.83
Poultry grit and mineral food	2,054	25,442	12.39
Other agricultural uses	821	4,939	6.02
Chemical and metallurgical:			
Cement manufacture	84,318	318,070	3.77
Lime manufacture	15,126	99,157	6.56
Dead-burned dolomite manufacture	286	1,192	4.17
Flux stone	3,192	15,744	4.93
Chemical stone	508	2,749	5.41
Glass manufacture	500	6,120	12.24
Sulfur oxide removal	2,361	12,857	5.45
Special:			
Mine dusting or acid water treatment	1,263	11,142	8.82
Asphalt fillers or extenders	3,714	27,823	7.49
Whiting or whiting substitute	2,259	75,210	33.29
Other fillers or extenders	3,795	88,694	23.37
Other miscellaneous uses:			
Abrasives	13	78	6.00
Flour (slate)	W	W	W
Paper manufacture	W	W	W
Other specified uses not listed	3,060	23,278	7.61

See footnotes at end of table.

TABLE 13—Continued

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (thousand metric tons)	Value (thousands)	Unit value
Unspecified:[2]			
Actual	240,597	$1,346,073	$5.59
Estimated	91,268	479,452	5.25
Total[3]	1,116,000	5,915,500	5.30
Total[4] [5]	1,230,200	5,915,500	4.81

W Withheld to avoid disclosing company proprietary data; included with "Other specified uses not listed."

[1] Includes stone used in drain fields, building products, and waste material.

[2] Includes production reported without a breakdown by use and estimates for nonrespondents.

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

[4] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[5] Total shown in thousand short tons and thousand dollars.

TABLE 14

CRUSHED LIMESTONE[1] AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1 1/2 inch):				
Macadam	1,931	8,778	1,764	8,295
Riprap and jetty stone	14,762	68,824	1,017	6,510
Filter stone	5,373	27,348	222	1,201
Other coarse aggregate	3,652	25,553	481	2,496
Coarse aggregate, graded:				
Concrete aggregate, coarse	60,761	307,248	9,948	54,632
Bituminous aggregate, coarse	46,716	238,553	9,251	54,612
Bituminous surface-treatment aggregate	12,903	71,144	1,519	9,608
Railroad ballast	2,444	11,462	1,171	5,586
Other graded coarse aggregate	11,908	62,292	3,194	18,169
Fine aggregate (-3/8 inch):				
Stone sand, concrete	11,334	64,670	1,235	7,756
Stone sand, bituminous mix or seal	12,600	58,539	2,243	11,014
Screening, undesignated	16,923	77,320	1,728	8,390
Other fine aggregate	1,021	4,059	511	2,872
Coarse and fine aggregates:				
Graded road base or subbase	115,247	456,452	13,111	58,208
Unpaved road surfacing	22,592	102,277	1,152	5,240
Terrazzo and exposed aggregate	769	4,827	26	303
Crusher run or fill or waste	28,528	126,905	2,829	12,981
Other coarse and fine aggregates	10,401	46,416	3,159	16,639
Other construction materials	[2]7,262	[2]39,407	[3]778	[3]4,079
Roofing granules	286	2,247	W	W
Agricultural:				
Agricultural limestone	11,010	58,058	1,511	14,804
Poultry grit and mineral food	1,999	24,702	W	W
Other agricultural uses	584	3,337	[4]142	[4]1,261

See footnotes at end of table.

TABLE 14—Continued

CRUSHED LIMESTONE[1] AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Limestone		Dolomite	
	Quantity	Value	Quantity	Value
Chemical and metallurgical:				
Cement manufacture	80,296	294,131	801	4,354
Lime manufacture	14,515	92,637	611	6,521
Dead-burned dolomite manufacture	—	—	286	1,192
Flux stone	2,561	13,044	549	2,071
Chemical stone	493	2,488	(5)	(5)
Glass manufacture	439	5,074	(5)	(5)
Sulfur oxide removal	2,361	12,857	—	—
Special:				
Mine dusting or acid water treatment	1,231	10,332	(5)	(5)
Asphalt fillers or extenders	1,479	15,392	(5)	(5)
Whiting or whiting substitute	2,241	74,671	(5)	(5)
Other fillers or extenders	2,019	27,993	383	8,856
Other miscellaneous uses:				
Abrasives	13	78	—	—
Other uses not listed	[6]1,727	[6]13,358	598	7,067
Unspecified:[7]				
Actual	152,381	789,536	8,061	41,182
Estimated	60,778	298,328	1,072	6,103
Total[8]	723,500	3,540,300	69,400	382,000
Total[9] [10]	797,600	3,540,300	76,500	382,000

W Withheld to avoid disclosing company proprietary data; included with "Other construction materials" or "Other agricultural uses."

[1] Includes a minor amount of limestone-dolomite reported without a distinction between the two.

[2] Includes waste material.

[3] Includes building products, waste material, and "Roofing granules."

[4] Includes "Poultry grit and mineral food."

[5] Included with "Other uses not listed."

[6] Includes paper manufacture.

[7] Includes production reported without a breakdown by end use and estimates for nonrespondents.

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

[9] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[10] Total shown in thousand metric tons and thousand dollars.

TABLE 15

CRUSHED LIMESTONE[1] AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE AND USE

(Thousand metric tons and thousand dollars)

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	4,641	20,758	3,853	17,855	2,496	9,712	765	3,314	3,326	13,985
Arizona	4	W	77	W	67	W	30	W	4	W
Arkansas	W	W	W	W	806	3,446	W	W	W	W
California	297	2,659	422	1,106	551	2,249	99	917	704	6,781
Colorado	—	—	—	—	W	W	—	—	—	—
Connecticut	W	W	—	—	—	—	—	—	10	153
Florida	16,050	96,087	7,782	52,968	19,015	68,048	129	595	9,624	38,777
Georgia	823	5,283	1,355	8,189	878	5,066	55	355	827	5,034
Hawaii	275	3,057	—	—	487	5,292	W	W	332	3,540
Idaho	—	—	—	—	—	—	—	—	—	—
Illinois	7,113	35,478	5,796	33,078	15,867	69,612	1,157	6,694	2,073	9,550
Indiana	5,047	20,420	5,709	26,333	8,453	36,966	1,356	5,571	1,713	7,267
Iowa	1,676	11,447	2,192	13,994	5,667	30,558	382	2,574	856	4,078
Kansas	946	5,588	720	4,362	2,506	11,196	143	900	3,248	13,968
Kentucky	4,810	20,907	9,986	43,786	11,361	49,280	4,288	16,809	3,135	13,206
Louisiana	—	—	W	W	—	—	—	—	—	—
Maine	79	346	339	W	—	—	29	186	—	—
Maryland	1,789	11,575	1,931	12,463	879	5,075	364	2,340	3,987	24,035
Massachusetts	—	—	W	W	W	W	W	W	W	W
Michigan	2,183	8,734	236	1,190	3,319	12,533	98	539	1,260	5,475
Minnesota	255	1,164	450	1,220	2,475	8,564	175	721	305	1,638
Mississippi	W	W	W	W	W	W	W	W	W	W
Missouri	1,796	8,874	4,102	18,569	12,443	58,899	3,643	12,770	4,104	17,759
Montana	—	—	—	—	—	—	W	W	—	—
Nebraska	275	1,904	W	W	874	5,974	162	1,397	636	3,761
Nevada	—	—	1	4	178	W	—	—	—	1
New Hampshire	—	—	—	—	—	—	—	—	—	—
New Jersey	W	W	W	W	W	W	—	—	W	W
New Mexico	322	1,274	26	30	138	289	8	31	27	215
New York	2,442	17,974	8,967	59,439	3,368	17,060	619	4,494	9,364	52,761
North Carolina	124	818	W	W	241	1,290	38	291	109	666
Ohio	4,585	18,242	4,894	22,222	12,077	49,930	903	4,842	5,587	22,656
Oklahoma	1,759	8,512	578	2,889	1,205	3,664	97	518	2,701	9,490
Oregon	—	—	—	—	—	—	—	—	—	—
Pennsylvania	4,924	27,488	12,319	71,499	9,765	48,507	854	5,060	7,117	37,652
Rhode Island	—	—	—	—	—	—	—	—	W	W
South Carolina	W	W	W	W	W	W	—	—	W	W
South Dakota	W	W	W	W	W	W	W	W	W	W
Tennessee	4,799	26,432	12,683	62,759	10,211	49,902	1,238	6,068	6,467	30,949
Texas	13,070	59,829	9,911	44,148	18,988	51,641	915	5,374	2,723	7,130
Utah	W	W	W	W	239	750	21	175	W	W
Vermont	—	—	—	—	—	—	—	—	—	—
Virginia	2,092	12,667	2,173	13,642	2,621	13,084	482	2,767	2,903	14,949
Washington	—	—	10	W	—	—	—	—	W	W
West Virginia	993	5,367	2,160	10,540	1,241	6,558	595	3,136	2,569	12,891
Wisconsin	1,089	4,706	977	3,873	10,920	38,735	256	1,109	1,253	3,800
Wyoming	W	W	W	W	W	W	W	W	W	W
Total[2]	84,255	437,590	99,648	526,158	159,335	663,879	18,901	89,548	76,966	362,166
Total withheld	556	3,647	2,537	16,610	596	3,419	493	2,834	1,298	5,839
Grand total[2]	84,800	441,200	102,200	542,800	159,900	667,300	19,400	92,400	78,300	368,000
Grand total[3] [4]	93,500	441,200	112,600	542,800	176,300	667,300	21,400	92,400	86,300	368,000

See footnotes at end of table.

TABLE 15—Continued

CRUSHED LIMESTONE[1] AND DOLOMITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE AND USE

(Thousand metric tons and thousand dollars)

	Cement manufacture		Agricultural uses		Lime manufacture		Other uses		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Alabama	2,113	5,086	287	2,089	1,760	8,063	7,982	39,806	27,222	120,667
Arizona	W	W	—	—	W	W	3,980	23,183	4,161	23,183
Arkansas	—	—	156	1,600	—	—	6,186	30,708	7,148	35,753
California	12,566	45,072	29	523	—	—	3,439	61,377	18,108	120,685
Colorado	W	W	W	W	—	—	2,819	15,012	2,819	15,012
Connecticut	—	—	W	W	—	—	1,478	17,815	1,487	17,968
Florida	3,515	18,297	1,197	8,423	—	—	6,022	29,235	63,334	312,429
Georgia	W	W	W	W	—	—	1,336	8,116	5,273	32,043
Hawaii	291	2,121	W	W	—	—	30	407	1,416	14,416
Idaho	W	1,073	W	W	—	—	316	352	316	1,426
Illinois	3,333	14,345	2,411	9,902	—	—	23,737	136,490	61,487	315,149
Indiana	3,230	8,348	1,415	7,497	—	—	9,940	53,460	36,862	165,861
Iowa	W	W	1,168	11,166	W	W	18,417	94,342	30,358	168,158
Kansas	1,816	6,710	139	443	—	—	9,331	47,495	18,848	90,662
Kentucky	W	W	1,566	7,250	W	W	13,874	74,810	49,020	226,048
Louisiana	—	—	—	—	—	—	W	W	W	W
Maine	W	W	—	—	W	W	979	8,044	1,425	8,577
Maryland	2,474	7,141	W	W	—	—	3,959	39,195	15,382	101,824
Massachusetts	W	W	W	W	W	W	W	W	813	10,498
Michigan	5,609	13,033	207	1,219	W	W	17,448	67,615	30,360	110,338
Minnesota	—	—	240	870	—	W	3,420	13,346	7,320	27,523
Mississippi	W	W	104	667	—	—	W	W	2,102	8,122
Missouri	4,295	15,445	1,419	5,781	399	1,853	19,917	92,140	52,119	232,091
Montana	W	W	W	W	W	W	1,816	7,066	1,816	7,066
Nebraska	W	W	230	1,683	—	—	4,585	24,153	6,763	38,871
Nevada	W	W	W	W	238	3,927	W	W	1,013	6,998
New Hampshire	—	—	—	—	—	—	W	W	W	W
New Jersey	—	—	W	W	—	—	W	W	W	W
New Mexico	W	W	—	—	—	—	718	3,395	1,238	5,234
New York	3,722	12,863	94	814	—	—	6,698	40,898	35,273	206,303
North Carolina	—	—	16	W	—	—	3,105	21,815	3,633	24,880
Ohio	W	W	748	4,860	W	W	22,816	103,163	51,611	225,915
Oklahoma	2,794	6,325	259	1,300	W	W	13,993	65,163	23,386	97,861
Oregon	W	W	—	—	—	—	W	W	W	W
Pennsylvania	6,436	35,808	734	8,201	603	4,939	10,471	70,585	53,223	309,739
Rhode Island	—	—	W	W	—	—	W	W	W	W
South Carolina	—	—	—	—	—	—	W	W	2,475	13,658
South Dakota	W	W	—	—	W	W	2,580	9,017	2,580	9,017
Tennessee	W	W	545	4,092	W	W	6,815	42,345	42,759	222,547
Texas	9,932	27,460	508	3,071	1,769	7,952	8,361	50,265	66,177	256,869
Utah	W	W	W	W	W	W	4,121	27,540	4,381	28,466
Vermont	—	—	—	—	—	—	1,726	9,349	1,726	9,349
Virginia	W	W	982	12,474	1,263	8,936	5,604	34,134	18,120	112,653
Washington	—	—	20	511	—	—	510	9,419	540	9,930
West Virginia	W	W	18	171	—	—	5,130	35,648	12,706	74,312
Wisconsin	—	—	476	3,073	W	W	8,110	31,729	23,081	87,025
Wyoming	—	—	—	—	—	—	925	3,987	925	3,987
Total[2]	62,126	219,125	14,967	97,681	6,032	35,670	232,495	1,281,834	790,805	3,909,112
Total withheld	18,971	79,360	279	4,481	9,380	64,679	4,060	27,814	2,088	13,222
Grand total[2]	81,100	298,500	15,200	102,200	15,400	100,300	XX	XX	792,900	3,922,300
Grand total[3] [4]	89,400	298,500	16,800	102,200	17,000	100,300	XX	XX	874,100	3,922,300

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

[1] Includes a minor amount of limestone-dolomite reported without a distinction between the two.

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

[3] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[4] Total shown in thousand short tons and thousand dollars.

TABLE 16

CRUSHED MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Quantity	Value
Coarse aggregate, graded:		
Concrete aggregate, coarse	14	299
Coarse and fine aggregates:		
Crusher run or fill or waste	15	65
Other construction materials[1]	102	3,163
Agricultural:		
Poultry grit and mineral food[2]	15	214
Chemical and metallurgical:		
Cement manufacture	451	2,485
Special:		
Mine dusting or acid water treatment	3	77
Whiting or whiting substitute	3	99
Other fillers or extenders	975	49,585
Other specified uses not listed	131	86
Unspecified:[3]		
Actual	1,676	14,120
Estimated	122	3,062
Total[4]	3,500	74,000
Total[5] [6]	3,900	74,000

[1] Includes filter stone, graded roadbase or subbase, riprap and jetty stone, roofing granules, stone sand, concrete, terrazzo, and exposed aggregates and unpaved road surfacing.

[2] Includes other agricultural uses.

[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.

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[6] Total shown in thousand short tons and thousand dollars.

TABLE 17
CRUSHED GRANITE AND TRAPROCK SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Granite		Traprock	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1 1/2 inch):				
Macadam	946	4,184	225	1,541
Riprap and jetty stone	2,810	20,555	1,248	10,434
Filter stone	1,631	11,578	787	4,564
Other coarse aggregate	777	4,267	1,018	8,889
Coarse aggregate, graded:				
Concrete aggregate, coarse	20,646	137,128	6,442	49,454
Bituminous aggregate, coarse	13,644	92,246	5,557	36,104
Bituminous surface-treatment aggregate	2,734	21,702	2,013	15,867
Railroad ballast	7,899	46,484	2,604	14,732
Other graded coarse aggregate	2,440	16,522	3,050	22,171
Fine aggregate (-3/8 inch):				
Stone sand, concrete	4,122	25,395	1,554	15,905
Stone sand, bituminous mix or seal	4,811	23,853	1,470	9,863
Screening, undesignated	9,100	46,374	1,538	9,041
Other fine aggregate	666	4,192	583	4,602
Coarse and fine aggregates:				
Graded road base or subbase	28,565	142,608	18,390	92,193
Unpaved road surfacing	2,005	8,756	4,062	18,817
Terrazzo and exposed aggregates	357	2,701	139	530
Crusher run or fill or waste	4,692	25,398	3,580	16,349
Other coarse and fine aggregates	1,184	7,014	4,393	30,353
Other construction materials	3,998	24,973	[1]1,909	[1]11,813
Roofing granules	—	—	893	9,167
Special:				
Asphalt fillers or extenders	1,824	8,664	22	170
Other fillers or extenders	([2])	([2])	171	429
Other uses not listed	[3]795	[3]5,374	139	727
Unspecified:[4]				
Actual	43,434	275,713	14,412	93,024
Estimated	9,843	56,760	8,094	48,754
Total[5]	168,900	1,012,400	84,300	525,500
Total[6] [7]	186,200	1,012,400	92,900	525,500

[1] Includes drain fields.

[2] Included with "Other uses not listed."

[3] Includes other agricultural uses and poultry grit and mineral food.

[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.

[6] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[7] Total shown in thousand short tons and thousand dollars.

TABLE 18
CRUSHED SANDSTONE AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Sandstone		Quartzite	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1 1/2 inch):				
Riprap and jetty stone	306	1,897	94	639
Filter stone	122	694	79	443
Other coarse aggregate	96	631	W	W
Coarse aggregate, graded:				
Concrete aggregate, coarse	1,541	7,964	291	1,741
Bituminous aggregate, coarse	1,815	12,026	408	2,461
Bituminous surface-treatment aggregate	591	4,145	151	1,312
Railroad ballast	294	1,671	153	964
Other graded coarse aggregate	40	266	80	636
Fine aggregate (-3/8 inch):				
Stone sand, concrete	1,081	7,963	224	1,081
Stone sand, bituminous mix or seal	747	5,082	109	476
Screening, undesignated	772	4,351	393	2,075
Other fine aggregate	24	138	—	—
Coarse and fine aggregates:				
Graded road base or subbase	3,945	17,562	685	3,799
Unpaved road surfaces	432	2,435	166	768
Terrazzo and exposed aggregates	70	915	W	W
Crusher run or fill or waste	907	2,969	319	1,464
Other coarse and fine aggregates	W	W	14	90
Other construction materials	785	4,206	14	108
Agricultural:				
Poultry grit and mineral food	—	—	([1])	([1])
Chemical and metallurgical:				
Cement manufacture	242	1,358	([1])	([1])
Flux stone	—	—	([1])	([1])
Special:				
Asphalt fillers or extenders	([1])	([1])	—	—
Other fillers or extenders	154	1,095	38	389
Other miscellaneous uses[2]	30	173	170	1,343
Unspecified:[3]				
Actual	7,189	49,456	2,009	11,462
Estimated	3,094	19,166	629	4,671
Total[4]	24,300	146,200	6,000	35,900
Total[5] [6]	26,800	146,200	6,600	35,900

W Withheld to avoid disclosing company proprietary data: included with "Other construction materials."

[1] Included with "Other miscellaneous uses."

[2] Includes other uses not listed.

[3] Includes production reported without breakdown by end use and estimates for nonrespondents.

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

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[6] Total shown in thousand short tons and thousand dollars.

TABLE 19

CRUSHED VOLCANIC CINDER AND SCORIA AND CRUSHED MISCELLANEOUS STONE[1] SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

(Thousand metric tons and thousand dollars)

Use	Volcanic cinder and scoria		Miscellaneous stone	
	Quantity	Value	Quantity	Value
Coarse aggregate (+1 1/2 inch):				
Macadam	—	—	W	W
Riprap and jetty stone	W	W	120	690
Filter stone	62	204	68	387
Other coarse aggregate	—	—	128	545
Course aggregate, graded:				
Concrete aggregate, coarse	114	1,484	1,009	4,339
Bituminous aggregate, coarse	—	—	1,265	6,087
Bituminous surface-treatment aggregate	—	—	620	1,957
Railroad ballast	W	W	15	98
Other graded coarse aggregate	W	W	228	1,327
Fine aggregate (-3/8 inch):				
Stone sand, concrete	—	—	121	640
Stone sand, bituminous mix or seal	—	—	258	1,017
Screening, undesignated	—	—	171	718
Coarse and fine aggregates:				
Graded road base or subbase	171	749	5,805	22,963
Unpaved road surfacing	156	485	1,095	5,579
Terrazzo and exposed aggregate	430	2,779	67	444
Crusher run or fill or waste	26	112	584	3,183
Other coarse and fine aggregates	—	—	42	279
Other construction materials[2]	249	1,645	1,445	9,227
Agricultural:				
Poultry grit and mineral food	—	—	(3)	(3)
Other agricultural uses	W	W	88	413
Chemical and metallurgical:				
Cement manufacture	—	—	2,448	15,169
Special:				
Other fillers or extenders	—	—	(4)	(4)
Other specified uses not listed[5]	58	461	185	1,992
Unspecified:[6]				
Actual	663	4,415	10,772	67,164
Estimated	158	1,102	7,477	41,505
Total[7]	2,100	13,400	34,000	185,700
Total[8,9]	2,300	13,400	37,200	185,700

W Withheld to avoid disclosing company proprietary data; included with "Other construction materials," or "Other specified uses not listed."

[1] Includes marl, shell, slate, and other stone.

[2] Includes other fine aggregates and roofing granules.

[3] Included with "Other agricultural uses."

[4] Included with "Other specified uses not listed."

[5] Includes flour (slate).

[6] Includes production reported without a breakdown by end use and estimates for nonrespondents.

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

[8] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[9] Total shown in thousand short tons and thousand dollars.

TABLE 20

CRUSHED STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY REGION AND METHOD OF TRANSPORTATION

(Thousand metric tons)

Region	Truck	Rail	Water	Other	Not transported	Not specified	Total[1]
Northeast:							
New England	7,905	544	(2)	(2)	3,248	10,117	21,800
Middle Atlantic	72,263	1,870	4,959	661	7,198	39,346	126,300
Midwest:							
East North Central	93,572	3,323	16,558	4,949	9,790	79,920	208,100
West North Central	47,029	2,481	5,946	2,110	8,099	58,686	124,400
South:							
South Atlantic	146,480	15,269	5,269	168	19,300	84,843	271,300
East South Central	75,480	2,765	12,275	1,105	10,987	21,010	123,600
West South Central	45,104	15,278	714	2,232	17,380	40,828	121,500
West:							
Mountain	19,300	3,427	(2)	293	3,617	10,753	37,400
Pacific	39,016	3,504	461	6,460	8,468	23,660	81,600
Total[1]	546,100	48,500	46,200	18,000	88,100	369,200	1,116,000
Total[3] [4]	602,000	53,400	50,900	19,800	97,100	407,000	1,230,200

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

[2] Less than 1/2 unit.

[3] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[4] Total shown in thousand short tons and thousand dollars.

TABLE 21

NUMBER OF CRUSHED AND BROKEN STONE OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1993, BY STATE

State	Mining operations on land				Dredging operations	Total active operations
	Stationary	Portable	Stationary and portable	No. plants or unspecified		
Alabama	40	2	—	1	—	43
Alaska	3	10	2	6	—	21
Arizona	16	9	1	8	—	34
Arkansas	32	10	2	5	—	49
California	73	30	9	34	1	147
Colorado	11	10	5	8	—	34
Connecticut	18	1	—	—	—	19
Florida	35	30	6	13	9	93
Georgia	68	3	1	4	—	76
Hawaii	13	7	2	6	—	28
Idaho	5	36	4	3	—	48
Illinois	92	57	11	3	—	163
Indiana	65	3	6	4	—	78
Iowa	25	169	—	18	2	214
Kansas	28	85	2	4	—	119
Kentucky	76	10	—	1	—	87
Louisiana	1	1	—	—	1	3

TABLE 21—Continued

NUMBER OF CRUSHED AND BROKEN STONE OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1993, BY STATE

State	Mining operations on land					
	Stationary	Portable	Stationary and portable	No. plants or unspecified	Dredging operations	Total active operations
Maine	5	4	1	1	—	11
Maryland	23	5	3	1	—	32
Massachusetts	20	4	2	2	—	28
Michigan	16	12	1	7	—	36
Minnesota	10	35	—	2	—	47
Mississippi	3	2	—	—	—	5
Missouri	90	78	9	4	—	181
Montana	11	5	—	1	—	17
Nebraska	4	5	4	1	—	14
Nevada	4	9	1	—	—	14
New Hampshire	8	1	—	2	—	11
New Jersey	14	1	6	—	—	21
New Mexico	17	21	3	4	—	45
New York	65	16	12	4	—	97
North Carolina	80	5	5	4	—	94
North Dakota	—	—	—	1	—	1
Ohio	88	12	10	4	1	115
Oklahoma	43	7	7	1	—	58
Oregon	40	85	7	18	—	150
Pennsylvania	133	27	15	19	—	194
Rhode Island	7	—	—	—	—	7
South Carolina	27	2	1	2	—	32
South Dakota	9	1	1	—	—	11
Tennessee	104	7	4	2	—	117
Texas	70	47	18	9	1	145
Utah	7	14	2	1	—	24
Vermont	5	7	1	4	—	17
Virginia	93	4	5	2	—	104
Washington	23	62	7	27	—	119
West Virginia	26	12	2	1	—	41
Wisconsin	19	123	—	17	—	159
Wyoming	6	4	—	—	—	10
Total	1,671	1,090	178	259	15	3,213

TABLE 22
U.S. EXPORTS OF CRUSHED STONE IN 1993, BY DESTINATION

(Metric tons)

Destination	Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
North America:					
Bahamas, The	1,519	—	—	—	1,519
Barbados	—	—	28	66	94
Bermuda	17	—	—	28	45
Canada	4,004,787	783	4,261	175,838	4,185,669
Costa Rica	—	—	40	—	40
El Salvador	40	—	—	—	40
Guatemala	—	—	20	—	20
Jamaica	14,778	—	5	38	14,821
Mexico	2,653	26	439	3,584	6,702
Panama	—	—	74	18	92
Trinidad and Tobago	—	—	36	—	36
Total[1]	4,023,795	809	4,904	179,572	4,209,079
South America:					
Brazil	1,355	—	—	—	1,355
Colombia	—	—	—	13	13
Ecuador	—	—	37	704	741
Guyana	—	—	—	20	20
Suriname	—	—	—	10	10
Venezuela	191	14	37	347	589
Total[1]	1,544	14	73	1,094	2,727
Europe:					
Austria	3,920	32	—	—	3,952
Belgium	53,993	—	—	—	53,993
Denmark	6,680	—	—	—	6,680
Finland	56	—	—	—	56
France	10,040	127	74	—	10,241
Germany	126,542	1,509	32	8	128,091
Ireland	318	160	—	—	478
Italy	118,709	37	—	—	118,746
Netherlands	8,170	99	11	25	8,305
Norway	—	—	4	—	4
Poland	—	—	—	36	36
Portugal	3,160	—	—	—	3,160
Spain	4,074	—	—	—	4,074
Sweden	5,340	—	—	—	5,340
Switzerland	2,309	—	—	136	2,445
United Kingdom	62,939	336	147	1,011	64,433
Total[1]	406,249	2,300	268	1,216	410,034
Asia:					
China	19,153	—	—	—	19,153
Hong Kong	443	—	—	144	587
India	780	—	—	3	783
Indonesia	11,580	3	—	—	11,583

See footnotes at end of table.

TABLE 22—Continued

U.S. EXPORTS OF CRUSHED STONE IN 1993, BY DESTINATION

(Metric tons)

Destination		Limestone for cement manufacturing	Other	Chalk, crude	Granules, chippings	Total[1]
Asia—Continued:						
Japan		61,275	725	2	222	62,224
Korea, Republic of		67,825	313	—	38	68,176
Singapore		—	1	—	47	48
Sri Lanka (Ceylon)		—	—	—	—	—
Taiwan		25,273	—	268	179	25,720
Thailand		—	—	—	6	6
Total[1]		186,329	1,042	270	639	188,280
Oceania:						
Australia		4,153	—	82	1,651	5,886
New Zealand		—	—	—	2	2
Total		4,153	—	82	1,653	5,888
Middle East:						
Israel		—	—	15	—	15
Kuwait		37	—	—	—	37
Saudi Arabia		—	—	67	401	468
Total		37	—	82	401	520
Africa:						
British Indian Ocean		—	—	—	7,802	7,802
Egypt		10	—	—	—	10
South Africa, Republic of		14	—	—	—	14
Total		24	—	—	7,802	7,826
Grand total[1]		4,622,000	4,200	5,700	192,400	4,824,400
Grand total[2]	short tons	5,095,000	4,600	6,300	212,000	5,317,900
Total value	thousands	$27,300	$3,200	$1	$8,800	$39,300

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

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

Source: U.S. Bureau of the Census.

TABLE 23

U.S. IMPORTS OF CRUSHED STONE AND CALCIUM CARBONATE FINES, BY TYPE

(Thousand metric tons and thousand dollars)

Type	1992		1993	
	Quantity	C.i.f. value	Quantity	C.i.f. value
Crushed stone and chips:				
Limestone[1]	2,917	23,248	4,976	41,070
Limestone for flux or cement manufacturing	3,538	31,906	3,069	21,392
Quartzite	1	442	(2)	343
Other	562	4,373	353	6,232
Total[3]	7,017	59,969	8,399	69,037
Calcium carbonate fines:[4]				
Natural chalk	(2)	55	(2)	255
Calcium carbonates other chalk	2	658	44	5,056
Total	2	713	44	5,311
Grand total[3]	7,000	60,700	8,400	74,300
Grand total[5] [6]	7,700	60,700	9,300	74,300

[1] Excludes limestone for cement manufacturing.

[2] Less than 1/2 unit.

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

[4] Excludes precipitated calcium carbonate.

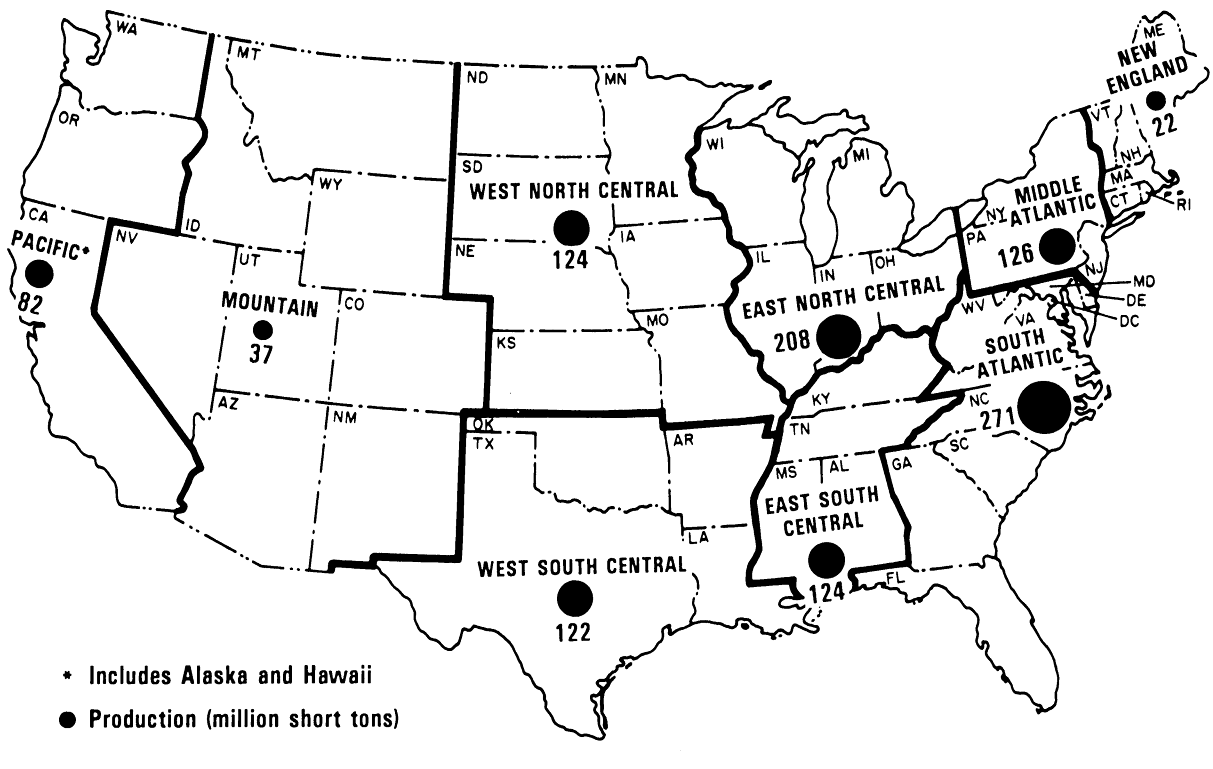
[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

[6] Total shown in thousand short tons and thousand dollars.

Source: U.S. Bureau of the Census.

FIGURE 1

PRODUCTION OF CRUSHED STONE IN THE UNITED STATES IN 1993, BY GEOGRAPHIC REGION



DIMENSION STONE

By Harold A. Taylor, Jr.

Mr. Taylor, a physical scientist with 28 years of industry and Federal Government experience, including U.S. Bureau of Mines experience, has been the commodity specialist for dimension stone since 1981. Domestic survey data were prepared by Robin Richardson, statistical assistant.

Production of dimension stone increased slightly to 1.24 million metric tons (1.36 million short tons) valued at $217 million. Slightly more than one-half of the dimension stone produced was granite. Limestone, marble, sandstone, slate, and quartzite also were produced.

Exports of dimension stone increased 5% in value to $58 million. The value of dimension stone imports for consumption decreased slightly to $398 million, equivalent to 183% of the value of domestic production.

DOMESTIC DATA COVERAGE

Domestic production data for dimension stone are developed by the U.S. Bureau of Mines (USBM) from voluntary surveys of U.S. producers of rough and finished dimension stone. Of the 318 dimension stone operations surveyed for 1993, including those that were idle, 264, or 83%, responded, representing 92% of the value shown in table 1. Production data for nonrespondents were estimated using preliminary production reports, adjusted prior years' production levels, and employment data. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Dimension stone is a natural rock material that has been selected, trimmed, or cut to specified or indicated shapes or sizes, with or without one or more mechanically dressed surfaces. This includes rough stone, rubble, ashlar, blocks, panels, tile, and curvilinear shapes. Finished surface requirements may vary from a controlled fractured surface to ground and polished. The most prominent required qualities of dimension stone are strength, toughness, hardness, and resistance to environmental damage. Color and grain structure contribute largely to price and marketability. The principal types of dimension stone used in construction are granite, marble, limestone, sandstone, and slate.

Stone classification by type in the dimension stone industry is somewhat ambiguous and does not correspond in some respects with the same terms used in mineralogical rock descriptions. The USBM generally accepts the classification reported by producers. Granite includes all feldspathic crystalline rocks of predominantly interlocking texture with mineral grains visible to the naked eye; these include igneous and metamorphic rocks, including quartz diorites, syenites, quartz porphyries, gabbros, anorthosites, and gneisses. White, gray, black, pink, and red are the common colors for granite, but greens, browns, and other shades are produced in some localities.

Limestone includes dolomitic types as well as calcitic. The latter contain less than 5% magnesium carbonate ($MgCO_3$). Dolomitic limestone contains 5% to 40% $MgCO_3$. Marble is a recrystallized (metamorphosed) limestone containing grains of calcite or dolomite or both. In commercial usage, it is any calcareous crystalline rock or serpentine, a hydrous magnesium silicate, capable of taking a polish. Travertine is a type of marble similar to onyx except that it is precipitated from warm or hot water; it has a banded cellular structure and contains cavities up to 1 centimeter in width that are lined with microstalactites. Dark green serpentines are classified as marble in the industry because they are often crisscrossed with marblelike veinlets of lighter materials, chiefly calcite or dolomite, and because of their ability to take a high polish.

Commercial sandstone is a sedimentary rock consisting mostly of quartz, sometimes with feldspar, or rock fragments of clastic texture bonded by silica, clay, calcite, or iron oxide. Bluestone is a dense, hard, fine-grained feldspathic sandstone that splits easily along a plane into thin, smooth slabs. It is commonly dark or slate gray in color, and its name no longer has color significance. Brownstone is a feldspathic sandstone of brown reddish-brown color caused by abundant interstitial iron oxide. Flagstone may be either a sandstone or a slate that splits into large, thin slabs.

Quartzite is a metamorphic equivalent of sandstone that has been firmly cemented by secondary silica or by recrystallization so that it is essentially homogeneous and fractures through rather than around the original sand grains.

Slate is a fine-grained metamorphic rock derived from shale, siltstone, or claystone. It has prominent cleavage that is oriented independently from the original sedimentary bedding. Mineral constituents are quartz, mica, sericite, or chlorite with assorted minor accessories. Shale is composed mostly of original clay minerals, and cleavage is parallel to the bedding.

Traprock is a commercial term for all dark, igneous rocks too fine in grain size to be called black granite. In addition to extrusive flow rocks such as basalt, andesite, or dacite, traprock includes intrusive igneous rocks such as diabase, diorites, gabbros, pyroxenites, amphibolites, and peridotites.

Miscellaneous stones used for dimension purposes include schist, soapstone, argillite, and many others.

Geology-Resources

Domestic resources of most types of dimension stone used in construction are practically unlimited. There is considerable interstate transportation of certain types of stone such as Indiana limestone, Georgia marble and granite, and Vermont granite, marble, and slate. A lack of deposits of certain specific varieties of dimension stone especially noted for their aesthetic qualities in architecture and artifact manufacture is an important cause of importation of these varieties; for example, brightly colored marbles from Italy.

Technology

Mining.—Present mining methods range from antiquated and very inefficient to modern and technically superior. Quarrying methods include use of various combinations of diamond saws, wire saws, diamond wire saws, chain saws, channeling machines, drilling machines, wedges, and broaching tools. The choice of equipment depends on the type of dimension stone, size and shape of deposit, production capacity, labor costs, economics, and management investment attitudes.

Little blasting is done in the mining of dimension stone. Blocks cut from the face are sawed or split into smaller or thinner blocks for ease in transportation and handling and taken to processing plants, often at the quarry site, for final cutting and finishing operations.

Processing.—Stone-sawing equipment includes large circular saws 3 meters or more in diameter, some with diamond inserts and some using other abrasives; diamond circular saws of smaller size; and reciprocating diamond-bladed or loose-abrasive gang saws for multiple cuts. Various types of diamond and other equipment are used for smoothing, polishing, edging, and decorating the finished stone products. *(See table 2.)*

Economic Factors

The depletion allowance for dimension stone is 14%. Dimension stone quarries are generally in hilly areas remote from areas of dense population. Because land use for other purposes is limited, the cost of land is reasonable.

Transportation costs for dimension stone are high because of its weight and because special handling methods are required to prevent damage to the finished stone. A single stone panel broken in transit not only results in the loss of the many employee-hours of skilled labor required to produce it, but also can cause construction delays that are even more costly. Nevertheless, dimension stone is routinely shipped long distances by motor and rail freight, and special domestic varieties are shipped by ocean freight to foreign countries.

Operating Factors

Environmental requirements vary from State to State and are often a cause of conflict between State or local governments and the quarry operators.

Stone primary and waste products are not toxic, nor are the supplies utilized in their production. However, sufficient exposure to silica-rich stone dust can cause silicosis.

The approximate number of employees in the dimension stone industry by stone kind are granite, 9,600; limestone, 1,100; marble, 1,500; slate, 950; and sandstone and other dimension stone, 850. Of the total 14,000 employees, about 3,100 are employed in quarrying and approximately 10,900 in finishing operations. Major States for employment were Georgia with 2,100 employees, Vermont with 1,700, Minnesota with 1,250, North Carolina with 850, Texas with 700, and Indiana with 650.

Fuel is used to power quarrying equipment, and electricity is used for sawing and finishing. Water is used in some quarries to cool equipment such as chain saws and in sawing and finishing plants to cool the equipment; water consumption is relatively minimal in all instances.

ANNUAL REVIEW

Production

Dimension stone was produced by 162 companies at 256 quarries in 35 States, including Puerto Rico. Leading States, in order of tonnage, were Georgia, Indiana, and Massachusetts, together producing 39% of the Nation's total. Of the total production, 51% was granite, 30% was limestone, 9% was sandstone, 3% was slate★3% was marble, and the remaining 4% was miscellaneous stone. Miscellaneous stone included quartzite, argillite, schist, soapstone, and traprock (basalt). Leading producing companies in terms of tonnage were Fletcher Granite Co. Inc., in Massachusetts and New Hampshire; Cold Spring Granite Co., principally in California, Minnesota, South Dakota, and Texas; and Rock of Ages Corp. in New Hampshire and Vermont.

Granite.—Dimension granite includes all coarse-grained igneous rocks. Production increased 5% to 624,200 tons and decreased 5% in value to $110.5 million. Granite was produced by 58 companies at 100 quarries in 19 States. Georgia continued to be the leading State, producing 28% of the U.S. total, followed by Massachusetts and Vermont. These three States together produced 64% of the U.S. total. Fletcher Granite Co., Cold Spring Granite, and Rock of Ages were the leading producers and accounted for 47% of U.S. production by tonnage.

Limestone.—Dimension limestone includes bituminous, dolomitic, and siliceous limestones. It was produced by 36 companies at 44 quarries in 14 States. Indiana, the leading State, was followed by Wisconsin and Kansas. Leading producers were Indiana Limestone Co. Inc., Halquist Stone Co. Inc., and Eden Stone Co., Inc. The top three companies accounted for 31% of U.S. output.

Halquist Stone Co. of Sussex, WI, has been planning a large expansion of its limestone tile business. The company bought a tile line that was installed near the end of the year. Domestic demand for limestone tile has been increasing rapidly, mostly as a substitute for marble and granite.

Marble.—Dimension marble includes certain hard limestones, travertines, and any other calcareous stone that can be polished. Dimension marble was produced by 9 companies at 16 quarries in 9 States, including Puerto Rico. Vermont, Georgia, and Tennessee, in order of tonnage, were the three leading States, accounting for approximately 62% of U.S. output. Leading producers were Vermont Quarries Corp., Dixie Marble Inc., and Georgia Marble Co. The top three companies accounted for 78% of the U.S. output.

Vermont Marble Co. disposed of its dimension marble operations. The company leased its Danby marble quarry to R.E.D. Graniti, which plans to increase production and sell the product as rough block, mostly overseas. The operating subsidiary is Vermont Quarries Corp.

Vermont Marble also sold its verde antique quarry to Marble Modes of New York, NY, which will be operated as Vermont Verde Antique International Inc. Marble Modes added a diamond chain saw and plans to reequip the rest of the quarry. Some of the finishing equipment was sold to U.S. Quarried Slate Products Co., and the balance of the equipment and plant was sold to Gawet Marble & Granite Inc.

Gawet also bought the Luck Stone Co. operation in Tennessee as part of a major expansion. The purchase included a quarry for Tennessee pink marble and a plant built in 1989, including gang saws, a polisher, a tile line, and other cutting and finishing equipment. Gawet will operate its newly acquired operation under the name Tennessee Marble Co.

Sandstone.—Dimension sandstone includes calcareous- and siliceous-cemented sandstones or conglomerates. Quartzite, which is also included, may be described as any siliceous-cemented sandstone. Sandstone was produced by 26 companies at 45 quarries in 14 States. The leading three States were, in order of volume, Ohio, Utah, and Oklahoma. Briar Hill Stone Co., American Building and Stone, Inc. and Rock Island Stone Co. were the leading producers and accounted for 35% of U.S. production. In addition to the quantities shown in table 6, dimension quartzite totaled 27,822 tons worth $2,716,000. The tonnage was 33% flagging.

Slate.—Dimension slate was produced by 19 companies at 26 quarries in 6 States. The two leading States, Vermont and Pennsylvania, in order of volume, accounted for 69% of U.S. output. The top three producers, U.S. Quarried Slate Products Inc., A. Dally and Sons Inc., and Alfred McAlpine Inc., accounted for an estimated 44% of U.S. output by volume.

Miscellaneous Stone.—Miscellaneous dimension stone was produced by nine companies from nine quarries in five States and totaled 34,846 tons valued at $4,034,000. *(See tables 3, 4, 5, and 6.)*

Consumption and Uses

Dimension stone was marketed over wide areas. Industry stockpiles were not monitored, and production during 1993 was assumed to equal consumption.

Consumption of domestic dimension stone increased slightly to 1.24 million tons valued at $217 million. Ashlars and partially squared, dressed pieces were 17% of the total value of consumption, followed by curbing with 15%; rough monumental stone with 13%; rough blocks for building and construction with 12%; dressed monumental stone with 12%; and other uses, 31%.

Of the total consumption of domestic granite, 29% by value was curbing, 25% was rough monumental stone, and 15% was dressed monumental stone.

Consumption of domestic limestone totaled 366,018 tons valued at $50.2 million, of which 40% was ashlars and partially squared pieces, 19% by value was dressed slabs and blocks for building and construction, and 18% was rough blocks for building and construction.

Limestone tile is an important new product that is rapidly gaining popularity. For several years now, tiles made out of hard limestone have sometimes been used as substitutes for other stones, particularly granite tile. These tiles (or slabs) have sometimes been domestic, but more commonly were French or Spanish limestones. They were used in applications where granite or marble are customarily used. Now tile of softer limestones are being made and sold. Specific applications known include some flooring areas not subject to heavy traffic or grit-bearing footwear. *(See tables 7, 8, 9, 10, 11, and 12.)*

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 roofing material, alternates such as sheet metal, wood shingles, asbestos-cement shingles, and tile are available. For blackboards, it competes with colored glass, porcelain-enameled steel, and special painted surfaces.

Two helpful articles on stone in

Washington, DC, appeared in Stone World. One described the stone used in the building now being leased to the USBM as its headquarters.[1] The other identified the stones used in the major monuments, the U.S. Capitol, a number of major nearby buildings, and thumbnailed the present local quarries.[2]

Prices

The average price for dimension stone decreased to $176 per ton, down slightly from $182 in 1992.

Foreign Trade

Exports.—Exports of dimension stone, more than 50% of which was granite, increased 5% in value.

Imports.—Imports for consumption of dimension stone decreased slightly in value to $398 million, mostly because of minor decreases in imports of major categories of dimension stone. On a value basis, marble accounted for 48% of imports, followed by granite, 27%. *(See tables 13, 14, 15, and 16.)*

World Review

Although some production of dimension stone occurred in most countries of the world, the major producer again was Italy, accounting for about one-half of world production. Other major producers were Brazil, China, Finland, India, Norway, Portugal, Spain, Sweden, Turkey, and the United States.

Internazionale Marmi e Macchine Carrara S.p.A. has issued the following updated production statistics for certain nations: For granite in 1992, China produced 1,867,000 tons; India (1991-92), 989,500 tons; Italy, 1,100,000 tons; Korea (Republic of), 1,380,000 tons; South Africa (Republic of), 574,800 tons; and Spain, 980,000 tons. For granite in 1991, China produced 652,000 tons; Italy, 1,374,000 tons; Korea (Republic of), 1,541,000 tons; South Africa (Republic of), 672,600 tons; and Spain, 1,150,000 tons. For marble in 1992, China produced 678,000 tons; France, 634,000 tons; India (1991-92), 1,966,400 tons; Italy, 4,800,000 tons; Mexico, 712,000 tons; Portugal, 962,000 tons; Spain, 2,000,000 tons; and Turkey, 650,000 tons. For marble in 1991, China produced 625,000 tons; France, 686,100 tons; Italy, 4,115,000 tons; Mexico, 750,000 tons; Portugal, 950,000 tons; Spain, 2,210,000 tons; and Turkey, 650,000 tons.

Australia.—Fraser Range Granite NL announced that it will shortly begin to quarry four kinds of granite in the Fraser Range area of Western Australia. Its commercial production began in mid-1992 to fill some building contracts in Sydney. It hopes to export significant amounts of rough block.

Canada.—Jarvis Resources Ltd. announced the availability of marble tile, slabs, and sills in polished, honed, and sand finishes from its new finishing plant. There are six colors and veinings in gray and gray-brown colors presently available, with additional types to come later. These quarries are 35 kilometers north of Sudbury, Ontario.

India.—The International Labour Office in Geneva, a United Nations agency, documented the bonded labor practices in the Indian dimension stone industry in its "World Labour Report 1993." Bonded labor is a defacto form of slavery, because it involves giving an advance that the laborer has to pay from future earnings. But at very low wages and with the employer usually charging for tools and/or accommodations, the debt is never repaid. On the death of the original laborer, the employer may insist that the debt be honored by the child, thus creating another bonded laborer. Bonded laborers in all industries in India may number in the millions, although the Government of India acknowledges only 353,000! Many of these laborers are children. Although the Government is attempting to stop the practice, its prosecution of guilty employers is minimal and its laborer rehabilitation program is not very effective yet. Bonded laborers are concentrated in a few industries, one of which is stone quarrying.

According to information in Dimensional Stone, bonded laborers, particularly children, are used in many quarries in India. The dimension stone product is often exported to U.S. and world markets. Dimensional Stone urged the industry not to do business with firms unwilling to certify that they are nonusers of bonded laborers and now refuses to take advertisements from such firms. The All India Granites & Stone Association wrote the magazine to protest the policy and the political smears behind it, stating that bonded labor was totally nonexistent in the industry, that the industry always paid its laborers at least the minimum wage with liberal leave and bonuses for festivals, and that the industry's employees totaled fewer than 200,000.

A number of sizable quarries, particularly granite, have been recently opened in Rajasthan State. Total capacity for finished marble slabs in Rajasthan is 37 million square meters and for marble tile is 14 million square meters; these numbers represent the majority of all-India marble capacity. A joint venture called Immaculate Stones Ltd. announced it would build a granite quarrying and finishing operation in 1994 in Orissa State with the collaboration of Italian dimension stone equipment manufacturer Terzago S.p.A. Nagarjuna Granites Ltd. is expanding its plant to an annual capacity of 75,000 square meters of tile and panel. Charminar Granites Exports Ltd. announced it would build an operation in Andhra Pradesh with capacities of 50,000 square meters of tile per year and 40,000 square meters of slab and panel per year.

Canadian granite monument producers filed a dumping and subsidy case against Indian black granite memorials and slabs more than 8 centimeters thick with Revenue Canada Taxation. Revenue Canada Taxation will collect information from the complainants and the defendants; a nonresponse will result in a determination for the other side. If a preliminary determination of injury results, a duty of 89% could be imposed; it would be permanent upon a final determination of injury.

Italy.—Ifint, the investment arm of Fiat's (automotive) Agnelli family, has purchased a stake in Georgia Marble Co. for $100 million from First Chicago Corp., along with 17 other firms for a grand total of $300 million.

The Carrara area has the potential for a sizable crushed marble industry based on the waste from dimension marble production. The amount of waste available is immense and incalculable; it blankets the mountains, giving the appearance of snow. The large amount of waste is the result of innumerable years of quarrying; Carrara marble yields minimal waste per ton quarried. According to a survey of 55 dumps, almost one-half of the material is unusable, low-calcium carbonate Pietra di Cardozo, a material with a sizable crystalline silica content. Several crushed marble plants using waste as a raw material already exist, one of them at Pianello.

Korea, Republic of.—Il Shin Stone Co., one of the countries largest producers, has expanded to the point that it has 22 gangsaw plants around the country and finishes 240,000 square meters of granite per month, two-thirds of which is domestically consumed.

Portugal.—Portugal produces major amounts of such stones as granite (250,000 tons produced in 1991) and limestone, but the largest amount produced is the 950,000 tons of marble. Granite is mostly produced in the north near such cities as Porto and Braga. Limestone is quarried at scattered locations, several of which are in the far south near Tavira. Marble is mostly produced east of Lisbon in the Estremoz-Evora area; this area alone has 240 quarries and is a major center for finishing operations. However, new environmental laws, including the establishment of national parks, are expected to impede the opening of new quarries.[3]

South Africa, Republic of.—South African granite producers are shifting their exports from rough block to polished slab to save on transportation costs. For example, 30% of the original rough block is lost as waste after conversion to polished slab. Their transportation and handling costs total 70% of the value of the stone by the time it arrives in Italy.

Keeley Granite, the major granite producer, has acquired extensive mineral rights to the Rustenburg Gray and African Red granites. Several Italian firms have bought into local granite producers. South African black granite producers have been troubled with competing material from Zimbabwe.

Current Research

An article on the latest methods for removing stone dust from the water and air circulating in a stone finishing plant was published. A variety of air and water filtration systems was described. Air filtration systems have the advantage of cleaning the air in a more controlled way rather than opening a window or door and having employees wear face masks.[4]

In response to stone consumers' need for lightweight materials, Pedrini S.p.A. began offering a sectioning machine that can make 6.5-millimeters- (0.25-inch)-thick granite tile. In addition, the company is offering a scanning machine that inspects marble and granite tile for uniformity of color, broken corners, cracks, and other defects.

The reinforced thin-cut stone panel can be used in places where weight is a consideration, such as elevators and yachts. The stone is only 5 millimeters (3/16 inches) thick and is often anchored to a metal honeycomb.

OUTLOOK ★ ★

Projected demand for dimension granite totaled 1.3 million tons for 1995 and 2 million tons for the year 2000. Demand for dimension marble totaled 300,000 tons for 1995 and 500,000 tons for the year 2000. Demand for dimension limestone totaled 360,000 tons for 1995 and 400,000 tons for the year 2000, while demand for slate ought to be 35,000 tons in 1995 and 37,000 tons in the year 2000. This slow rate reflects a major drop in the market for building stone in 1989-93 and a welcomed recovery later in the 1990's. Certain segments will continue to grow rapidly, such as for uses in kitchens and bathrooms. The supply will be adequate and is likely to shift in favor of domestic producers.

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[1] Taylor, H. A World of Stones in the City of Stone. Stone World, v. 10, No. 3, Mar. 1993, pp. 105-106.

[2] ———. Touring the Capital's Stone Sites/Local Stones of Washington, DC. Stone World, v. 10, No. 10, Oct. 1993, pp. 33-35.

[3] Loughborough, R. Portugal's Minerals. Ind. Miner., No. 308, May 1993, pp. 47-65.

[4] Sailer, J. Dust in the Wind...and the Water. Stone World, v. 10, No. 4, Apr. 1993, pp. 44-60.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publication

Dimension Stone. Ch. in Mineral Commodity Summaries, annual.
Dimension Stone. Ch. in Minerals Yearbook, annual.
Dimension Stone. Reported annually in Mineral Industry Surveys.
Directory of Principal Dimension Stone Producers in the United States.
Leading Country Activity.
Market Activity.

Other Sources

Dimensional Stone.
Industrial Minerals (United Kingdom).
Stone Industries (United Kingdom).
Stone World.

TABLE 1
SALIENT U.S. DIMENSION STONE STATISTICS

(Thousand metric tons and thousand dollars)

	1989	1990	1991	1992	1993
Sold or used by producers:					
Quantity[1] thousand metric tons	1,123	1,118	1,157	[r]1,061	1,235
Quantity[2] thousand short tons	1,238	[e]1,232	1,275	[r]1,169	1,362
Value[1]	$210,878	[e]$232,130	$211,494	[e]$192,744	$216,930
Exports (value)	$34,610	$54,019	$64,947	$54,904	$57,888
Imports for consumption (value)	$525,052	$586,243	$474,914	$403,922	$397,821

[e]Estimated. [r]Revised.

[1] Includes Puerto Rico for 1990, 1991, 1992, and 1993.

[2] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 2
U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1994	Jan. 1, 1994
Slate: Rough blocks or slabs	2514.00.0000	3.7% ad valorem	25% ad valorem.
Rough blocks or slabs of marble, travertine, and other calcareous monumental or building stone	2515.00.0000		
Marble and travertine:			
Crude or roughly trimmed	2515.11.0000	$3.46 per cubic meter	$22.95 per cubic meter.
Marble, merely cut	2515.12.0010	2.1% ad valorem	13% ad valorem.
Travertine, merely cut	2515.12.0020	6% ad valorem	50% ad valorem.
Other calcareous stone alabaster	2515.20.0000	6% ad valorem	50% ad valorem.
Rough blocks or slabs of granite, porphyry, basalt, sandstone, and other monumental or building stone	2516.00.0000		
Granite:			
Crude or roughly trimmed	2516.11.0000	Free	$8.83 per cubic meter.
Merely cut	2516.12.0000	4.2% ad valorem	60% ad valorem.
Sandstone:			
Crude or roughly trimmed	2516.21.0000	Free	$5.30 per cubic meter.
Merely cut	2516.22.0000	6% ad valorem	50% ad valorem.
Other monumental or building stone	2516.90.0000	6% ad valorem	50% ad valorem.
Setts, curbstones, and flagstones	6801.00.0000	4.2% ad valorem	60% ad valorem.
Worked monumental or building stone	6802.00.0000		
Tiles and cubes under 7cm square, granules	6802.10.0000	6.9% ad valorem	40% ad valorem.
Other stone and articles with a flat or even surface:			
Marble, travertine and alabaster:	6802.21.0000		
Travertine	6802.21.1000	6% ad valorem	50% ad valorem.
Other	6802.21.5000	2.1% ad valorem	13% ad valorem.
Other calcareous stone	6802.22.0000	6% ad valorem	50% ad valorem.
Granite	6802.23.0000	4.2% ad valorem	60% ad valorem.
Other stone	6802.29.0000	7.5% ad valorem	30% ad valorem.
Other:			
Marble, travertine, and alabaster:	6802.91.0000		
Marble:			
Slabs	6802.91.0500	2.8% ad valorem	15% ad valorem.
Other	6802.91.1500	6% ad valorem	50% ad valorem.

TABLE 2—Continued

U.S. IMPORT DUTIES ON DIMENSION STONE

Tariff item	HTS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1994	Jan. 1, 1994
Other—Continued:			
Marble, travertine, and alabaster—Continued:			
★ Travertine:			
Articles of subheading 6802.21.1000 that have been dressed or polished, but not further worked	6802.91.2000	6% ad valorem	50% ad valorem. ☆
Other	6802.91.2500	5.3% ad valorem	40% ad valorem.
Alabaster	6802.91.3000	5.3% ad valorem	50% ad valorem.
Other calcareous stone	6802.92.0000	6% ad valorem	50% ad valorem.
Granite	6802.93.0000	4.2% ad valorem	60% ad valorem.
Other stone	6802.99.0000	6.5% ad valorem	40% ad valorem.
Worked slate and articles:	6803.00.0000		
Roofing slate	6803.00.0010	6.6% ad valorem	25% ad valorem.
Other	6803.00.0050	3.7% ad valorem	25% ad valorem.

TABLE 3

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES,[1] BY STATE

State	1991		1992[e]		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Alabama	8,665	$2,449	W	W	W	W
California	40,603	5,254	21,130	$4,148	29,082	$6,299
Colorado	W	W	5,855	252	4,315	1,374
Connecticut	15,009	1,739	W	W	W	W
Georgia	[2]196,803	[2]21,282	[r][2]180,257	[r][2]20,027	[2]176,291	[2]18,746
Idaho	9,873	970	W	W	W	W
Indiana	[2]171,467	[2]27,596	172,739	26,767	[2]155,616	[2]22,876
Kansas	[2]27,948	[2]3,128	W	W	[2]24,728	[2]2,539
Maryland	11,208	1,067	10,310	1,024	19,345	2,024
Massachusetts	62,897	11,646	59,725	9,292	152,536	21,323
Minnesota	41,545	13,962	32,833	11,436	33,466	11,766
New Hampshire	31,573	5,013	34,153	5,460	53,106	8,674
New York	16,292	3,162	16,526	2,779	19,275	3,436
North Carolina	33,617	10,568	23,014	7,469	31,733	12,268
Ohio	[2]42,666	[2]2,443	31,805	2,244	[2]25,738	[2]1,207
Oklahoma	[2]3,426	[2]596	4,701	706	[2]2,350	[2]838
Pennsylvania	38,086	10,459	37,855	10,822	35,665	9,892
South Carolina	8,010	854	W	W	W	W
Tennessee	3,139	260	3,084	320	4,553	552
Utah	20,937	1,429	W	W	W	W
Vermont	84,058	31,013	113,398	34,639	97,352	27,875
Virginia	10,021	3,061	W	W	W	W
Wisconsin	[2]55,238	[2]6,221	[r][2]50,862	[r][2]5,827	121,573	13,098
Other[3]	223,927	47,324	[r]261,960	[r]49,532	248,498	52,143
Total[4]	1,157,007	211,494	[r]1,060,207	[r]192,744	1,235,222	216,930
Total[5]	1,275,382	211,494	[r]1,168,678	[r]192,744	1,361,599	216,930

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Includes Puerto Rico.

[2] Totals only include Georgia granite, Indiana limestone, Kansas limestone, Ohio sandstone, and Oklahoma granite; other stone included with "Other."

[3] Includes data for Arizona, Arkansas, Illinois, Iowa, Maine, Michigan, Missouri, Montana, New Mexico, Puerto Rico, South Dakota, Texas, and Washington.

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

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 4
DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY STATE

State	1992[e]		1993		
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Georgia	[r]180,257	[r]$20,027	176,291	1,943	$18,746
Massachusetts	59,725	9,292	152,536	2,038	21,323
New Hampshire	34,153	5,460	53,106	710	8,674
North Carolina	29,756	9,600	29,755	398	11,600
Oklahoma[1]	4,701	706	2,350	31	838
Pennsylvania	12,247	13,230	10,834	142	2,955
South Carolina	6,438	697	W	W	W
Vermont	65,807	W	70,478	959	W
Other[1] [2]	200,910	56,636	128,891	1,651	46,347
Total[3]	[r]593,994	[r]115,648	624,240	7,872	110,484
Total[4]	[r]654,766	[r]115,648	688,107	7,872	110,484

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1]Includes a small amount of other dimension stone for 1992.

[2]Includes California, Colorado, Connecticut, Maine, Minnesota, Missouri, New York, South Carolina, South Dakota, Texas, Virginia, and Wisconsin.

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

[4]One metric ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 5
DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

State	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Indiana	155,616	2,346	$22,876
Kansas	24,728	321	2,539
Wisconsin	118,593	1,634	10,275
Other[1]	67,081	902	14,540
Total	366,018	5,203	50,230
Total[2]	403,466	5,203	50,230

[1]Includes Alabama, Arkansas, California, Iowa, Minnesota, New Mexico, New York, Ohio, Oklahoma, Texas, and Utah.

[2]One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 6
DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY STATE

State	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
New York	8,202	116	$870
Ohio	25,738	391	1,207
Pennsylvania	13,196	186	1,655
Other[1]	66,223	934	4,000
Total[2]	113,358	1,629	7,731
Total[3]	124,956	1,629	7,731

[1]Includes Alabama, Arizona, Arkansas, California, Colorado, Indiana, Kansas, Michigan, North Carolina, Oklahoma, and Utah.

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

[3]One metric ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 7

DIMENSION STONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993,[1] BY USE

Use	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	243,803	3,413	$26,004
Irregular-shaped stone[2]	102,171	1,240	9,467
Monumental	209,279	2,539	28,371
Other[3]	24,769	317	2,623
Dressed stone:			
Ashlars and partially squared pieces	194,612	2,662	37,899
Slabs and blocks for building and construction	53,921	750	24,144
Monumental	41,757	486	25,083
Curbing	222,400	2,921	32,922
Flagging	61,313	854	5,230
Flagging (slate)	5,988	—	866
Roofing slate	14,091	—	10,891
Structural and sanitary	4,560	—	3,906
Flooring slate	4,230	—	2,918
Other[4]	52,328	658	6,606
Total	1,235,222	15,840	216,930
Total[5]	1,361,599	15,840	216,930

[1] Includes Puerto Rico.

[2] Includes rubble.

[3] Includes rough stone used for flagging and unspecified uses.

[4] Includes minor amount of paving blocks, slate used for billiard tabletops, blackboard, bulletin boards and school slates, and unspecified uses.

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 8

DIMENSION GRANITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	81,264	1,039	$13,169
Irregular-shaped stone[1]	16,640	197	1,698
Monumental	205,717	2,492	27,497
Dressed stone:			
Ashlars and partially squared pieces	50,593	661	12,795
Slabs and blocks for building and construction	15,008	200	6,268
Monumental	36,954	424	16,059
Curbing	214,116	2,806	32,369
Other[2]	3,948	52	628
Total[3]	624,240	7,872	110,484
Total[4]	688,107	7,872	110,484

[1] Includes rubble and a minor amount of uses not specified.

[2] Includes stone used for flagging, paving block, and unspecified uses for dressed stone.

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

[4] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 9

DIMENSION LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	128,800	1,918	$8,862
Irregular-shaped stone[1]	56,449	756	5,333
Dressed stone:			
Ashlars and partially squared pieces	84,688	1,191	20,009
Slabs and blocks for building and construction	25,652	371	9,420
Flagging	27,461	375	2,517
Other[2]	42,969	592	4,089
Total	[3]366,018	5,203	50,230
Total[4]	403,467	5,203	50,230

[1] Includes uses not specified.

[2] Includes dressed monumental, curbing, and unspecified uses for dressed stone.

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

[4] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 10

DIMENSION MARBLE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993,[1] BY USE

Use	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	16,875	219	$3,329
Other[2]	5,263	68	1,000
Dressed stone:			
Ashlars and partially squared pieces	1,355	18	W
Slabs and blocks for building and construction	7,522	98	7,702
Other[3]	4,626	60	9,224
Total	35,641	463	[4]21,254
Total[5]	39,288	463	21,254

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

[1] Includes Puerto Rico.

[2] Includes rubble, irregular-shaped stone, moumental stone, and unspecified uses.

[3] Includes stone used for monumental purposes, a small amount of flagging, and unspecified.

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

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 11

DIMENSION SANDSTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (metric tons)	Cubic feet (thousands)	Value (thousands)
Rough stone:			
Rough blocks for building and construction	14,309	202	$465
Irregular-shaped stone[1]	21,621	302	1,842
Other[2]	110	2	27
Dressed stone:			
Ashlars and partially squared pieces	43,734	645	3,235
Slabs and blocks for building and construction	2,446	36	305
Flagging	21,537	310	1,240
Other[3]	9,603	133	617
Total[4]	113,358	1,629	7,731
Total[5]	124,956	1,629	7,731

[1] Includes rubble.

[2] Includes uses not specified.

[3] Includes dressed monumental, curbing, and unspecified uses for dressed stone.

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

[5] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 12

DIMENSION SLATE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1993, BY USE

Use	Quantity (metric tons)	Value (thousands)
Flagging	5,988	$866
Roofing	14,091	10,891
Structural and sanitary purposes	4,560	3,906
Flooring	4,230	2,918
Other[1]	3,758	1,858
Total	32,628	[2]20,440
Total[3]	35,966	20,440

[1] Includes a minor amount of slate used for billiard tabletops, blackboard, school slates, and unspecified uses.

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

[3] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

TABLE 13
U.S. EXPORTS OF DIMENSION STONE, BY TYPE

Type	1992 Quantity (thousand metric tons)	1992 Value (thousand dollars)	1993 Quantity (thousand metric tons)	1993 Value (thousand dollars)	Major destination in 1993, (percent)[1]
Marble, travertine, alabaster worked	19	2,839	34	2,561	Canada, 40.
Marble, travertine—crude or roughly trimmed	4	1,154	3	936	Canada, 46.
Marble, travertine—merely cut, by sawing or otherwise	4	2,070	5	1,103	Mexico, 29.
Granite, crude or roughly trimmed	60	12,253	61	13,787	Italy, 40.
Granite, merely cut by sawing or otherwise	47	18,444	73	17,840	Japan, 35.
Granite, dressed, worked	12	6,010	9	5,178	Canada, 70.
Sandstone, crude or roughly trimmed	1	138	1	286	Canada, 90.
Sandstone, merely cut, by sawing or otherwise	6	1,221	6	1,227	Canada, 94.
Slate, worked and articles of slate	NA	7,695	NA	11,065	The Bahamas, 29.
Slate, whether or not roughly trimmed or merely cut	NA	380	NA	740	Canada, 58.
Other calcareous monumental or building stone; alabaster	5	918	4	942	Canada, 40.
Other monumental or building stone	11	1,782	15	2,223	Canada, 50.
Total	NA	54,904	NA	57,888	

NA Not available.

[1] By value.

Source : Bureau of the Census.

TABLE 14
U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY

(Thousand cubic feet and thousand dollars)

Country	Rough granite• [1]		Dressed granite•					
			Stone and articles		Worked		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1990:								
Brazil	186	466	57	716	258	4,016	315	4,732
Canada	650	6,506	30	2,068	278	21,350	308	23,418
China	120	450	10	195	75	1,599	85	1,794
India	45	1,578	246	674	492	9,736	738	10,410
Italy	343	5,138	726	17,040	3,095	91,096	3,821	108,136
Mexico	3	35	1	22	45	1,002	46	1,024
Portugal	225	709	54	390	72	1,235	126	1,625
Saudi Arabia	—	—	18	463	12	404	30	867
South Africa, Republic of	86	2,790	1	53	13	556	14	609
Spain	66	189	50	1,283	450	14,135	500	15,418
Other	86	1,361	67	1,368	185	6,570	252	7,938
Total	1,810	19,222	1,260	24,272	4,975	151,699	6,235	175,971
Total[3] [4]	51	19,222	36	24,272	141	151,699	177	175,971
1991:								
Brazil	151	377	125	1,576	347	5,395	472	6,971
Canada	450	5,128	35	2,423	217	16,664	252	19,087
China	77	290	20	394	101	2,163	121	2,557
India	9	304	285	781	559	11,065	844	11,846

See footnotes at end of table.

TABLE 14—Continued

U.S IMPORTS FOR CONSUMPTION OF DIMENSION GRANITE, BY COUNTRY

(Thousand cubic feet and thousand dollars)

Country	Rough granite[e] [1]		Dressed granite[e]					
			Stone and articles		Worked		Total[2]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1991—Continued:								
Italy	166	2,485	436	10,232	2,468	72,535	2,904	82,767
Mexico	6	66	([5])	2	8	56	8	58
Portugal	450	1,418	22	160	60	1,038	82	1,198
Saudi Arabia	11	102	1	35	15	509	16	544
South Africa, Republic of	40	1,287	—	—	8	406	8	406
Spain	10	29	29	748	312	9,790	341	10,538
Other	57	792	32	626	210	6,034	242	6,660
Total[2]	1,427	12,278	985	16,977	4,305	125,655	5,290	142,632
Total[3] [4]	40	12,278	28	16,977	122	125,655	150	142,632
1992:								
Brazil	211	526	127	1,596	465	7,235	592	8,831
Canada	237	2,967	29	2,036	161	12,366	190	14,402
China	42	157	17	328	99	2,024	116	2,352
India	25	852	560	1,395	788	14,181	1,348	15,576
Italy	80	1,205	200	4,701	1,767	47,198	1,967	51,899
Mexico	21	228	([5])	([5])	3	22	3	22
Portugal	160	507	9	62	46	798	55	860
Saudi Arabia	14	134	4	118	16	521	20	639
South Africa, Republic of	56	1,642	1	55	5	253	6	308
Spain	53	153	16	399	215	6,429	231	6,828
Other	75	890	19	429	138	4,063	157	4,492
Total[2]	974	9,261	982	11,120	3,703	95,090	4,685	106,210
Total[3] [4]	28	9,261	28	11,120	105	95,090	133	106,210
1993:								
Brazil	133	332	121	1,374	758	10,725	879	12,099
Canada	261	3,261	29	1,835	167	11,652	196	13,487
China	30	113	19	340	125	2,328	144	2,668
India	22	750	725	1,643	927	15,176	1,652	16,818
Italy	39	592	189	4,032	1,627	39,530	1,816	43,562
Mexico	10	106	8	54	33	218	41	273
Portugal	78	248	33	209	36	562	69	771
Saudi Arabia	9	89	1	30	21	630	22	660
South Africa, Republic of	31	915	1	393	9	414	10	807
Spain	79	228	32	685	190	4,947	222	5,632
Other	89	1,058	27	562	163	4,352	190	4,914
Total[2]	781	7,692	1,185	11,155	4,056	90,535	5,241	101,690
Total[3] [4]	22	7,692	34	11,155	115	90,535	148	101,690

[e] Estimated.

[1] Includes crude or roughly trimmed, and merely cut by sawing or otherwise.

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

[3] To convert cubic feet to cubic meters, multiply cubic feet by 0.02831685.

[4] Total quantity and total value in thousand cubic meters and thousand dollars.

[5] Less than 1/2 unit.

Sources: Bureau of the Census for values and the U.S. Bureau of Mines for quantity.

TABLE 15

U.S IMPORTS FOR CONSUMPTION OF MAJOR CATEGORIES OF DIMENSION MARBLE AND OTHER CALCAREOUS STONE, BY COUNTRY

Country	Dressed marble slabs		Dressed marble—other		Dressed marble and other calcareous stone[1]		Rough marble[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991:								
Total	62,195	$73,627	57,629	$71,173	135,243	$86,735	3,252	$4,095
Total[3]	68,558	73,627	63,525	71,173	149,080	86,735	3,585	4,095
1992:								
China	1,492	1,118	1,240	1,302	2,958	1,357	420	175
France	179	239	776	699	8,862	12,546	28	47
Greece	7,791	8,112	3,407	4,196	3,736	2,923	278	58
India	104	174	437	907	153	180	22	22
Italy	26,336	28,589	30,298	35,428	23,782	25,966	1,481	1,280
Mexico	481	515	943	1,207	21,569	8,499	134	94
Portugal	1,695	1,748	911	886	5,662	4,211	107	112
Spain	2,434	2,973	3,501	4,368	20,521	22,017	134	166
Other	8,557	8,842	12,379	16,127	27,444	7,188	448	429
Total[4]	49,069	52,310	53,892	65,120	114,688	84,887	3,053	2,383
Total[3]	54,089	52,310	59,406	65,120	126,422	84,887	3,365	2,383
1993:								
China	922	749	839	1,034	1,929	1,520	99	74
France	62	97	307	421	23,421	11,546	25	29
Greece	12,215	7,652	3,685	4,603	3,545	2,973	273	92
India	237	228	564	659	258	152	168	58
Italy	26,046	24,540	34,824	33,801	25,742	24,635	707	938
Mexico	336	334	1,091	1,366	9,792	8,444	87	138
Portugal	1,276	1,356	1,044	1,275	5,442	3,976	22	9
Spain	2,585	2,264	3,717	4,371	24,930	21,217	166	289
Other	9,952	9,100	8,362	12,793	11,855	7,329	247	233
Total[4]	53,630	46,320	54,433	60,323	106,914	81,795	1,795	1,863
Total[3]	59,117	46,320	60,002	60,323	117,853	81,795	1,979	1,863

[1] HTS No. 6802.92.0000: The material from Italy is almost all marble; from France, is both limestone and marble; from Spain is almost all marble; and from Mexico, is both limestone and marble.

[2] Marble-merely cut by sawing or otherwise.

[3] One short ton is equal to 907 kilograms or 2,000 pounds. To convert metric tons to short tons, divide metric tons by 0.907185.

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

Source: Bureau of the Census as modified by the U.S. Bureau of Mines.

TABLE 16
U.S. IMPORTS FOR CONSUMPTION OF DIMENSION STONE, BY TYPE

Type	1992		1993		Major source for 1993, (percent)[1]
	Quantity	Value (thousands)	Quantity	Value (thousands)	
Calcareous stone—other[2] metric tons	2,890	$2,831	18,680	$3,285	Italy, 32.
Marble, travertine alabaster and other do.	4,370	4,921	3,367	3,474	Italy, 43.
Sandstone, merely cut, by sawing or otherwise do.	315	181	102	60	China, 12.
Slate, roofing million square feet	5.1	2,958	3.6	1,839	Spain, 58.
Slate, whether or not roughly trimmed or merely cut	NA	2,051	5,940	2,573	Italy, 85.
Slate, worked and articles of slate, and other	NA	16,638	NA	20,795	Italy, 49.
Stone, worked monumental or building stone—other metric tons	32,919	40,745	44,130	49,154	Italy, 31.
Travertine, monumental or building stone and articles thereof do.	5,023	2,419	6,853	3,928	Italy, 92.
Travertine, worked monumental or building stone do.	8,205	6,460	10,077	8,353	Italy, 94.
Other monumental or building stone do.	12,880	3,487	14,919	3,500	South Africa, Republic of, 49.
Other stone—monumental or building stone—articles thereof do.	2,134	1,060	2,493	1,186	Mexico, 48.

NA Not available.

[1] By value.

[2] HTS No. 6802.22.0000.

Source: Bureau of the Census.

SULFUR

By Joyce A. Ober

Mrs. Ober, a physical scientist with 16 years of industry and U.S. Bureau of Mines experience, has been a commodity specialist since 1986. Domestic survey data were prepared by Pamela G. Shorter, statistical assistant; and the international production table was prepared by Ron Hatch, international data coordinator.

Domestic production of sulfur increased for the first time since 1989, but consumption declined for the fourth consecutive year. However, the United States maintained its position as the leading producer and consumer of sulfur and sulfuric acid in the world. The quantity of sulfur recovered during the refining of petroleum and the processing of natural gas continued its upward trend established in 1938, the year the U.S. Bureau of Mines (USBM) started publishing data on the production of this type of sulfur. The production of sulfur through the Frasch process was slightly higher than it had been in 1992 although listed production data only represents 10 months of Frasch data to conform with proprietary data requirements. Frasch production increased as a result of significant improvements in production rates at the newest Frasch mine. Total production of sulfur from all sources increased but shipments decreased and stocks grew.

Byproduct sulfuric acid from the Nation's nonferrous smelters and roasters, essentially mandated by laws concerning sulfur dioxide emissions, supplied a significant quantity of sulfuric acid to the domestic merchant acid market. Marketing continued to be difficult for some producers because smelters were near western copper mines and far from major sulfuric acid markets.

Worldwide, sulfur production was virtually unchanged from that of 1992, with a 13% decrease in Frasch production and a 6% increase in the amount recovered from petroleum and natural gas processing. Frasch production was lower because the final Mexican mine closed during the year, Polish mines operated at low rates, Iraq had not resumed full production following the war in the Persian Gulf, and political and economic problems continued in Eastern Europe and the former U.S.S.R. Recovered elemental production increased in Asia, the Middle East, North America, and Western Europe; decreased in Eastern Europe and the former U.S.S.R.; and remained about the same in the rest of the world. Nearly three-quarters of the world's elemental sulfur production came from recovered sources; the quantity of sulfur supplied from these sources was dependent on the world demand for fuels and petroleum products, not on the demand for sulfur.

World sulfur consumption decreased an estimated 8%. Consumption in fertilizer production decreased, and consumption for a myriad of industrial uses continued to be pressured by environmental constraints placed on the products produced or effluents from the chemical processes utilizing sulfur or its major derivative, sulfuric acid.

World trade of elemental sulfur decreased by an estimated 1.7 million metric tons, about 11% below levels recorded in 1992. U.S. sulfur inventories increased 64% during 1993, and worldwide producers' stocks of elemental sulfur increased a more modest 11%. *(See table 1 and figure 1.)*

DOMESTIC DATA COVERAGE

Domestic production data for sulfur are developed by the USBM from four separate, voluntary surveys of U.S. operations. Typical of these surveys is the "Elemental Sulfur" survey. Of the 175 operations to which a survey request was sent, all but 1 responded, representing virtually 100% of the total production shown in table 1. Production data for the nonrespondent was obtained from another public source.

BACKGROUND

Sulfur, through its major derivative sulfuric acid, ranks as one of the more important elements utilized by humanity as an industrial raw material. It is of prime importance to every sector of the world's industrial and fertilizer complexes. Sulfuric acid consumption has been regarded as one of the best indexes of a nation's industrial development.

Also known as brimstone, "the stone that burns," sulfur was used in small quantities for thousands of years. Ancient people were probably first drawn to native sulfur by its bright yellow color and pungent odor. Early humanity used sulfur as a colorant for cave drawings, as a fumigant, for medicinal purposes, and as incense. As early as 2000 B.C., the Egyptians used sulfur in the bleaching of linen textiles. In the Odyssey, Homer refers to its use as a fumigant. During the Peloponnesian War, fifth century B.C., the Greeks burned a sulfur-pitch mixture to generate suffocating gases. The Romans combined brimstone with tar, pitch, and other combustible materials to produce the first incendiary weapons. Muslims during the "Golden Age of Arabic Science," from about A.D. 700, developed alchemy and were probably the first producers of sulfuric acid. Sulfur is a necessary ingredient in gunpowder, which was developed as a pyrotechnic in China by the 10th century. Gunpowder's introduction into Europe led to its use in warfare in the 14th century and made sulfur an important mineral commodity for the first time.

However, it was not until the birth of the science of chemistry in the 1700's and the growth of chemical industries in the 1800's that sulfur became of major importance to the world outside of its use in warfare. Early chemists soon recognized the importance of sulfuric acid as the cheapest and most versatile of the mineral acids, and it rapidly became and remains the most commonly used acid in the chemical industry. More sulfuric acid is produced in the United States every year than any other chemical; about 96 million tons was produced in 1993.[1]

Sulfur is one of the few elements that occurs in the native, or elemental, state. It also occurs combined with iron and base metals as sulfide minerals, and with the alkali metals and alkali earths as sulfate minerals. In petroleum, sulfur is found in a variety of complex organic compounds, and in natural gas as hydrogen sulfide (H_2S) gas. In coal, sulfur occurs in complex organic compounds and as "coal brasses" (pyrites-marcasite). Commercial production of sulfur in the United States is accomplished by a variety of methods dictated by the source of sulfur.

Definitions, Grades, and Specifications

Bright Sulfur.—Crude sulfur free of discoloring impurities and bright yellow in color.

Brimstone.—Synonymous with crude sulfur.

Broken Sulfur.—Solid crude sulfur crushed to minus 20-centimeter size.

Crude Sulfur.—Commercial nomenclature for elemental sulfur.

Dark Sulfur.—Crude sulfur discolored by minor quantities of hydrocarbons ranging up to 0.3% carbon content.

Elemental Sulfur.—Processed sulfur in the elemental form produced from native sulfur or combined sulfur sources, generally with a minimum sulfur content of 99.5%.

Frasch Sulfur.—Elemental sulfur produced from native sulfur sources by the Frasch mining process.

Native Sulfur.—Sulfur occurring in nature in the elemental form.

Prilled Sulfur.—Solid crude sulfur in the form of pellets produced by cooling molten sulfur with air or water.

Pyrites.—Iron sulfide minerals that include pyrite, marcasite, and pyrrhotite.

Recovered Sulfur.—Elemental sulfur produced from combined sulfur sources by any method.

Slated Sulfur.—Solid crude sulfur in the form of slatelike lumps produced by allowing molten sulfur to solidify on a water-cooled, moving belt.

Sulfur Ore.—Unprocessed ore containing native sulfur.

Sulfuric Acid.—Sulfuric acid of commerce produced from all sources of sulfur, generally reported in terms of 100% H_2SO_4 with a 32.69% sulfur content.

Products for Trade and Industry

Elemental sulfur of commerce, sometimes called crude sulfur or brimstone, may be marketed in either the liquid or the solid phase, generally with a minimum sulfur content of 99.5%. Most elemental sulfur marketed in North America is sold as liquid sulfur. In worldwide commerce, sulfur is shipped either as broken sulfur or formed sulfur. Formed sulfur—prills, slates, and pastilles—is generally preferred to broken sulfur because it is less prone to dusting and the release of fugitive dust at terminals where sulfur is stored and transferred from one transportation mode to another. Sulfuric acid may be sold at various strengths, usually depending on the requirements of the consumer. The acid is generally marketed on a 100% basis, but is normally shipped at 66° Baume (93% H_2SO_4), as 98% acid, or as 20% to 22% fuming oleum, which is sulfur trioxide dissolved in sulfuric acid.

Industry Structure

Over the centuries, many fundamental changes have occurred in the sources of sulfur supply. Early civilizations obtained their meager requirements from native sulfur deposits in or around volcanoes. The increase in demand for sulfur in the late 1700's and early 1800's was largely satisfied from extensive native sulfur deposits in Sicily. Monopolistic practices by the owners of sulfur mining facilities in Sicily led to exorbitant sulfur prices, causing consumers to adopt iron pyrites as the second major sulfur source during the mid- to late 19th century. The development in 1895 of the Frasch process for mining the large native deposits associated with salt domes in Louisiana and Texas brought a new and important source of sulfur to the United States and world markets. Frasch sulfur and pyrites maintained their joint predominance as world sulfur sources through the mid-1970's.

With small beginnings in the 1930's and increasing significantly from the 1950's onward, environmentally mandated or involuntary sulfur recovered during natural gas processing and petroleum refining grew to surpass Frasch sulfur and pyrites as the world's major source of sulfur. In addition, increasing quantities of byproduct sulfuric acid from smelting operations have been produced to comply with pollution control laws and environmental regulations worldwide.

Sulfur in its various forms is produced worldwide, with no single nation predominating as a producer or supplier to world markets. In 1993, world sulfur production and consumption amounted to 52.3 million and 53.1 million metric tons, respectively. The United States was the world's largest producer and consumer; the United States also was a net importer of sulfur. Following the breakup of the U.S.S.R., Canada became the second largest sulfur producer and maintained its position as the world's leading exporter of elemental sulfur. China, the world's third largest producer and largest pyrites producer, was also the third largest sulfur consumer, satisfying most of its sulfur requirements from internal sources. Ranking other leading producers in terms of sulfur production has become difficult, with Japan, Mexico, Poland, Russia, and Saudi Arabia all producing between 2 million and 3 million tons in 1993. Poland and Saudi Arabia followed Canada as leading exporters with nearly identical amounts.

Geology-Resources

Sulfur is widely distributed in nature, constituting 0.060% of the Earth's crust. Sulfur combines with most other elements, except the inert gases and nitrogen. Practically all plant and animal life on Earth contains some sulfur. Only a very small portion of the world's sulfur resources occurs in sufficiently concentrated quantities to justify commercial extraction by mining or other recovery methods. Sulfur is one of the few substances found in nature in the elemental form; it also occurs combined with other elements as sulfides, sulfates, or organic compounds in sedimentary, metamorphic, and igneous rocks, as well as in all fossil fuels. By type, sulfur deposits are classified as follows:

Native (Elemental) Sulfur Deposits.—These include deposits (1) in anhydrite-limestone cap rock on the top and flanks of salt domes, (2) in bedded anhydrite-gypsum evaporite basin formations, and (3) in unconsolidated volcanic deposits. In salt dome cap rock and evaporite beds, the sulfur is believed to have been formed by hydrocarbon reduction of anhydrite, assisted by bacterial action. Volcanic sulfur was produced by the reaction between escaping hydrogen sulfide and sulfur dioxide.

Large deposits over salt domes are mined in the gulf coast regions of the United States and Mexico. Extensive deposits in evaporites are mined in west Texas, Iraq, Poland, and the former U.S.S.R. Together, these deposits are by far the principal source of mined elemental sulfur, generally extracted by the Frasch hot-water process. Most volcanic sulfur occurrences are in the circum-Pacific belt. Volcanic sulfur deposits are locally important, but furnish only a minor portion of the world's sulfur supply.

Sulfide Deposits.—These include deposits of (1) ferrous sulfides (pyrite, marcasite, and pyrrhotite) that, while they may contain minor quantities of nonferrous metals, are generally mined and processed for their sulfur content and (2) nonferrous metal sulfides, which are mined for their metal content and in the processing produce sulfur in the form of sulfuric acid. In order of importance from the quantity of acid produced, sulfide minerals of copper, lead, zinc, molybdenum, nickel, mercury, arsenic, antimony, and silver are the most noted in the nonferrous sulfide group.

Sulfate Deposits.—These include bedded deposits of anhydrite and gypsum. Although they are mined on a large scale worldwide for their mineral content, they represent one of the world's largest, yet virtually untapped sulfur resources. Existing technology can recover elemental sulfur from these sources, but the economics are presently unfavorable.

Natural Gas.—Hydrogen sulfide occurs as a component of natural gas in many parts of the world. To market this "sour" natural gas, the hydrogen sulfide must be removed and, consequently, as additional sour natural gas fields have been brought into production, elemental sulfur recovered from these fields has become a major source of the world sulfur supply. Major deposits of sour natural gas occur in western Canada, the Near East, and the former U.S.S.R.; substantial deposits occur in the mountain and gulf coast regions of the United States and in Germany, France, Mexico, and Venezuela.

Petroleum and Tar Sands.—Complex organic sulfur compounds occur as a component of petroleum and tar sands in a wide range of concentrations. In the refining of petroleum or bitumen from tar sands, a portion of the sulfur is removed and recovered in the elemental form. Changing environmental regulations have required larger proportions of contained sulfur to be removed annually. The vast petroleum reserves of the Near East contain high percentages of sulfur, as do many of the recent discoveries in Mexico and off the U.S. west coast. Additionally, Canadian tar sands constitute a major sulfur resource.

Coal and Oil Shale.—Sulfur occurs as pyrites or complex organosulfur compounds in varying concentrations in both coal and oil shales. Although little sulfur is produced from these vast resources at present, the potential for large-scale output exists in the United States and in the rest of the world.

Economic Factors

During the past 20 years, world sulfur price leadership has shifted from dominance by the U.S. Frasch producers to the Canadian exporters. The transfer was aided in the 1980's by Canada's ability to export most of its production from the Port of Vancouver and by its willingness to ship large volumes of sulfur from vatted stocks. The maturation of Sultran Ltd., dealing almost exclusively with sulfur destined for the offshore market, into a well-organized and skilled transportation arm of the Canadian sulfur industry aided immeasurably in Canada's ascension to world price leadership. However, the steep price reductions in the past 3 years have confused the issue of price leadership. Canada's role is still very important, but the oversupply of sulfur in Europe, Poland, and Saudi Arabia also has had an effect on prices.

In the United States, the quoted liquid Frasch sulfur price, f.o.b. terminal Tampa, FL, has traditionally been the benchmark price. Toward the end of 1992, the industry abandoned this practice. Although a Tampa Frasch price was published weekly in trade publications, reports in those publications indicated that contract prices were not greatly influenced by these posted prices, and only one Frasch producer continued to post weekly prices. 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 significantly below the Tampa quote to ensure prompt sale and reduce storage costs. This marketing strategy has resulted in restricting Frasch sulfur sales from many market areas that they formerly served.

During the 1980's, the sulfur price

showed a significant degree of volatility compared with its prior history, and the early years of the 1990's continued that trend. *(See figure 2.)*

Operating Factors

Increasing environmental concerns have had an impact on the sulfur industry, as they have had on most other industries. The effects on the sulfur industry can be interpreted as both positive and negative as far as sulfur is concerned, but certainly positive in terms of decreasing pollution.

Even before the Clean Air Act became law in 1977, oil refineries and natural gas processors realized the necessity of removing sulfur from their products and offgases. The USBM began collecting data on recovered sulfur in 1938, and references were made to this type of sulfur prior to that, but with no official data to quantify the recovery. At first, recovered sulfur was considered a waste material, not a commercial byproduct. As time went on, the importance of recovered sulfur increased as sulfur demand increased faster than the supply of Frasch and other native sulfur. Recovered sulfur became the primary domestic source of elemental sulfur in 1982.

The Clean Air Act set limits on the quantity of pollutants that could be released into the atmosphere. Sulfur dioxide was identified as one of the most common pollutants and one of the major contributors of acid rain, known to damage both natural and artificial environments. New gas-cleaning apparatus removed as much sulfur dioxide as was technologically possible from offgases. Petroleum refiners and gas processors have recovered increasingly greater percentages of sulfur from the gas stream as elemental sulfur, metal smelters (especially nonferrous metals) recovered byproduct sulfuric acid, and coal and oil burning electric powerplants recovered byproduct gypsum (calcium sulfate), cutting emissions dramatically. The type of byproduct recovered was determined by the sulfur content of the gas stream; elemental sulfur was recovered when the sulfur dioxide content was relatively high.

Amendments to the Clean Air Act of 1990 required a 50% reduction of sulfur dioxide emissions by the year 2000, and electric power stations are believed to be the source of 70% of all sulfur dioxide emissions. For this reason the 1990 amendments will concentrate on the further reduction of emissions from electric utilities. Existing technology to recover elemental sulfur from powerplant offgases has a cost estimated to be 50% higher than the cost of recovering byproduct gypsum. Although some byproduct gypsum is consumed in the same end uses as natural gypsum, much of it is disposed as waste.[2] Although no utilities currently are recovering commercial quantities of elemental sulfur in the United States, two projects have been announced. Tampa Electric Co. will recover 75,000 to 90,000 tons of sulfuric acid (25,000 to 30,000 tons sulfur equivalent) annually at its powerplant in Polk County, FL.[3] A full-scale sulfur recovery system will be installed at PSI Energy's Wabash River generating station in Terre Haute, IN. Expected to be completed in 1995, this plant should recover about 14,000 tons of elemental sulfur per year.[4] As landfill costs become higher, elemental sulfur recovery will become a more attractive alternative to byproduct gypsum production.

Over the years, larger quantities of sulfur have been recovered for a number of reasons, including increased petroleum refining and natural gas processing, more stringent limitations on sulfur dioxide emissions, and higher sulfur contents of the crude oil refined. Other contributing factors are lower sulfur content limits set on petroleum-based fuels.

As sulfur supplies, either as elemental sulfur or byproduct sulfuric acid, have grown due to increased environmental awareness, the demand for sulfur has decreased in some consuming industries for the same reason. Some industries (i.e., uranium processing) have contracted or completely disappeared owing to concerns regarding environmental damage caused by their processes. Other industries, such as titanium dioxide production, have converted to more environmentally "friendly" processes that do not use sulfuric acid. In addition, many consumers who continue to use sulfuric acid are putting new emphasis on regenerating or recycling spent acid.

Another area where improved air quality has had an impact on sulfur use is in agriculture. As reduced sulfur dioxide emissions decreased acid rain, sulfur content of soils also has decreased. Sulfur is now recognized as an important plant nutrient, necessary for the most efficient use of other nutrients and optimum plant growth. Because many soils are now deficient in sulfur, a demand for sulfur-containing fertilizers has been created, and farmers must now apply a nutrient that previously had not been required.

Increased environmental awareness has created a dilemma for sulfur producers. While pollution reduction requirements have created increased supplies of sulfur and sulfur products, similar requirements have caused a decrease in demand. This situation will persist and the imbalance between supply and demand could increase, causing inventories to continue to increase. Disposing of excess sulfur, recovered while cleaning the air to protect the environment, may create another environmental problem.

ANNUAL REVIEW

Legislation and Government Programs

The 1990 amendments to the Clean Air Act required a 50% reduction from 1980 levels of sulfur dioxide emission nationwide by the year 2000. The 1990 Act contained an innovative measure to control emissions through market-based incentives rather than more traditional, strict, inflexible rules. The Emission Allowance Market (EAM) makes it possible for companies that have been able to reduce emissions at their operations to sell unneeded allowances to companies that have not been able to meet pollution reduction requirements.

Other types of pollutants will eventually be controlled by this process, but sulfur dioxide will be managed first. Because electric powerplants are believed to be the source of about 70% of all sulfur dioxide emissions in the United States, the EAM currently concentrates on that industry. In 1993, the

Environmental Protection Agency proposed the expansion of the EAM program to include all facilities that emit pollutants linked to acid rain.[5] The Chicago Board of Trade (CBoT) administers allowance sales.

Utilities are assigned emission allowances based on historic fuel consumption and sulfur dioxide emission data. These assigned allowances will decrease over time to meet the goal of 50% reduction. Additional allowances are available for purchase on the open market. Each utility must buy its assigned allowances directly from the Government at a predetermined price. If a specific power station finds it cannot meet its pollution requirements, it must buy additional allowances on the open market or from another utility that has reduced its emissions and thus possesses emission allowances that are in excess of its needs. Additional allowances may be purchased directly from companies offering them for sale or through auctions at the CBoT. All of the Government's unassigned allowances will be sold through CBoT.

Phase 1 of the EAM program will affect the 10 largest power stations in 21 Eastern and Midwestern States. Compliance will be required by January 1, 1995; sales of future emission allowances began at the CBoT in March. Phase 2 will encompass approximately 700 remaining smaller utilities with compliance required by January 1, 2000. As time passes, all emission allowances will be purchased through auction or on the open market, with none through direct sale from the Government.[6]

Production

Elemental Sulfur.—Elemental sulfur production was slightly higher in 1993 than it was the previous year, but shipments were 7% lower in quantity and 38% lower in value.

Production statistics are collected on a monthly basis and published in the USBM Sulfur Monthly Mineral Industry Survey. Beginning in November 1993, significant improvement of the production level at one of the Frasch mines resulted in one Frasch company becoming the dominant producer with more than 75% of the total Frasch production and shipments. When this situation occurs, the data must be withheld from publication or aggregated with other data to avoid revealing company proprietary data. For this reason all Frasch data listed represent only 10 months of collected data, with the additional 2 months of data aggregated with the corresponding information for sulfur recovered during natural gas processing.

As a result, meaningful comparison of Frasch and recovered sulfur data between 1993 and 1992 is not possible and has not been attempted.

Frasch.—Native sulfur associated with the cap rock of salt domes and in sedimentary deposits is mined by the Frasch hot-water method, in which the native sulfur is melted underground and brought to the surface by compressed air. In 1993, four Frasch mines operated in Louisiana and Texas. Mines in Texas were Pennzoil Sulphur Co., at Culberson, and Texasgulf Inc. (TG), at Boling Dome in Wharton County. Freeport Sulphur Co. owned and operated two mines in Louisiana, the Caminada Pass Mine 14 kilometers offshore in the Gulf of Mexico and Main Pass, 27 kilometers offshore.

Texasgulf Inc.'s Newgulf Frasch Mine on Boling Dome closed in December after more than 60 years of production from this deposit. With the closure of the mine, the town of Newgulf, TX, believed to be the only remaining company town in the United States, closed also. Built by the company in 1928 to provide housing and services for the workers at the mine, including shopping, churches, schools, and recreational facilities, the houses were being sold to individuals for relocation off company property.[7]

Main Pass is the newest Frasch mine in the world, with production beginning in April 1992. The mine reached full capacity of about 5,400 tons per day at the end of December 1993, earlier than anticipated after a slower than expected startup. At capacity, Main Pass is believed to be the lowest cost Frasch operation in the world due to its high water and thermal efficiencies. Freeport pumps about 33% less water for each ton of sulfur produced than other Frasch producers.[8] The National Society of Professional Engineers named Main Pass one of the top eight U.S. engineering achievements of 1992.[9]

Improved production rates at Main Pass prompted Freeport to announce the closure of its Caminada Pass Mine, with total shutdown expected by early 1994. The cost of producing sulfur from Caminada was significantly higher than at Main Pass, and Main Pass alone will supply the company's internal consumption and sales requirements.[10]

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. Recovered elemental sulfur was produced by 59 companies at 150 plants in 26 States, 1 plant in Puerto Rico, and 1 plant in the U.S. Virgin Islands. Most of these plants were of relatively small size, with only 22 reporting an annual production exceeding 100,000 tons. By source, 52% was produced at 3 coking plants and 86 refineries or satellite plants treating refinery gases. The remainder was produced by 27 companies at 61 natural gas treatment plants. The five largest recovered-sulfur producers in 1993 were Exxon Co. U.S.A., Standard Oil Co. (California), Standard Oil Co. (Indiana), Mobil Oil Corp., and Shell Oil Co. The 50 plants owned by these companies accounted for 53% of recovered elemental sulfur output during the year. *(See tables 2, 3, and 4.)*

Byproduct Sulfuric Acid.—Byproduct sulfuric acid at copper, lead, molybdenum, and zinc roasters and smelters amounted to 13% of the total domestic production of sulfur in all forms. Eight acid plants operated in conjunction with copper smelters, and eight were accessories to lead, molybdenum, and zinc smelting and roasting operations. The six largest acid plants (all at copper mines) accounted for 81% of the output. The five largest producers of byproduct sulfuric acid were all copper producers. They were Phelps Dodge Corp., Magma Copper Co., ASARCO Incorporated, Kennecott Corp., and Cyprus Miami Mining Corp. Their eight plants produced 86% of the 1993 total. *(See table 5.)*

Pyrites, Hydrogen Sulfide, and Sulfur Dioxide.—The total sulfur contained in these products did not constitute a significant portion of total domestic sulfur production. *(See figure 3.)*

Consumption and Uses

Domestic consumption of sulfur in all forms was about 8% lower in 1993 than it was in 1992. In 1993, 83% of the sulfur consumed was obtained from domestic sources compared with 79% in 1991 and 77% in 1990. The sources of supply were domestic elemental sulfur, 71%, and combined domestic byproduct sulfuric acid, pyrites, hydrogen sulfide, and sulfur dioxide, 12%. The remaining 17% was supplied by imports of Frasch and recovered elemental sulfur.

The USBM collected end-use data on sulfur and sulfuric acid according to the Standard Industrial Classification of industrial activities. Shipments by end use of elemental sulfur were reported by 59 companies, and shipments of sulfuric acid were reported by 50 companies. Shipments of both elemental sulfur and sulfuric acid were reported by seven companies.

Sulfur differs from most other major mineral commodities in that its primary use is as a chemical reagent rather than a component of a finished product. Its predominant use as a chemical reagent generally required that it first be converted to an intermediate chemical product prior to its initial use by industry. The largest sulfur end use, sulfuric acid, represented 87% of reported consumption with an identified end use. 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 also were tabulated as "Unidentified." Although there are no supporting data, it could be reasonably assumed that a significant portion of the sulfur in the "unidentified" category was shipped to sulfuric acid producers or was exported.

Sulfuric acid, because of its desirable properties, retained its position, both domestically and worldwide, as the most universally used mineral acid and the largest volume inorganic chemical in terms of the quantity produced and consumed. U.S. consumption of sulfur in sulfuric acid (100% basis) was slightly lower in 1993 owing to decreases in demand for sulfuric acid in industrial uses. Demand for sulfuric acid for the production of phosphoric acid, the largest single end use, was 5% lower than that of 1992. Sulfuric acid demand for copper ore leaching, the second largest end use, increased 7% according to reports from sulfuric acid producers. Reported shipments of sulfuric acid for petroleum refining and other petroleum and coal products were not significantly different from those of 1992, but reported consumption of elemental sulfur in those end uses was 85% higher.

According to the 1993 canvass reports, company receipt of spent or contaminated sulfuric acid for reclaiming totaled 2.3 million tons. The largest source of this spent acid continued to be the petroleum refining industry, which accounted for 49% of the total returned. About 900,000 tons of spent acid was reclaimed from chemical producers. The remaining reclaimed acid was from manufacturers of ferrous and nonferrous metals, paper, storage batteries, and some unidentified sources.

The largest use of sulfur in all forms, for agricultural purposes, decreased from 9.3 million tons in 1992 to about 9.0 million tons due to decreases in consumption for the production of nitrogenous and phosphatic fertilizers. Consumption in phosphatic fertilizers was nearly 5% less than that in 1992, reflecting the condition of the phosphate industry. The estimated quantity of sulfur needed to manufacture exported phosphatic fertilizers decreased by 500,000 tons to 4.4 million tons, indicating that consumption for fertilizers intended for domestic consumption was nearly the same as it had been in 1992. *(See tables 6, 7, and 8 and figure 4.)*

Stocks

Yearend inventories held by Frasch and recovered elemental sulfur producers increased 71% from those of 1992, indicating an oversupply situation. Combined yearend stocks amounted to approximately a 43-day supply compared with a 23-day supply in 1992, a 34-day supply in 1991, a 40-day supply in 1990, and a 37-day supply in 1989 based on apparent consumption of all forms of sulfur. *(See table 9.)*

Markets and Prices

The posted price for Frasch sulfur exterminal Tampa, FL. began the year at $88 per ton and dropped to $83 in March and $68 in November. On the basis of total shipments and value reported to the USBM, the average value of shipments of Frasch sulfur, f.o.b. mine, for domestic consumption and exports combined decreased from $58.15 to $51.60 per ton. The average value, f.o.b. plant, for shipments of recovered elemental sulfur varied widely by geographic region; the national average value for the year was $25.06 per ton, almost $20 per ton less than the average for 1992. The average value for all elemental sulfur was $31.86 per ton in 1993, 34% lower than that in 1992. *(See table 10.)*

Foreign Trade

Exports of elemental sulfur from the United States, including the U.S. Virgin Islands, decreased 32% in quantity and 43% in value. According to the Bureau of the Census, exports from the west coast were 536,000 tons or 82% of total U.S. exports.

The United States continued to be a net importer of sulfur; imports exceeded exports by about 1.4 million tons in 1993. Frasch and recovered sulfur from Mexico and recovered elemental sulfur from Canada, both delivered to U.S. terminals and consumers in the liquid phase, furnished nearly 100% of all U.S. sulfur import requirements. Total elemental sulfur imports decreased 25% in quantity; imports by rail from Canada decreased 18%, while waterborne shipments from Mexico were 41% lower than those in 1992. Imports from other sources were negligible.

The United States also had significant trade in sulfuric acid. Sulfuric acid exports increased slightly from those of 1992. Imports, which were significantly greater than exports, 40% of which were by rail from Canada and 31% waterborne from Europe. The tonnage increased 23% from the quantity reported in 1992; the value of imported sulfuric acid increased 3%. Approximately 776,000 tons of acid was imported into the Tampa, FL, area, about 70% higher than the Tampa acid imports of the previous year. Two sulfuric acid terminals were established there in 1989. *(See tables 11, 12, 13, and 14.)*

World Review

Although world production was virtually unchanged from that of 1992, consumption was down for the fifth consecutive year, and prices were lower in terms of constant dollars than they had been for at least 20 years and probably longer. Frasch producers experienced production cutbacks, and as consumption decreased, international competition for available markets became more intense.

Industry Structure.—In 1993, the global sulfur industry remained divided into two sectors, discretionary and nondiscretionary. In one, the mining of sulfur or pyrites was the sole objective; this voluntary production of native sulfur or pyrites was based on the orderly mining of discrete deposits, with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the other, sulfur or sulfuric acid was recovered as an involuntary byproduct, the quantity of output subject to demand for the primary product irrespective of sulfur demand. In 1993, involuntary sources represented almost 66% of the elemental sulfur produced worldwide.

Poland, Ukraine, and the United States were the only countries that produced 1 million tons or more of native sulfur using either the Frasch method or conventional mining methods. Small quantities of native sulfur were produced in Asia, Europe, and North and South America. Pyrites were the prime sulfur source in southern Africa, China, much of Eastern Europe, Finland, Italy, North Korea, and Spain and were an important source in Scandinavia and Philippines.

Recovered elemental sulfur was the predominant sulfur source in Canada, France, Germany, Russia, Saudi Arabia, and the United States. Additionally, recovered elemental sulfur was an important source in Iran, Japan, and Mexico.

International sulfur trade was dominated by a limited number of exporting countries; exports from Canada, Saudi Arabia, Poland, Germany, the United States, and Mexico, in descending order of the quantity shipped, accounted for 81% of sulfur trade in 1993. Major sulfur importers in 1993 were Morocco, the United States, India, Tunisia, and Brazil, in descending order of importance, all with imports of more than 1 million tons.

Capacity.—The data in table 15 are rated capacity for Frasch mines, elemental sulfur mining facilities and attendant beneficiation plants, pyrites mines and plants, sulfur and/or sulfuric acid recovery units associated with petroleum refineries, natural gas processing plants, metal smelting operations, electric powerplants, and coke ovens as of December 31, 1993. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the facility, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with a minimum of capital expenditure. Rated capacity is not equivalent to engineering (design) capacity of installed equipment.

Frasch mines operate continuously, and capacity is related to the quantity of superheated water that can be injected into the associated sulfur deposit. The nature of Frasch mining makes capacity quite variable over time and depends on the number of "steaming wells," water injection rates, water losses from the formation, location of wells within the deposit, and length of time that the deposit has been worked. The rated capacity or realizable capacity of a Frasch mine generally decreases as the deposit becomes depleted.

Petroleum refineries—large, very costly, and complex processing facilities designed to produce a spectrum of fuels and petrochemical products—operate continuously. Sulfur recovery units make up only a small segment of these facilities; because sulfur recovery is mandated by environmental considerations, the installed sulfur recovery capacity at petroleum refineries generally exceeds the expected sulfur production. To ensure that the loss of a sulfur recovery unit does not require the shutdown of the entire refinery, multiple sulfur recovery units, each capable of servicing the petroleum refinery, are installed. The quantity of sulfur recovered by domestic petroleum refineries in the United States during 1993 was equal to slightly more than 50% of the installed engineering capacity. Rated capacity for petroleum refineries is assumed to be 50% of installed engineering capacity.

Natural gas processing plants may be installed to service gasfields and/or oilfields that contain significant quantities of associated gas. Gas plants are designed to accommodate the natural gas from a specific field that may contain, in addition to methane, which is sold as pipeline gas, varying amounts of nitrogen, carbon dioxide, helium, condensable hydrocarbon liquids, and poisonous hydrogen sulfide. The poisonous nature of hydrogen sulfide makes its removal from pipeline gas imperative. Sulfur removal and recovery plants in natural gas facilities vary in size from small units rated at 5 to 10 tons per day to multiple-train plants capable of recovering thousands of tons per day. In general, sulfur recovery rates from gasfields approximate installed engineering capacity, based on a 340- to 345-day-per-year operation of all units, in the first 7 years of operation. In succeeding years, sulfur recovery declines steadily because the gas apparently becomes "sweeter" over time and because gas flow rates drop as the field is depleted. Rated capacity for gas processing plants is based on the age of the plant and its recent production history.

Rated capacity for plants operating in conjunction with metal smelters, powerplants, and coking operations is assumed to approximate engineering capacity. Where information on design capacity is unknown, rated capacity was estimated to be equal to the greatest output recorded by a plant or country in the past 5 years. World rated sulfur annual production capacity is significantly lower than the installed world engineering capacity of approximately 91 million tons. *(See table 15.)*

Abu Dhabi.—Sulfur recovery has increased significantly during the past 2 years; sulfur production tripled in 1993 and was expected to expand further. Although still a relatively minor sulfur producer, the events in Abu Dhabi indicate what can be expected as more countries become increasingly environmentally conscious. Existing, but never operated, sulfur recovery apparatus was refurbished and enlarged at the Das Island gas processing plant and put into operation. Prior to this, the sulfur gas stream had been flared, releasing sulfur dioxide into the atmosphere.[11]

Canada.—Production of elemental sulfur was 7.3 million tons, 12% higher than that of the previous year, byproduct sulfuric acid contributed an additional 900,000 tons of sulfur equivalent. Still the world's leading sulfur exporter, Canadian exports were down sharply in 1993 because the Canadian sulfur export organization, Prism Sulphur Corp., chose to stockpile rather than sell at prevailing low prices. With production up and exports down, stocks increased 2.3 million tons to about 5.6 million tons by the end of the year. Sulfur recovered from natural gas processing represented 78.8% of total Canadian production, with 7.3% from oil sands and 2.8% from oil refining. The remaining 11.1% was recovered as byproduct sulfuric acid from nonferrous smelters.

The majority of Canadian sulfur is produced in Alberta and British Columbia. With the completion of Shell Canada's Caroline natural gas recovery project in Alberta, an additional 1.5 million annual tons of sulfur capacity became operational in March. Sulfur from Caroline is destined for the offshore market with no facilities in place for shipping liquid sulfur to the United States. Production will be formed at a nearby forming facility or poured to block, the industry term for stockpiling that describes the process of pouring molten sulfur into huge forms with the sulfur forming solid blocks when cooled.[12]

Iraq.—The Mishraq Mine has the capacity to produce 1.6 million tons of Frasch sulfur and may have been upgraded to 2 million tons; the mine was not damaged during the Gulf War. Although reports from Iraq stated that the mine was approaching capacity in 1992,[13] there has been no evidence that has occurred. With Jordan as the only possible outlet due to the continued United Nations trade embargo, it is doubtful that production was more than 200,000 tons. If and when sanctions are lifted, production from Iraq will add to the worldwide surplus.

Kazakhstan.—Sulfur production began at the Tengiz oil and gas condensate field in the Republic of Kazakhstan in 1991. In April 1993, Chevron reached a 40-year agreement with the Government of Kazakhstan for a 50% interest in the further development of the Tengiz and Korolov oilfields and gasfields. Tengiz was believed to have huge oil reserves and associated sour gas. Korolov was much smaller, but with a higher sulfur content.

Originally, four production phases were planned for Tengiz, but for the time being, only Tengiz I and Tengiz II are expected to be completed. Tengiz II was expected to come on-stream in 1992, but experienced delays. If all phases of the project are completed, sulfur recovery capacity could be more than 3 million tons per year when oil production reaches its peak in the year 2010.

British Gas Corp. and Azienda Generali Italiana Petroli S.p.A. (AGIP) were negotiating with the Government of Kazakhstan concerning a joint venture to develop the Karachaganak oil and sour gas condensate field. Société Nationale Elf Aquitaine also was doing some seismic testing in the Temir area, but was far from producing any oil or gas, and thus farther from producing sulfur there.[14]

Kuwait.—Oil production resumed at the end of 1991 after oil well fires were extinguished and some refineries repaired following the Gulf War. Refinery repairs were slower than expected, and sulfur recovery was possible at only one refinery before the end of 1992. Sulfur recovery resumed at the other refineries in Kuwait early in 1993.[15]

Mexico.—Once a large Frasch producer, Mexico's last Frasch mine closed in May 1993 owing to the poor economics of Frasch sulfur. Three other Mexican mines closed in 1992. All remaining assets from the Government-owned sulfur operations were ceded to Petóleos Mexicanos (PEMEX), the Government-owned petroleum company. Pemex became responsible for the storage, transportation, and sales of its recovered sulfur. All sales had formerly been handled by the Frasch producers.[16]

Morocco.—Morocco was a major world importer of elemental sulfur because of consumption at its phosphate fertilizer facilities at Safi and Jorf Lasfar. Imports were about 2.6 million tons in 1993, a 4% increase from that of 1992.

Poland.—Native sulfur production has fallen more than 50% from nearly 4 million tons in 1991 to about 1.9 million tons in 1993. The new Osiek Mine officially opened near Grzybow in September after several months of test production. Production at the new mine, at the Jeziorko Mine at Tarnobrzeg, and the old Grzybow Mine is expected to maintain production at about 1993 levels in 1994.

The cost of production was reported to have been cut by about 50% by using a system to recycle hot water from nearby power stations, cutting labor costs, and closing nonproductive facilities (i.e., kindergartens and holiday homes).

Production ceased at the Machow Mine in 1992, but final transfer of the operation to local authorities was delayed. Environmental problems continue at Machow, and the cost of remediation, including the elimination of hydrogen sulfide emissions from the pit, was estimated at more than $200 million.[17] *(See table 16.)*

OUTLOOK

The outlook for the global sulfur industry is simple to describe: increased output and decreased consumption resulting in lower prices and growing inventories. Specific details are much more difficult. Which producers will suffer most from the oversupply situation is a question that can only be answered over time.

World sulfur demand is forecast to increase at an annual rate of about 1% per year for the next 10 years. World demand is projected to attain 55.6 million tons in 1998 and increase to about 60 million tons in the year 2003. In the short term, an optimistic forecast for U.S. sulfur demand is an increase from 11.8 million tons consumed in 1993 to 13.7 million tons in 1998 and 14.4 million tons in the year 2003; a more likely estimate is an increase to 13.5 million to 14.0 million tons by the end of the period.

Almost two-thirds of sulfur consumption in the United States is for agricultural uses. More than 80% of U.S. agricultural sulfur demand and almost 60% of world agricultural sulfur consumption was for the manufacture of phosphoric acid in 1993. World demand for phosphate fertilizers is forecast to increase at an annual rate of about 2.3% for the next 10 years. This indicates improved growth over predictions of the past few years, but is based on the fact that 1993 was an unusually bad year for fertilizer producers. It is assumed that 90% of the growth will be for the production of phosphoric acid to produce high-analysis fertilizers, which will directly affect world sulfur demand. Consumption of sulfur for phosphate fertilizer manufacture in the United States is divided into two main components: (1) demand for phosphate fertilizers consumed by domestic farmers and (2) demand for exported phosphate fertilizers.

In 1993, an estimated 4.4 million tons of sulfur was required to manufacture the phosphatic fertilizers exported from the United States compared with 3.5 million tons of sulfur for domestic phosphoric fertilizer use. Sulfur demand for domestically consumed phosphates is forecast to increase slightly for the next 2 years to make up for low production in 1993 and remain relatively stable thereafter.

The broad spectrum industrial or nonagricultural sulfur use category accounted for almost 39% of U.S. sulfur consumption and about 43% of world sulfur demand. Although significant variations in demand for the diverse elements within this broad category are expected in the United States and other geographic areas, world industrial demand is expected to average less than a 1% increase annually over the next 10 years, reaching almost 24 million tons in the year 2003.

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 and more voluntary operations will be curtailed. In 1980, voluntary sources of production—Frasch, native sulfur, and pyrites—accounted for 50% of world output, about 55 million tons. In 1993, these same sources supplied only 34% of world production, 52.6 million tons.

It is anticipated that in the short term, owing to decreased production at Frasch operations, world sulfur supply and demand will be closely balanced, and by the end of 1993 there were indications of tightening of supplies available for sale. However, a number of new recovered facilities were completed during the year and more will be completed soon, are under development, or are in the planning stage, further increasing supply sources.

In 1993, developments and changes at Frasch and other voluntary producers seem to be maintaining a relatively stable level of production with a slight downward trend. However, recovered sulfur production will continue to expand at a faster pace than demand, and as more countries enact environmental legislation on a par with North American and European laws, tremendous new quantities of sulfur will be recovered. More stringent regulation and compliance will be long-term developments and cannot be quantified at the current time, but changes are inevitable.

Statistics show that an oversupply situation existed in 1993; however, the decision by some producers to build stocks rather than sell at unfavorable prices resulted in what appeared as tightened supplies by yearend and indications that prices were beginning to rise. Material could continue to be withheld from sale through 1994, but if prices rise, sales at former levels could resume, and prices will once again fall. World sulfur production is predicted to reach nearly 61 million tons in 1998 and 64 million tons in 2003.

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TABLE 1

SALIENT SULFUR STATISTICS

(Thousand metric tons, sulfur content, and thousand dollars unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Production:					
Frasch	3,888	3,726	2,869	2,320	[1]1,904
Recovered[2]	6,510	6,536	6,645	7,048	[3]7,665
Other forms	1,194	1,298	1,306	1,295	1,390
Total	11,592	11,560	10,820	10,663	10,959
Shipments:					
Frasch	3,780	3,676	3,120	2,600	[1]1,477
Recovered[2]	6,475	6,483	6,682	7,094	[3]7,521
Other forms	1,194	1,298	1,306	1,295	1,390
Total	11,449	11,457	11,108	10,989	10,388
Exports, elemental[4]	1,024	972	1,196	966	656
Imports, elemental	2,260	2,571	3,020	2,725	2,039
Consumption, all forms	12,685	13,056	12,932	12,747	11,771
Stocks, Dec. 31: Producer, Frasch and recovered	1,301	1,423	1,194	809	1,382
Value:					
Shipments, f.o.b. mine or plant:					
Frasch	$378,712	$335,189	$271,599	$151,195	$100,672
Recovered[2]	$509,582	$479,011	$428,816	$315,438	$188,427
Other forms	$104,304	$117,139	$112,218	$76,125	$46,219
Total	$992,598	$931,339	$812,633	$542,758	$335,318
Exports, elemental[4] [5]	$107,126	$109,327	$119,713	$69,662	$39,726
Imports, elemental[5]	$209,465	$206,450	$241,749	$129,894	$49,627
Price, elemental, dollars per metric ton, f.o.b. mine or plant	$86.62	$80.14	$71.45	$48.14	$31.86
World: Production, all forms (including pyrites)	[r]58,924	[r]58,026	[r]55,723	[r]52,740	[e]52,270

[e] Estimated. [r] Revised.

[1] Includes 10 months of Frasch sulfur data. Two remaining months of Frasch data included with recovered sulfur data to conform with proprietary data requirements.

[2] Includes Puerto Rico and the U.S. Virgin Islands.

[3] Includes corresponding Frasch sulfur data for November and December.

[4] Includes exports from the U.S. Virgin Islands to foreign countries.

[5] Includes value of exports from the U.S. Virgin Islands to foreign countries.

TABLE 2

PRODUCTION OF SULFUR AND SULFUR-CONTAINING RAW MATERIALS IN THE UNITED STATES

(Thousand metric tons)

	1992		1993	
	Gross weight	Sulfur content	Gross weight	Sulfur content
Frasch sulfur	2,320	2,320	[1]1,904	[1]1,904
Recovered sulfur[2]	7,048	7,048	[3]7,665	[3]7,665
Byproduct sulfuric acid (100% basis) produced at copper, lead, molybdenum, and zinc plants	3,948	1,292	4,244	1,387
Other forms[4]	8	3	8	3
Total	XX	10,663	XX	10,959

XX Not applicable.

[1] Includes 10 months of Frasch sulfur data. Two remaining months of Frasch data included with recovered sulfur data to conform with proprietary data requirements.

[2] Includes Puerto Rico and the U.S. Virgin Islands.

[3] Includes corresponding Frasch sulfur data for November and December.

[4] Includes hydrogen sulfide, liquid sulfur dioxide, and pyrites.

TABLE 3

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE

(Thousand metric tons and thousand dollars)

State	1992			1993		
	Production	Shipments		Production	Shipments	
		Quantity	Value		Quantity	Value
Alabama	421	419	24,263	397	397	14,410
California	699	702	18,389	750	742	4,342
Florida	47	47	W	47	47	W
Illinois	267	269	12,285	297	295	8,340
Louisiana	732	731	42,936	[1]1,251	[1]1,124	[1]44,991
Michigan and Minnesota	184	185	7,708	158	157	733
Mississippi	659	679	32,001	589	580	12,752
New Mexico	54	55	1,424	50	50	321
North Dakota	82	82	1,723	81	81	1,825
Ohio	43	44	2,813	54	54	2,415
Pennsylvania	56	57	2,688	71	71	2,131
Texas	2,008	2,010	99,323	[1]2,312	[1]2,306	[1]67,376
Wyoming	1,056	1,067	31,712	907	909	6,981
Other[2]	740	746	38,173	695	706	21,810
Total[3]	7,048	7,094	315,438	7,665	7,521	76,060

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

[1] Includes corresponding Frasch sulfur data for November and December.

[2] Includes Arkansas, Colorado, Delaware, Indiana, Kansas, Kentucky, Montana, New Jersey, Utah, Virginia, Washington, Wisconsin, Puerto Rico, the U.S. Virgin Islands, and data indicated by symbol W.

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

TABLE 4

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT

(Thousand metric tons)

District and source	1992		1993	
	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	317	318	281	280
Natural gas	47	47	47	47
Total[1]	364	365	328	327
PAD 2:				
Petroleum and coke	698	699	721	716
Natural gas	85	85	83	83
Total	783	784	804	799
PAD 3:[2]				
Petroleum	2,620	2,639	2,856	2,869
Natural gas	1,352	1,354	[3]1,832	[3]1,690
Total	3,972	3,993	4,688	4,559
PAD 4 and 5:				
Petroleum	889	901	958	950
Natural gas	1,041	1,052	885	886
Total[1]	1,930	1,952	1,843	1,836
Grand total[1]	7,048	7,094	7,665	7,521

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

[2] Includes Puerto Rico and the U.S. Virgin Islands.

[3] Includes corresponding Frasch sulfur data for November and December.

TABLE 5

BYPRODUCT SULFURIC ACID[1] PRODUCED IN THE UNITED STATES

(Thousand metric tons, sulfur content, and thousand dollars)

Year	Copper plants[2]	Zinc plants[3]	Lead and molybdenum plants[3]	Total	Value
1989	1,005	134	51	1,190	103,526
1990	1,105	135	54	1,294	116,356
1991	1,101	137	64	1,302	106,891
1992	1,093	139	59	1,291	86,743
1993	1,191	130	66	1,387	61,062

[1] Includes acid from foreign materials.

[2] Excludes acid made from pyrites concentrates.

[3] Excludes acid made from native sulfur.

TABLE 6

CONSUMPTION OF SULFUR[1] IN THE UNITED STATES

(Thousand metric tons)

	1989	1990	1991	1992	1993
Frasch:					
Shipments	3,780	3,676	3,120	2,600	[2]1,477
Exports	330	348	448	362	246
Imports	1,086	1,129	1,259	845	100
Total	4,536	4,457	3,931	3,083	1,331
Recovered:					
Shipments[3]	6,475	6,483	6,682	7,094	[4]7,521
Exports	694	624	748	604	410
Imports	1,174	1,442	1,760	1,877	1,935
Total	6,955	7,301	7,694	8,368	9,046
Total elemental	11,491	11,758	11,625	11,451	10,377
Pyrites, shipments	W	W	W	W	W
Byproduct sulfuric acid, shipments	1,190	1,294	1,302	1,292	1,387
Other forms, shipments[5]	4	4	4	4	4
Total, all forms[6]	12,685	13,056	12,932	12,747	11,771

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

[1] Crude sulfur or sulfur content.

[2] Includes 10 months of Frasch sulfur data. Two remaining months of Frasch data included with recovered sulfur data to conform with proprietary data requirements.

[3] Includes Puerto Rico and the U.S. Virgin Islands.

[4] Includes corresponding Frasch sulfur data for November and December.

[5] Includes consumption of hydrogen sulfide, liquid sulfur dioxide, and data indicated by symbol W.

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

TABLE 7
SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons, sulfur content)

End use		Elemental sulfur[1]		Sulfuric acid (sulfur equivalent)		Total	
		1992	1993	1992	1993	1992	1993
102	Copper ores	—	—	648	696	648	696
1094	Uranium and vanadium ores	—	—	8	1	8	1
10	Other ores	—	—	46	49	46	49
20	Food and kindred products	W	W	—	—	W	W
26, 261	Pulpmills and paper products	27	W	296	304	323	304
28, 285, 286, 2816	Inorganic pigments, paints and allied products, industrial organic chemicals, other chemical products[2]	140	74	425	317	565	391
281	Other inorganic chemicals	124	122	192	232	316	354
282, 2822	Synthetic rubber and other plastic materials and synthetics	60	64	278	259	[r]338	323
2823	Cellulosic fibers, including rayon	—	—	43	51	43	51
283	Drugs	—	—	15	15	15	15
284	Soaps and detergents	W	W	50	45	50	45
286	Industrial organic chemicals	—	—	196	82	196	82
2873	Nitrogenous fertilizers	—	—	227	123	227	123
2874	Phosphatic fertilizers	—	—	8,300	7,906	8,300	7,906
2879	Pesticides	—	—	3	7	3	7
287	Other agricultural chemicals	756	914	38	30	794	944
2892	Explosives	—	—	12	9	12	9
2899	Water-treating compounds	—	—	131	94	131	94
28	Other chemical products	—	—	146	147	146	147
29, 291	Petroleum refining and other petroleum and coal products	308	571	385	388	693	959
331	Steel pickling	—	—	31	28	31	28
333	Nonferrous metals	—	—	30	26	30	26
33	Other primary metals	—	—	1	2	1	2
3691	Storage batteries (acid)	—	—	31	28	31	28
	Exported sulfuric acid	—	—	14	10	14	10
	Total identified[3]	[r]1,416	1,744	11,547	11,062	[r]12,963	12,806
	Unidentified	[r]669	1,008	793	824	[r]1,462	1,832
	Grand total[3]	[r]2,084	2,753	12,340	11,886	[r]14,424	14,639

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Unidentified."

[1] Does not include elemental sulfur used for production of sulfuric acid.

[2] No elemental sulfur was used in inorganic pigments and paints and allied products.

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

TABLE 8
SULFURIC ACID FROM SMELTERS SOLD OR USED IN THE UNITED STATES, BY END USE

(Thousand metric tons of 100% H_2SO_4)

SIC	Use	1992	1993
102	Copper ores	1,844	1,952
1094	Uranium and vanadium ores	15	—
10	Other ores	93	145
26, 261	Pulp mills and other paper products	94	337
2816	Inorganic pigments	W	W
281	Other inorganic chemicals	81	83
2823	Cellulosic fibers	W	W
283	Drugs	W	W
2873	Nitrogenous fertilizers	W	W
2874	Phosphatic fertilizers	580	286
287	Other agricultural chemicals	59	52
2899	Water-treating compounds	161	126
28	Other chemical products	4	16
291	Petroleum refining	15	11
331	Steel pickling	W	W
333	Nonferrous metals	7	12
3691	Storage batteries (acid)	18	16
	Unidentified	779	944
	Total domestic	3,750	3,980
	Exports	W	W
	Grand total	3,750	3,980

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

TABLE 9
YEAREND SULFUR STOCKS OF U.S. PRODUCERS

(Thousand metric tons)

Year	Frasch	Recovered	Total[1]
1989	1,109	193	1,301
1990	1,177	245	1,423
1991	979	216	1,194
1992	642	167	809
1993	W	1,382	1,382

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

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

TABLE 10
REPORTED SALES VALUES OF SHIPMENTS OF SULFUR, F.O.B. MINE OR PLANT

(Dollars per metric ton)

Year	Frasch	Recovered	Average
1989	100.18	78.70	86.62
1990	91.17	73.89	80.14
1991	87.05	64.17	71.45
1992	58.15	44.47	48.14
1993	51.60	25.06	31.86

TABLE 11
U.S. EXPORTS[1] OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	Value	Quantity	Value
Australia	2	1,344	27	2,496
Brazil	268	17,087	116	5,413
Canada	9	2,498	8	2,359
Colombia	12	755	9	679
Greece	17	1,158	—	—
India	—	—	29	1,585
Korea, Republic of	11	4,923	3	3,808
Mexico	109	8,252	90	6,169
Senegal	104	7,812	33	858
South Africa, Republic of	97	4,950	2	237
Taiwan	12	1,476	8	1,288
Tunisia	125	6,419	93	2,847
Other	200	12,988	236	11,986
Total[2]	966	69,662	656	39,726

[1] Includes exports from the U.S. Virgin Islands.

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

Source: Bureau of the Census.

TABLE 12
U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	362	$49	(1)	$49
Canada	84,725	6,701	89,758	6,191
China	31	39	2,130	164
Colombia	199	179	712	66
Costa Rica	991	325	1,269	97
Dominican Republic	1,172	62	1,737	98
Ecuador	1,049	64	(1)	7
Germany	—	—	877	29
Greece	138	5	—	—
Guatemala	(1)	46	1,280	48
Honduras	786	260	(1)	19
Israel	7,466	407	3,433	375
Korea, Republic of	2,039	859	1,124	657
Mexico	26,241	999	14,392	881
Morocco	15	24	—	—
Netherlands Antilles	17	13	4,356	161
Panama	2,705	135	4,842	144
Saudi Arabia	509	71	(1)	47
Taiwan	2,385	493	2,725	606
Thailand	90	92	(1)	83
Trinidad and Tobago	1,842	86	2,222	53
United Kingdom	87	6	2,197	126
Venezuela	1,195	39	(1)	42
Other	5,412	913	8,746	1,224
Total	139,456	[r]11,867	141,800	[2]11,169

[r] Revised.

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY

(Thousand metric tons and thousand dollars)

Country	1992		1993	
	Quantity	Value[1]	Quantity	Value[1]
Canada	1,857	$57,397	1,531	$27,250
Mexico	845	69,693	504	21,319
Other[2]	21	2,804	4	1,058
Total	[3]2,725	129,894	2,039	49,627

[1] Declared customs valuation.

[2] Includes Belgium, France, Germany, Japan, the Netherlands, and Venezuela in 1992; Chile, France, Germany, Japan, the Netherlands, Netherlands Antilles, and the United Kingdom in 1993.

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

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value[1] (thousands)	Quantity (metric tons)	Value[1] (thousands)
Argentina	3,609	$318	—	—
Belgium	—	—	9,961	$60
Canada	1,340,329	50,866	1,380,662	52,646
Chile	7,758	196	—	—
Germany	158,037	4,918	368,864	5,445
Italy	7,259	211	23,053	503
Japan	100,584	2,397	223,916	4,077
Mexico	156,381	4,046	120,929	2,449
Netherlands	28,883	631	81,200	1,571
Spain	23,731	589	74,967	1,711
Sweden	51,816	1,568	59,072	1,357
Switzerland	10,509	376	—	—
Trinidad and Tobago	8,583	175	—	—
United Kingdom	87,933	2,196	95,968	876
Other	(2)	8	(2)	5
Total[3]	1,985,414	68,496	2,438,592	70,698

[1] Declared c.i.f. valuation.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 15
WORLD SULFUR ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993, RATED CAPACITY, SULFUR IN ALL FORMS[1]

(Thousand metric tons, sulfur content)

	Capacity
North America:	
Canada	9,900
United States	11,170
Total	21,070
Latin America:	
Brazil	500
Chile	440
Mexico	2,775
Other	675
Total	4,390
Europe:	
Belgium	400
Finland	620
France	1,850
Germany	2,530
Italy	830
Netherlands	350
Poland	4,900
Spain	1,550
Sweden	544
Turkey	613
U.S.S.R.[2]	11,000
United Kingdom	500
Yugoslavia	750
Other	1,724
Total	28,161
Africa:	
South Africa, Republic of	1,000
Other	270
Total	1,270
Asia:	
China[e]	5,450
Iran	500
Iraq	1,600
Japan	4,100
Kuwait	330
Saudi Arabia	1,780
Other	1,400
Total	15,160
Oceania	330
World total	70,381

[e] Estimated.

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

[2] Dissolved in Dec. 1991; however information is inadequate to formulate reliable estimates for individual countries.

TABLE 16

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Algeria: Byproduct, natural gas and petroleum[e]	20	20	20	20	20
Australia: Byproduct:[e]					
Metallurgy	[r]213	[r]228	[r]223	[r]223	228
Petroleum	[r]70	[r]70	[r]70	[r]75	85
Total	[r]283	[r]298	[r]293	[r]298	313
Austria: Byproduct:					
Metallurgy	12	12	[r][e]11	[r][e]8	8
Natural gas and petroleum	[r]7	[r]6	[r]7	[r]9	9
Total	[r]19	[r]18	[r][e]18	[r][e]17	17
Bahrain: Byproduct, petroleum[e]	[r]5	[r]5	[r]5	[r]6	6
Belgium: Byproduct, all sources[e]	320	310	300	300	300
Bolivia: Native	8	2	3	[r](4)	1
Bosnia and Herzegovina: Byproduct, metallurgy	—	—	—	[r](4)	(4)
Brazil:[e]					
Frasch	[5]6	6	6	6	6
Pyrites	[5]72	[r]47	[r]64	[r]19	—
Byproduct:					
Metallurgy	[5]164	[r]172	[r]180	[r]190	229
Petroleum	[5]60	[r]93	[r]84	[r]89	94
Total	[5]302	[r]318	[r]334	[r]304	329
Bulgaria:[e]					
Pyrites	70	70	60	60	50
Byproduct, all sources	60	60	50	50	50
Total	130	130	110	110	100
Canada: Byproduct:					
Metallurgy	[r]836	[r]899	872	[r]931	[5]912
Natural gas	[r]5,115	[r]5,181	[r]5,488	[r]5,769	6,500
Petroleum[e]	[5]149	[5]207	230	235	235
Tar sands	[r]500	503	540	552	600
Total[e]	[r]6,600	[r]6,790	[r]7,130	[r]7,487	8,247
Chile:					
Native:					
Refined	[r]16	[r]29	[r]19	[r]24	1
From caliche	[e]1	(4)	(4)	(4)	(4)
Byproduct, metallurgy[e]	[r]180	[r]187	[r]278	[r]306	375
Total[e]	[r]197	[r]216	[r]297	[r]330	376
China:[e]					
Native	300	320	320	320	330
Pyrites	4,270	4,400	[r]4,940	[r]4,500	5,000
Byproduct, all sources	600	650	650	650	700
Total	5,170	5,370	[r]5,910	[r]5,470	6,030
Colombia:					
Native	46	32	[r]38	[r]39	39
Byproduct, petroleum[e]	8	8	9	[r]9	9
Total[e]	54	40	[r]47	[r]48	48

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Croatia: Byproduct:[e]					
Metallurgy	—	—	—	[r]1	1
Petroleum	—	—	—	[r]2	2
Total	—	—	—	[r]3	3
Cuba: Byproduct, petroleum[e]	7	7	7	7	7
Cyprus:[6] Pyrites	26	—	—	—	—
Czech Republic:[7] [8] Byproduct, all sources[e]	—	—	—	—	20
Czechoslovakia:[e] [8] [9]					
Native	6	6	6	6	—
Pyrites	50	50	50	50	—
Byproduct, all sources	40	40	40	40	—
Total[e]	96	96	96	96	—
Denmark: Byproduct, petroleum	19	12	[r]6	[r]10	10
Ecuador:[e]					
Native	4	4	4	4	4
Byproduct:					
Natural gas	5	5	5	5	5
Petroleum	5	5	5	5	5
Total	14	14	14	14	14
Egypt: Byproduct, natural gas and petroleum[e]	8	8	8	8	8
Finland:					
Pyrites	306	357	369	[r]350	350
Byproduct:					
Metallurgy	180	237	227	[e]225	225
Petroleum	41	[e]42	[e]40	[r]32	32
Total[e]	527	636	636	[r]607	607
France: Byproduct:					
Natural gas	647	666	794	[r]770	700
Petroleum	239	[e]233	225	[r]230	200
Unspecified[e]	150	150	180	[r]150	150
Total[e]	1,036	1,049	1,199	[r]1,150	1,050
Germany:					
Pyrites[e]	[5]214	150	95	25	—
Byproduct:					
Metallurgy	[r]240	[r]282	[r]198	[r]23	20
Natural gas and petroleum	[r]947	[r]858	[r]905	[r]1,016	980
Unspecified[10]	[r][e]300	[r]260	[r]84	[r]100	100
Total[e]	[r]1,701	[r]1,550	[r]1,282	[r]1,164	1,100
Greece:					
Pyrites	57	[r]60	35	[e]25	25
Byproduct:[e]					
Natural gas	[r]135	[r]135	[r]125	[r]120	120
Petroleum	5	5	[r]6	5	5
Total	[r]197	[r]200	[r]166	[r]150	150

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Hungary:[e]					
Pyrites	1	1	1	1	1
Byproduct, all sources	10	[r]9	8	8	8
Total	11	[r]10	9	9	9
India:					
Pyrites	39	94	128	[e]100	55
Byproduct:					
Metallurgy[e]	125	125	130	130	130
Petroleum	[r]10	10	12	[e]13	14
Total[e]	[r]174	229	270	243	199
Indonesia:[6] Native	4	4	[e]4	[e]4	4
Iran: Byproduct:[e]					
Metallurgy	40	45	50	50	50
Natural gas and petroleum	460	635	650	700	750
Total	500	680	700	750	800
Iraq:[e]					
Frasch	960	800	250	500	600
Byproduct, natural gas and petroleum	370	380	50	[r]100	200
Total	1,330	1,180	300	[r]600	800
Israel: Byproduct, natural gas and petroleum[e]	68	64	66	60	60
Italy:					
Pyrites	[r]325	[e]290	[r]200	[r]180	175
Byproduct, petroleums[e]	[5]315	297	[r]280	[r]290	300
Total	[r]640	587	[r]480	[r]470	475
Japan:					
Pyrites	62	53	30	[r]31	29
Byproduct:					
Metallurgy	1,321	1,336	[r]1,382	1,350	1,390
Petroleum	1,176	1,268	[r]1,244	1,250	1,250
Total	2,559	2,657	[r]2,656	[r]2,631	2,669
Kazakhstan: Native	—	—	—	[e]200	150
Korea, North:[e]					
Pyrites	200	200	210	210	210
Byproduct, metallurgy	30	30	30	30	30
Total	230	230	240	240	240
Korea, Republic of: Byproduct:[e]					
Metallurgy	[r]221	[r]221	[r]229	[r]260	263
Petroleum	[r]28	[r]65	[r]65	[r]100	200
Total	[r]249	[r]286	[r]294	[r]360	463
Kuwait: Byproduct, natural gas and petroleum[e]	375	300	[r]30	[r]150	175
Libya: Byproduct, natural gas and petroleum[e]	14	14	14	14	14
Macedonia:					
Pyrites	—	—	—	[r]—	—
Byproduct, metallurgy[e]	—	—	—	[r]6	6
Total	—	—	—	[r]6	6
Mexico:					
Frasch	[r]1,531	1,441	1,040	[r]710	[5]102

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Mexico—Continued:					
Byproduct:					
Metallurgy[e]	286	290	280	[r]817	800
Natural gas and petroleum	555	[r]682	754	[r]775	[5]733
Total[e]	[r]2,372	[r]2,413	2,074	[r]2,302	1,635
Namibia: Pyrites[e]	100	70	65	[r][5]81	80
Netherlands: Byproduct:[e]					
Petroleum	260	285	290	290	290
Metallurgy	125	125	125	125	125
Total	385	410	415	415	415
Netherlands Antilles: Byproduct, petroleum[e]	60	60	120	120	120
New Zealand: Byproduct, all sources	1	3	(4)	[e]1	1
Norway:[e]					
Pyrites	122	125	121	[5]125	125
Byproduct:					
Metallurgy	[5]75	75	75	75	75
Petroleum	13	15	15	15	15
Total[e]	210	215	211	215	215
Oman: Byproduct:					
Metallurgy	[r]—	[r]—	[r]—	[r]—	—
Natural gas and petroleum[e]	25	30	40	40	40
Total[e]	25	30	40	40	40
Pakistan:					
Native	—	(4)	(4)	(4)	(4)
Byproduct, all sources[e]	25	25	26	26	27
Total[e]	25	25	26	26	27
Peru:[e]					
Native	(4)	(4)	(4)	(4)	(4)
Byproduct, all sources	66	66	66	60	60
Total	66	66	66	60	60
Philippines:					
Pyrites[e]	[r]147	[r]158	[r]155	[r]64	114
Byproducts, metallurgy	[r]134	[r]120	[r]119	[r]111	147
Total[e]	[r]281	[r]278	[r]274	[r]175	261
Poland:[11]					
Frasch	4,276	4,027	3,302	[r]2,282	1,500
Native	588	637	633	[r]635	400
Byproduct:					
Metallurgy	[r]220	[r]200	[r]200	[r][e]200	200
Petroleum	[r]33	[r]28	[r]28	[r][e]25	25
Gypsum[e]	20	10	10	10	10
Total[e]	[r]5,137	[r]4,902	[r]4,173	[r]3,152	2,135
Portugal:[e]					
Pyrites	[5]91	95	96	95	95
Byproduct, all sources	3	3	4	4	4
Total	94	98	100	99	99
Qatar: Byproduct, natural gas[e]	52	52	52	52	52

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993^{e}
Romania:^{e}					
Pyrites	^{r}350	^{r}350	^{r}350	^{r}385	380
Byproduct, all sources	375	^{r}310	^{r}250	^{r}200	200
Total	^{r}725	^{r}660	^{r}600	^{r}585	580
Russia:^{e} [12]					
Native	—	—	—	100	100
Byproducts:					
Metallurgy	—	—	—	250	200
Natural gas	—	—	—	1,800	1,800
Total	—	—	—	2,150	2,100
Saudi Arabia: Byproduct, natural gas and petroleum	1,423	1,435	2,000	^{r}1,630	1,600
Serbia and Montenegro:					
Pyrites	—	—	—	^{r}3	3
Byproducts:					
Metallurgy	—	—	—	^{e}130	130
Petroleum	—	—	—	^{r}1	1
Total	—	—	—	^{r} ^{e}134	134
Singapore: Byproduct, petroleum^{e}	^{r}60	^{r}65	^{r}75	^{r}75	75
Slovenia: Byproduct, petroleum^{e}	—	—	—	^{e}1	1
South Africa, Republic of:					
Pyrites	461	452	293	384	375
Byproduct:					
Metallurgy^{e}	100	^{r}110	^{r}105	100	120
Petroleum^{e} [13]	120	120	120	120	140
Total[14]	682	683	517	603	635
Spain:					
Pyrites	^{r}894	748	^{r}546	^{r}510	327
Byproduct:^{e}					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	^{r}235	^{r}248	^{r}252	^{r}258	258
Petroleum	^{r}80	^{r}149	^{r}105	^{r}90	100
Total^{e}	^{r}1,211	^{r}1,147	905	^{r}860	687
Sweden:					
Pyrites	^{r}144	^{r}121	^{r}43	^{r} ^{e}38	40
Byproduct:^{e}					
Metallurgy	125	125	^{r}125	^{r}125	125
Petroleum	40	40	40	40	40
Total^{e}	^{r}309	^{r}286	^{r}208	^{r}203	205
Switzerland: Byproduct, petroleum^{e}	4	4	4	^{r}3	3
Syria: Byproduct, natural gas and petroleum^{e}	40	^{r}30	^{r}30	^{r}30	30
Taiwan: Byproduct, all sources	76	96	126	^{r}119	153
Trinidad and Tobago: Byproduct, petroleum^{e}	^{r}5	^{r}5	^{r}5	^{r}5	5
Turkey:					
Native	^{r}23	20	^{r}22	^{r} ^{e}21	20
Pyrites	96	^{r}65	^{r} ^{e}60	^{r} ^{e}40	33

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Turkey—Continued:					
Byproduct:					
Petroleum	13	14	[r]17	[r]17	17
Unspecified[e]	49	7	5	5	5
Total[e]	[r]181	[r]106	[r]104	[r]83	75
Turkmenistan: Native	—	—	—	[e]300	200
Ukraine: Native	—	—	—	[e]1,200	1,000
U.S.S.R.:[e] [15]					
Frasch	1,100	1,000	900	—	—
Native	2,350	2,000	1,800	—	—
Pyrites	2,150	1,900	1,700	—	—
Byproduct:					
Metallurgy	1,350	1,200	1,100	—	—
Natural gas	2,500	2,500	2,200	—	—
Petroleum	450	425	400	—	—
Total	9,900	9,025	8,100	—	—
United Arab Emirates: Abu Dhabi:					
Byproduct:[e]					
Natural gas	70	80	64	[r]200	225
Petroleum	10	10	10	[r]24	24
Total	80	90	74	[r]224	249
United Kingdom: Byproduct:[e]					
Metallurgy	[r]61	[r]64	[r]65	[r]60	72
Petroleum	[r]115	[r]135	[r]140	[r]175	200
Total	[r]176	[r]199	[r]205	[r]235	272
United States:					
Frasch	3,888	3,726	2,869	2,320	[16]1,904
Pyrites	W	W	W	W	W
Byproduct:					
Metallurgy	1,190	1,294	1,302	1,291	1,387
Natural gas	2,537	2,336	2,403	2,525	[17]2,848
Petroleum	3,973	4,200	4,242	4,524	4,817
Unspecified	4	4	4	3	3
Total	11,592	11,560	10,820	10,663	10,959
Uruguay: Byproduct, petroleum[e]	2	2	2	2	2
Venezuela: Byproduct, natural gas and petroleum[e]	125	[r]125	[r]155	[r]155	135
Yugoslavia:[18]					
Pyrites and pyrrhotite	[r]292	[r]219	[r]61	—	—
Byproduct:[e]					
Metallurgy	175	175	160	—	—
Petroleum	[r]3	3	[r]3	—	—
Total[e]	[r]470	[r]397	[r]224	—	—
Zaire: Byproduct, metallurgy[e]	29	24	16	11	7
Zambia:[e]					
Pyrites	[r]30	[r][5]31	[r]31	[r]32	34
Byproduct, metallurgy	[r]78	[r]71	[r]69	[r]75	75
Total	[r]108	[r]102	100	[r]107	109

See footnotes at end of table.

TABLE 16—Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1]

(Thousand metric tons)

Country[2] and source[3]	1989	1990	1991	1992	1993[e]
Zimbabwe:[e]					
Pyrites	21	29	31	[r]29	30
Byproduct, all sources	5	5	5	5	5
Total	26	34	36	[r]34	35
Grand total[14]	[r]58,924	[r]58,026	[r]55,723	[r]52,740	52,270
Of which:					
Frasch	[r]11,761	11,000	8,367	[r]5,818	4,112
Native	[r]3,346	[r]3,054	[r]2,849	[r]2,853	2,249
Pyrites	[r]10,590	[r]10,135	[r]10,590	[r]10,590	10,590
Byproduct:					
Coal (lignite) gasification	2	2	2	2	2
Metallurgy	[r]7,745	[r]7,895	[r]7,803	[r]7,361	7,588
Natural gas	[r]11,061	[r]10,955	[r]11,131	[r]11,241	12,250
Natural gas and petroleum, undifferentiated	[r]4,437	[r]4,587	[r]4,729	[r]4,707	4,754
Petroleum	[r]7,378	[r]7,887	[r]7,904	[r]7,885	8,329
Tar sands	[r]500	503	540	552	600
Unspecified sources	[r]2,084	[r]1,998	[r]1,798	[r]1,721	1,786
Gypsum	20	10	10	10	10

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Byproduct: Unspecified sources."

[1] Table includes data available through July 26, 1994.

[2] In addition to the countries listed, a number of nations may produce limited quantities of either elemental sulfur or compounds (chiefly H_2S or SO_2) as a byproduct of petroleum, natural gas, and/or metallurgical operations, but output, if any, is not quantitatively reported, and no basis is available for the formulation of reliable estimates of output. Countries not listed in this table that may recover byproduct sulfur from oil refining include Albania, Bangladesh, Brunei, Burma, Costa Rica, Guatemala, Honduras, Jamaica, Malaysia, Nicaragua, Paraguay, and the Republic of Yemen. Albania and Burma may also produce byproduct sulfur from crude oil and natural gas extraction. No complete listing of other nations that may produce byproduct sulfur from metallurgical operations (including processing of coal for metallurgical use) can be compiled, but the total of such output is considered as small. Nations listed in the table that may have production from sources other than those listed are identified by individual footnotes.

[3] The term "source" reflects both the means of collecting sulfur and the type of raw material. Sources listed include the following: (1) Frasch recovery; (2) native, comprising all production of elemental sulfur by traditional mining methods (thereby excluding Frasch); (3) pyrites (whether or not the sulfur is recovered in the elemental form or as acid); (4) byproduct recovery, either as elemental sulfur or as sulfur compounds from coal gasification, metallurgical operations including associated coal processing, crude oil and natural gas extraction, petroleum refining, tar sand cleaning, and processing of spent oxide from stack-gas scrubbers; and (5) recovery from the processing of mined gypsum. Recovery of sulfur in the form of sulfuric acid from artificial gypsum produced as a byproduct of phosphatic fertilizer production is excluded because to include it would result in double counting. It should be noted that production of Frasch sulfur, other native sulfur, pyrites-derived sulfur, mined gypsum-derived sulfur, byproduct sulfur from extraction of crude oil and natural gas, and recovery from tar sands are all credited to the country of origin of the extracted raw material; in contrast, byproduct recovery from metallurgical operations, petroleum refineries, and spent oxides are credited to the nation where the recovery takes place, which in some instances is not the original source country of the crude product from which the sulfur is extracted.

[4] Less than 1/2 unit.

[5] Reported figure.

[6] May also produce limited quantities of byproduct sulfur from oil refining.

[7] Formerly part of Czechoslovakia.

[8] All production in Czechoslovakia from 1989-92 is believed to have come from the Czech Republic.

[9] Dissolved Dec. 31, 1992.

[10] Data represent byproduct production from eastern states.

[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] Sulfur is believed to be produced from Frasch and pyrite, and as a petroleum byproduct, however information is inadequate to formulate reliable estimates.

[13] Includes estimated byproduct production from synthetic fuels.

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

[15] Dissolved in Dec. 1991.

[16] Includes 10 months of Frasch sulfur production data. Two remaining months of "Frasch" data included with "Byproduct: Natural gas" data to conform with proprietary data requirements.

[17] Includes Frasch sulfur production data for November and December.

[18] Dissolved in Apr. 1992.

FIGURE 1
TRENDS IN THE SULFUR INDUSTRY IN THE UNITED STATES

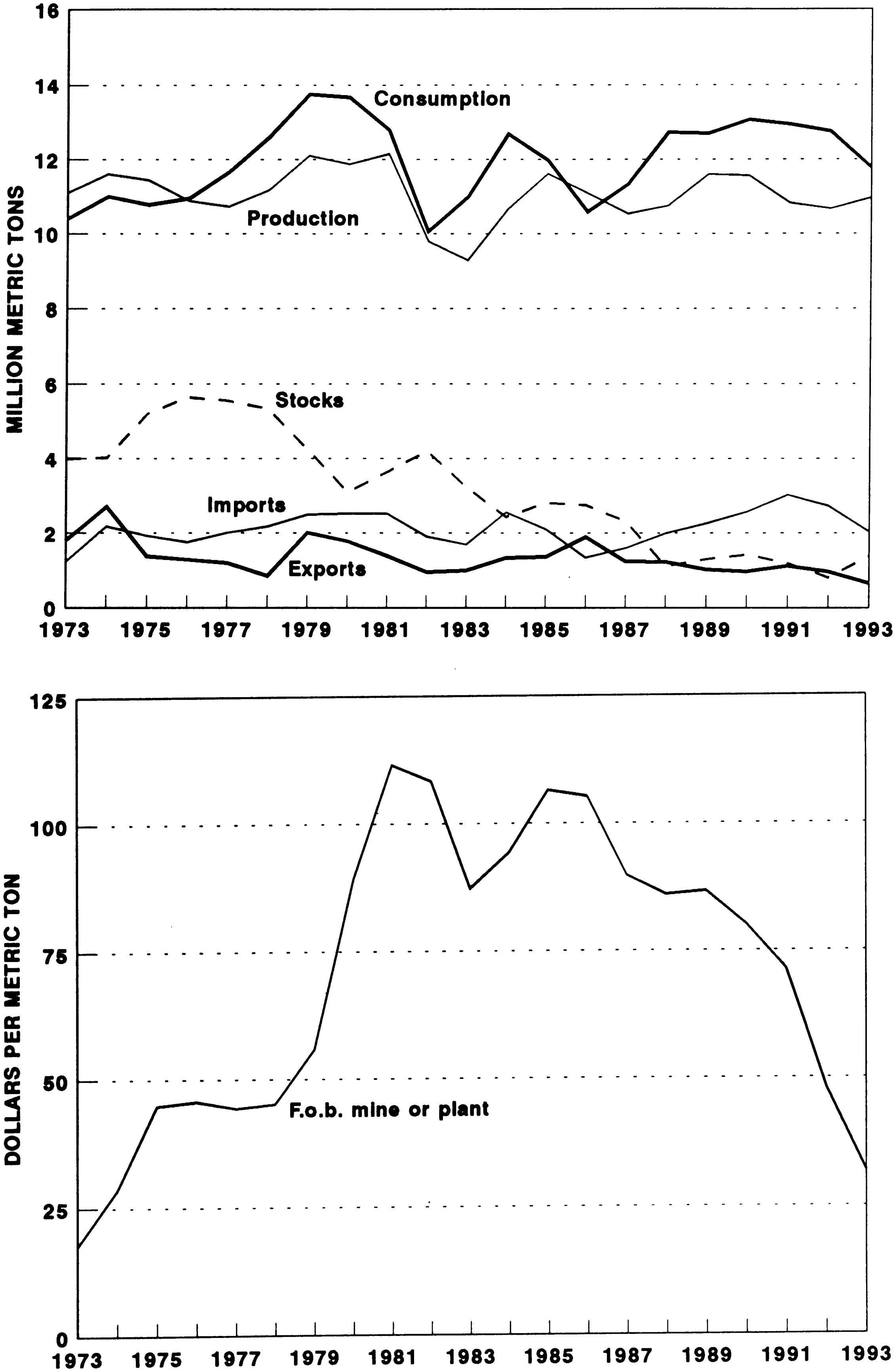
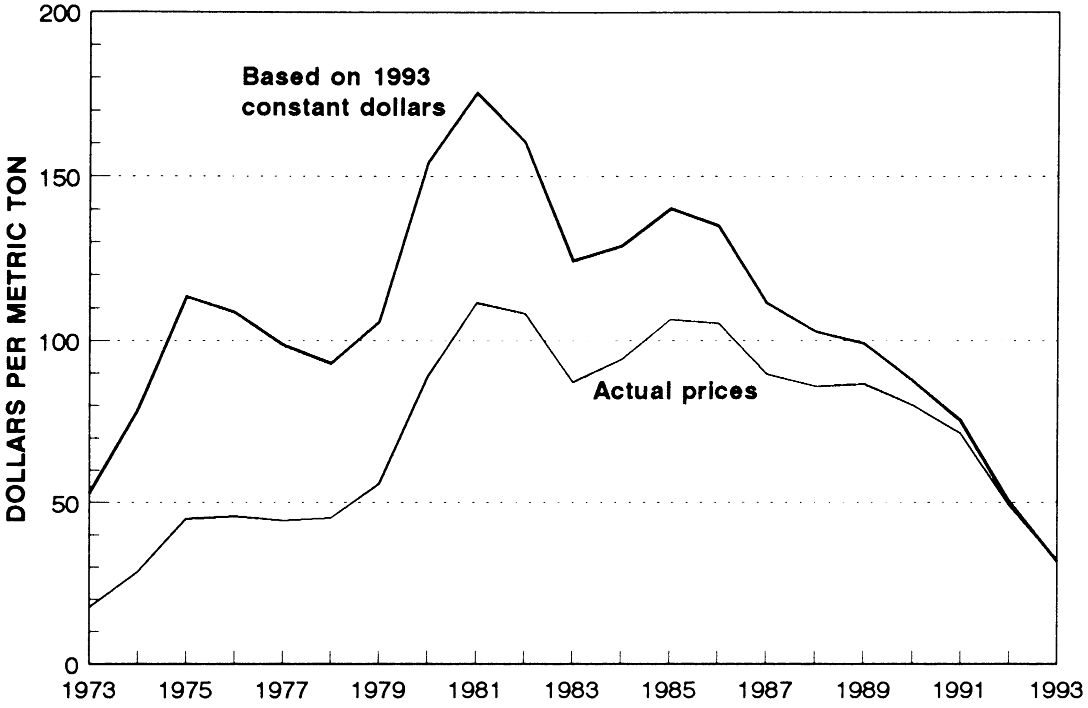


FIGURE 2

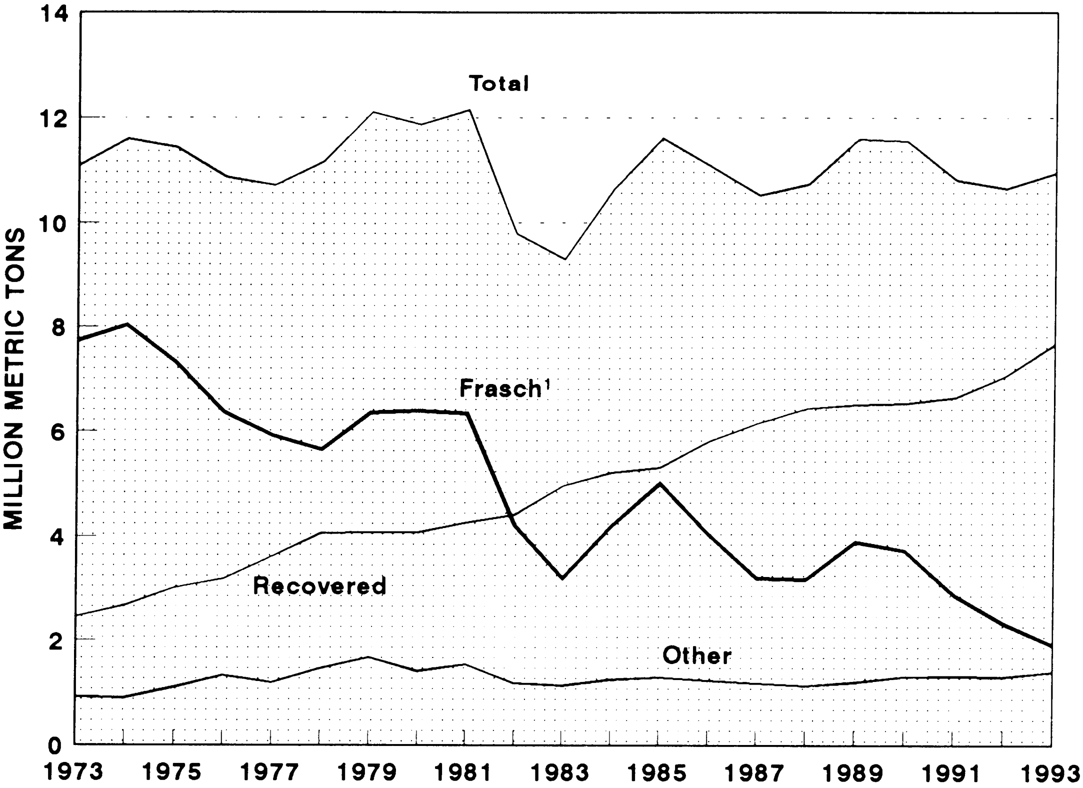
TIME-PRICE RELATIONSHIPS FOR SULFUR

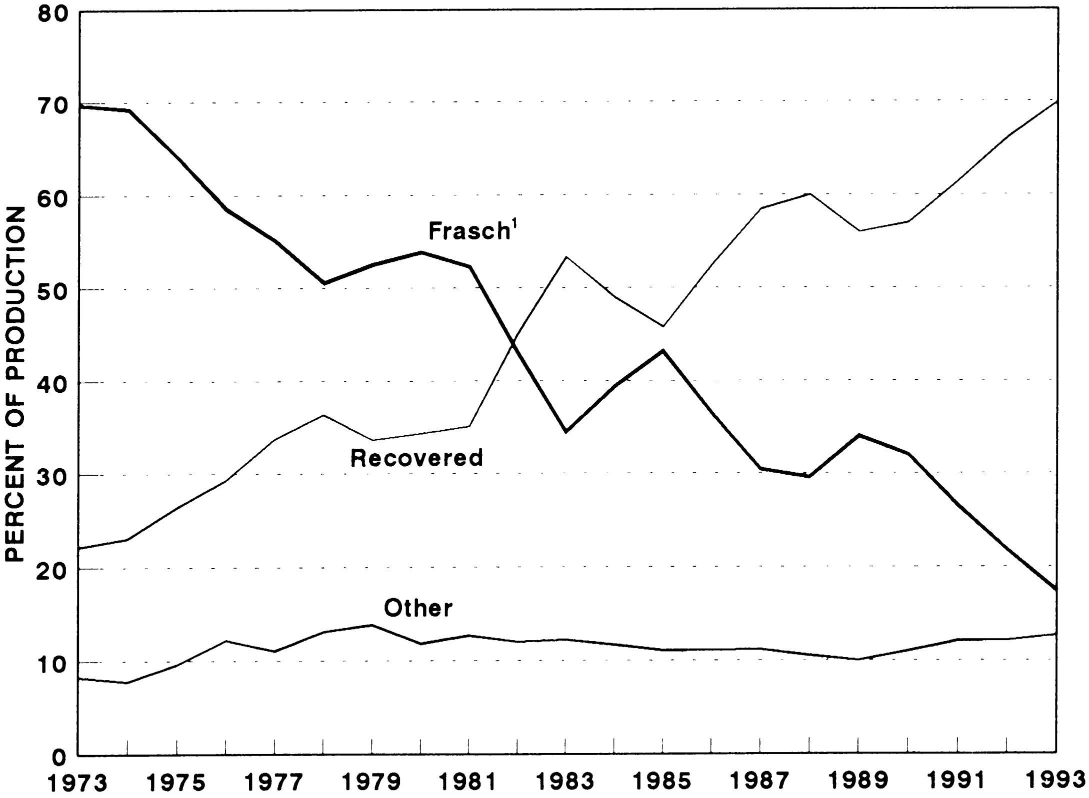


Based on the average reported prices for elemental sulfur (Frasch and recovered), f.o.b. mine and/or plant, these prices reflect approximately 90% of the shipments of sulfur in all forms during 1973-93.

FIGURE 3

TRENDS IN THE PRODUCTION OF SULFUR IN THE UNITED STATES





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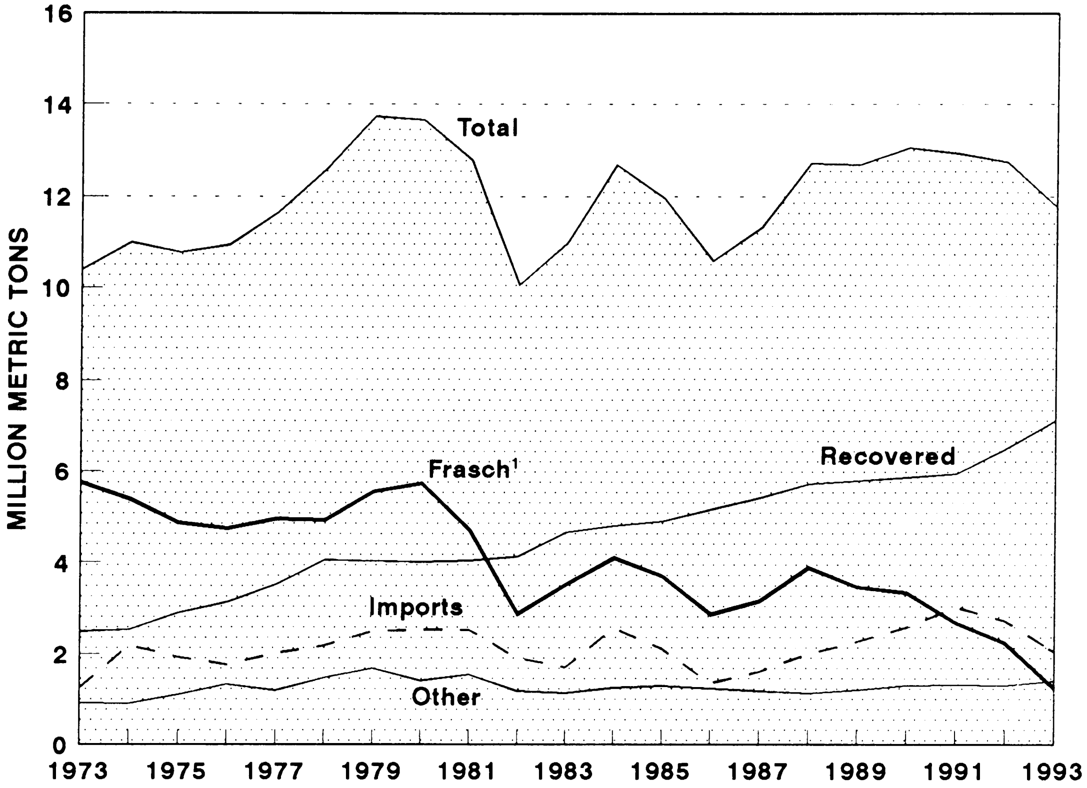
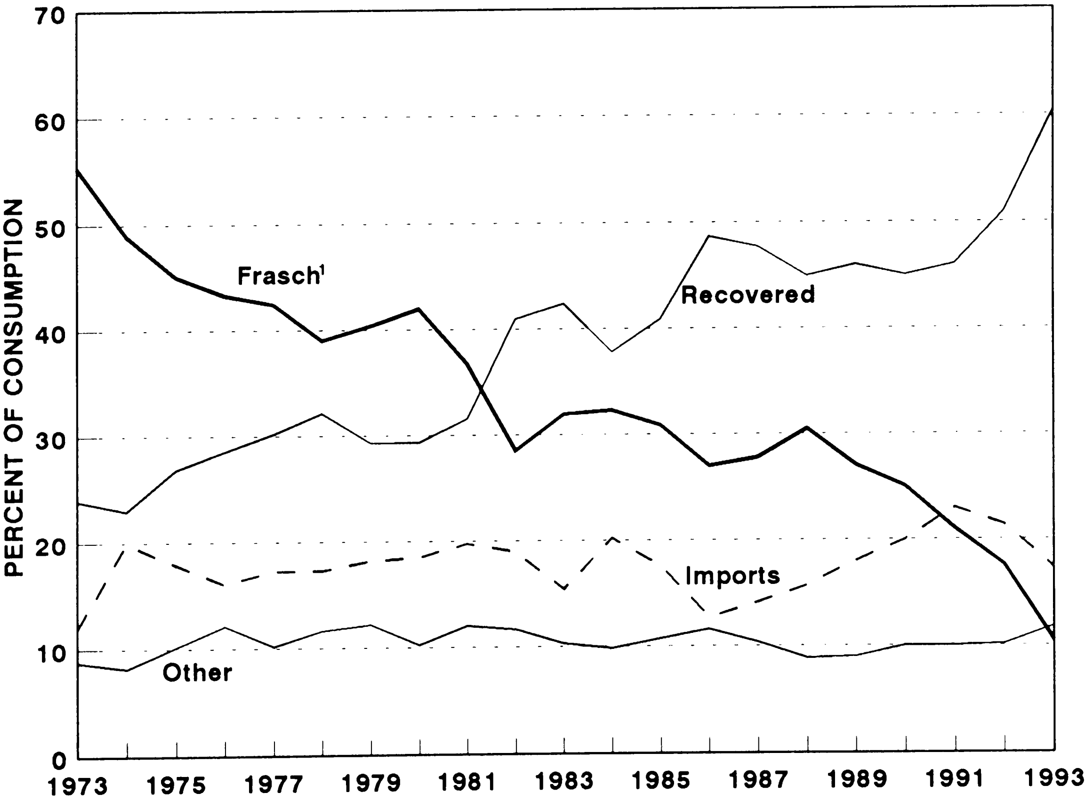
[1] Includes 10 months of Frasch sulfur data for 1993. Two remaining months of Frasch data are included with recovered sulfur data to conform with proprietary data requirements.

FIGURE 4

TRENDS IN THE CONSUMPTION OF SULFUR IN THE UNITED STATES





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[1] Includes 10 months of Frasch sulfur data for 1993. Two remaining months of Frasch data are included with recovered sulfur data to conform with proprietary data requirements.

TIN

By James F. Carlin, Jr.

Mr. Carlin, a physical scientist with the Branch of Metals, has been the commodity specialist for tin for 14 years. Domestic survey data were prepared by Elsie Isaac, statistical assistant; and international data tables were prepared by Jeremy Tidwell and Amy Durham, international data coordinators.

Domestic mine production of tin in 1993, a byproduct from one gold placer deposit in Alaska, was negligible. Twenty-five firms consumed about 86% of the primary tin used domestically. The major uses were as follows: cans and containers, 32%; electrical, 22%; construction, 10%; transportation, 11%; and other, 25%. The estimated value of primary metal consumption in 1993 was about $270 million.

About 11,700 metric tons of purchased old and new tin scrap, including tin alloys, was recycled in 1993. Of this, about 7,200 tons was old scrap. More than one-sixth of the tin consumed in the United States was produced from old scrap at detinning plants and 119 secondary nonferrous metal processing plants. There was continued interest in the recycling of used tin cans, largely due to the rising costs and limited space of landfills. The recycling rate for steel cans was above 40% in 1993, having risen from 15% in 1988.

Six thousand and twenty-two tons of pig tin was sold from the National Defense Stockpile in 1993, leaving 145,395 tons in inventory, all of which is authorized for ultimate disposal.

World tin mine output in 1993 remained essentially the same as that in 1992, the result of producer efforts to restrict production. Nevertheless, there was an excess of tin on the world market for the 12th consecutive year. Excess stocks were believed to be about 40,000 tons of tin at yearend.

The price of tin remained in a fairly narrow band throughout the year, declining somewhat and finishing the year at a level that was low by historical standards. Concern over the continuation of low tin prices was widespread among tin producers. In July, the tin price reached a 25-year low on the London Metal Exchange. Most world producers had a break-even point substantially above the prevailing tin price. Many producers announced production cutbacks or shutdowns.

Tin was mined in 29 countries in 1993, of which the top 5 accounted for about 75% of the world total of 178,000 tons. China was the largest producer with 26% of the world total, followed by Indonesia (16%), Brazil (15%), Bolivia (10%), and Peru (8%). World tin reserves were estimated at 7 million tons and were considered adequate to meet the world's tin requirements in the near future. The bulk of these tin reserves was in Asia and South America.

DOMESTIC DATA COVERAGE

Domestic consumption data for tin are developed by the U.S. Bureau of Mines from a voluntary survey of U.S. tin users. All of the 290 consumers to which a survey request was sent responded. *(See table 1.)*

BACKGROUND

Definitions, Grades, and Specifications

Primary or virgin tin metal is cast and sold as bars, ingots, pigs, and slabs in weights of 50 kilograms or less. Most of the tin metal imported into the United States is in the form of 45-kilogram pigs.

The American Society for Testing and Materials, Philadelphia, PA, announced a modification to the existing Standard Specification for Pig Tin (B339). Now, tin users may specify a new level of tin purity called "Grade A Tin for the Manufacture of Tinplate"; this specification calls for a new, lower lead impurity level of 0.020% maximum under the normal Grade A specification. This change was in response to industry concerns in recent years about possible deleterious effects caused by lead in tinplate.

The Steel Can Recycling Institute (SCRI), based in Pittsburgh, PA, announced that henceforth it will be called the Steel Recycling Institute. The name change reflected a broadening of its mission to encompass not only steel cans (which had been its sole focus since its 1988 founding), but all steel products, ranging from appliances to cars.

ANNUAL REVIEW

Production

The Cache Creek Mine, in the Tofty District near Manley Hot Springs, AK, was the only mine in the United States to produce significant amounts of tin concentrates. The tin was recovered as a byproduct of gold mining. The mine, owned by Shoreham Resources, Inc., Houston, TX, was in its fourth year of production. The tin output from the mine amounted to only a small fraction of domestic tin requirements.

The United States was believed to be the world's largest producer of secondary tin. Tin metal recovered from new tinplate scrap and from used tin cans was the only type of secondary tin available in the marketplace as free tin; other secondary tin was available in scrap materials as an alloying ingredient.

Secondary tin from recycled fabricated parts was used in many kinds of products and was a major source of material for the solder and the brass and bronze industries. The SCRI was funded by five domestic tinplate producers to advance the collection, preparation, and transportation of can scrap. SCRI maintained a program of having representatives in various regions of the United States work with municipalities, scrap dealers, and detinners to promote the recycling of tin cans. During 1993, SCRI announced that henceforth it would be called the Steel Recycling Institute (SRI). The name change reflected a broadening of its mission to encompass not only steel cans (which had been its sole focus since its 1988 inception), but all steel products ranging from appliances to cars. Since SRI's 1988 beginning, the steel can recycling rate grew from 15% to over 40% in 1993. SRI announced some landmark achievements for the previous year, 1992, including:

(1) For the first time ever, more than 1 million tons of steel cans (about 14 billion) was recycled domestically, resulting in a 41% recycling rate (up from 34% in 1991).

(2) In the 5 years through 1992, the recycling rate steadily increased, moving toward the steel industry's overall recycling rate of 66%.

(3) In 1992, more than 12 billion steel food cans were recycled. With a recycling rate of 44%, the steel food can continues to be the Nation's most recycled food container (in 1991, about 36% was recycled).

(4) The 1992 recycling rate for steel beverage cans (sometimes called bimetal cans) was about 50% (in 1991, about 46% was recycled).

(5) In 1992, about 15% of all steel "general line" cans (paint, aerosol, varnish, etc. cans) was recycled (in 1991, about 12% was recycled).

The SRI began an initiative calling for increased recycling of all empty paint and aerosol cans. SRI targeted these two types of containers as ones that municipalities operating curbside and dropoff recycling programs must include in their efforts if the steel industry is to reach its goal of recycling two out of every three steel cans by 1995. Paint cans and aerosol cans are categorized as "general-line" cans in the container industry, and steel cans hold a dominant market position in those styles. Recycling operators have displayed a reluctance heretofore to collecting used paint cans and aerosol cans due to the fact that some of them contain some residues that could be troublesome to remove. SRI cited two current studies, one by the Texas Water Commission and the other by S.C. Johnson Wax Co., that reportedly blunted such reluctance.

Consumption and Uses

Primary tin consumption remained about the same as that in 1992. All major consumption categories experienced similar demand as in 1992.

Tinplated steel and tin-free steel accounted for 26% of the 132 billion cans shipped domestically; aluminum accounted for 74%. This compared to 1992 figures showing steel accounting for 27% of the 131 billion cans shipped domestically and aluminum accounting for 73%. Aluminum held an overwhelming advantage in the beverage can market, while steel dominated in the food can and the "general-line" markets.

Bev-Pak Inc., headquartered in Des Plaines, IL, with production facilities in Monticello, IN, announced that effective in early 1994 it would be switching all of its three beverage can production lines to aluminum, thereby eliminating its status as a steel purchaser and a major producer of steel cans. The company started in the late 1980's and immediately forged for itself a special niche as a producer of steel cans. Bev-Pak had claimed about 50% of the domestic steel beverage can market and a 2% share of the total U.S. beverage can market. The beverage can market has been increasingly dominated by aluminum during the past 30 years. The company attributed the switch in materials to recently lowered prices for aluminum can sheet and to the end of its contracts with Coca-Cola, Pepsi Cola, and 7-Up, which had desired steel cans for certain steel-producing Midwestern States. Industry sources felt the switch by Bev-Pak represented about a 1% slice of the 4-million-ton-per-year tin mill products market. Another major firm in the beverage can market, the Ball Corp., based in Muncie, IN, had been for many years a major producer of steel cans but ceased its steel can manufacturing 2 years ago; Ball had steel can production lines in Ohio and Texas. Crown Cork & Seal Co., headquartered in Philadelphia, PA, still operated two steel can production lines that can be switched between aluminum and steel feedstocks.

U.S. Can Corp., headquartered in Oak Brook, IL, announced it has agreed to purchase Baltimore, Md-based, Steeltin Can Corp. and two affiliated firms. Steeltin is a regional producer of containers for the specialty food and paint markets. *(See tables 2, 3, and 4.)*

Markets and Prices

Marketing of tin metal in the United States was performed mostly through trading firms, which imported the tin from a variety of countries and warehoused the tin in this country until they sold it to customers. Foreign-owned trading firms tended to dominate the field. Most tin dealers were based in or near New York, NY. Some tin also was marketed directly in the United States by large foreign producers who maintained sales offices here and sold their tin metal, usually on a 1-year contract basis, only to the largest users. Foremost among these direct-sale operations was Indo-Metal Corp., which served as the exclusive North American sales outlet for tin metal produced by Indonesia's Government-owned tin production organization.

The price of tin metal, as published in Metals Week, generally declined rather steadily throughout the year, ending the year at 15% below the beginning price. The LME remained the primary trading focus for tin. The Kuala Lumpur Commodities Exchange in Malaysia continued as an active tin trading forum.

The London Metal Exchange (LME) announced that Pittsburgh, PA, would be its next U.S. warehouse location for approved delivery of all LME-traded metals (except copper), including tin. Although Pittsburgh was chosen as the locale, specific warehouse facilities there still needed to be chosen, inspected, and approved. Pittsburgh was the 10th U.S. location for LME-approved deliveries. In addition to tin, the warehouse was able to handle aluminum, lead, nickel, and zinc.

Foreign Trade

For the second consecutive year, Brazil was the major source of U.S. tin metal imports. Bolivia ranked second, followed by Indonesia, China, and Hong Kong (apparently a transhipper).

Imports increased substantially, perhaps in response to lower Government stockpile disposals.

Imports of tin in all forms (ore and concentrate, metal, and waste and scrap) remained free of U.S. duty. *(See tables 5, 6, and 7.)*

World Review

Australia.—The first stage of the Emmaville tin project in New South Wales was completed with the commissioning of the first of two tin concentration plants. Associated Gold Fields Ltd. and Q International Resources Ltd. each own 25% of the property, with the privately held New South Wales firm, Transit Mining Ltd., holding the remaining 50%. The project is now ready to enter its next phase with the construction of a second, larger concentrator at the mine. The projected facility, with a total capacity of 100 cubic meters (m^3) per hour, was expected to be operational by mid-1994. Once completed, the plant could produce about 130 tons of concentrates monthly compared with current output of about 20 tons monthly. Indicated reserves are 500,000 m^3, with 4 kilograms of tin per m^3. At full capacity, the project was expected to have a life of 3 years. The joint-venture partners partly lease and partly own the smaller concentrator but will fully own the second one. Concentrates were being sold to Malaysian smelters on a trail basis, with average grades of 70% tin.

Renison Consolidated Goldfields Ltd. announced that it was considering developing additional tin prospects at its underground mine in Tasmania. A new deposit, Rendeep, was identified below existing workings, and a feasibility study was commissioned with a yearend completion date. A 600-meter shaft would be needed to access the new prospect.

Belgium.—One of the few remaining European tin smelters, Metallo-Chimique, in Beerse, announced plans to increase production in 1993 to about 6,600 tons of refined tin from 5,000 tons in 1992. The firm also produces lead and copper from scrap sources around the world. Its total scrap consumption is estimated to be about 17,000 tons monthly.

Bolivia.—The executive director of the Government-owned mining organization, COMIBOL, announced that all but one of COMIBOL's mines may cease production soon. He attributed low metal prices for the organization's continued heavy losses. Some of the targeted mines were tin mines. The Colquiri Mine, a tin-zinc mine, may be one of them. COMIBOL intended to send invitations to tender for the construction of a new treatment plant at Colquiri to produce tin oxide. One tin mine that COMIBOL foreshadowed to remain open was the Huanuni Mine, which produces high-grade tin ore for the Vinto tin smelter.

The Government-owned smelting organization, Empresa Nacional de Fundiciones (ENAF), announced that it expected to produce about 19,000 tons of tin metal in 1993, including 4,000 tons for Peru's Minsur tin mine under a toll contract. The tin smelter at Vinto had raised production steadily since 1987, when output was only 2,600 tons out of a capacity of 25,000 tons. The smelter produces two grades of tin metal: A-1, which grades 99.5% tin and comprised 40% of output; and A-2, which graded 99.99% tin and comprised 60% of output. ENAF announced that the smelter's entire output had low lead content. About 70% of ENAF's output was exported to the United States, while another 20% remained in South America.

The Bolivian Supreme Court authorized the Bolivian Government to evict tin miners who had been occupying the Catavi tin mine. This paved the way for the Brazilian tin mining organization, Paranapanema, to begin working tin tailings at Catavi, which it had been leasing from COMIBOL since June 1992. The unlawful occupation of the mine had caused Paranapanema to suspend its operations for about 18 months. Paranapanema agreed to pay COMIBOL a 5% production royalty pegged to international tin prices. It reportedly planned to invest $8 million in the project and expected to construct a concentrator by mid-1995.

It was announced that Japan's Metal Mining Agency would continue drilling operations in 1993-94 in the Alto Colquiri area of Bolivia. Large reserves of lead, silver, tin, and zinc reportedly were confirmed there. The Japanese agency began undertaking geological and physical studies of the Colquiri area in 1991 as part of Japan's assistance program to Bolivia. Recent exploration excavation confirmed the existence of about 500,000 tons of ore containing 0.7% tin, 3.38% zinc, and 0.7% lead. In addition, an estimated 190,000 tons of reserves containing 0.5% tin, 1.12% zinc, and 0.14% lead was discovered as pits were dug deeper, and large veins believed to have a high content of tin and zinc were found. The drilling site was adjacent to the Colquiri Mine, owned by Bolivia's state-operated Corporacíon Minera de Bolivia (COMIBOL), whose reserves could be exhausted in less than 10 years.

Brazil.—The recently privatized Cia. Siderurgica Nacional (CSN), the country's largest steel producer, announced plans to invest $20 million to begin making thinner gauge tinplate. The aim was to better compete with a local aluminum smelter that supplied a Reynolds Aluminum plant here; the latter reportedly controlled 100% of the domestic beverage can market. CSN, which makes 0.15- to 0.26-millimeter-gauge tinplate mostly for motor oil cans, would begin making 0.11-millimeter-gauge tinplate in 1995 for two-piece cans for breweries and soft drink firms. To facilitate these developments, CSN signed a technical assistance agreement with Hoogovens Group (Holland) and was negotiating a similar agreement with Thyssen Steel AG (Germany).

The Metalurgica Matarazzo Group announced it would invest $35 million to build a plant to make 900 million steel cans annually. Matarazzo expected a future partnership with CSN involving tinplate and tin cans. CSN indicated that its studies in Brazil have shown no clear preference for one type (aluminum or steel) of metal can over the other, in contrast to the United States, where aluminum beverage cans predominated, and Europe where steel cans predominated.

Mineracão Canopus, the country's fourth largest tin mining company, announced plans to reduce output at its mines in Para State by 40%, in view of continued low tin prices. Canopus, a subsidiary of Brazil's Silex Trading, was expected to produce only 750 tons of tin metal this year. This is the second cut Canopus enacted in recent years; 2 years ago it cut output 20%, to 1,200 tons annually. Canopus indicated that because of the geological makeup of its mines, which were based on alluvial and rock cassiterite deposits, it was not economically worthwhile to mine at prices below $6,000 per ton. Reserves at its three mine sites were limited, so the firm wanted to defer exploiting them until the price went up. Canopus' ore was transported from Para State, in Amazonia, to São Paulo State for toll-smelting at SNA Minerios e Metais. The company indicated that it exported its entire output, mostly to Europe and the United States, with about 15% going to Argentina.

Cia. Estanifera do Brasil (Cesbra) announced it would continue to toll smelt tin concentrate in 1993 from Peru's Minsur tin mine, under a renewal of an agreement in operation for 2 years. The new 2-year renewal calls for the tin metal to be exported to the United States. Minsur also had some tin-in-concentrate toll smelted at Bolivia's ENAF smelter, with the balance of its mine output shipped to tin smelters in Malaysia.

Clear evidence emerged of continued smuggling of tin values from the Bom Futuro tin mine in Rondônia State. In one raid, Federal police seized 20 tons of cassiterite being smuggled from the mine site. The cassiterite was in almost 600 sacks, later held in a Federal police warehouse. Although cassiterite smuggling from Bom Futuro was generally thought to be much lower that 3 years ago, the 20-ton haul was described by Federal police as being "the tip of the iceberg."

Canada.—Rio Algon Ltd. announced that it was finalizing contract terms with a Toronto-based environmental services company for the destruction and reclamation of the facilities and land around the defunct East Kemptville tin mine in Nova Scotia. Dismantling was expected to start by yearend. The Provincial government of Nova Scotia had unsuccessfully sought an operator for the mine during the past year in an attempt to save the approximately 200 jobs the facility represented. Rio Algon officials estimated costs of about $10 million to tear down the buildings and restore the site. However, some reclaimable assets from the mill would reduce the net costs. Prior to its closure a few years ago, the mine was the largest tin mine in North America.

China.—Moves were underway to open the country's mining sector to more foreign investment. The Beijing Ministry of Geology and Mineral Resources and the United Nations sponsored a conference in May to consider suggestions on draft rules for foreign exploration and exploitation of mineral resources. The Government intended to grant 20-year permits, renewable for 10 years, to foreign firms to explore a maximum area of 100 km^2 for minerals. There would be no limit for regional geological, geophysical, and geochemical surveys and airborne remote sensing geological surveys. Under the draft law, foreign companies could explore either on their own or in partnership with Chinese organizations. The conference felt that China should speed up the exploration of its mineral resources to keep pace with the country's rapid economic growth, which was 12% last year and could exceed 10% this year.

The Kawasaki Steel Corp. (Japan) announced that it was nearing completion of a feasibility study for the construction of a new tinplating line in China. Kawasaki had been approached in late 1992 by officials from the Wuxi semi-integrated steelworks near Shanghai about building a tinplating line there. The Wuxi works currently produced only bar steel and reportedly desired to broaden its base to supply tinplate for food cans. The feasibility study reportedly included options to build a 60,000-, 100,000-, or 150,000-ton-per-year line.

The Nippon Steel Corp. (Japan) announced it had begun a feasibility study in China for the construction of tinplate manufacturing facilities in Guangzhou, Guangdong Province. The initiative was taken by the Guangdong Provincial government, which would like to have a plant able to make thin tinplate for food and beverage cans. The tin mills operating in China could only make heavy gauge tinplate.

Reports indicated that the new Shanghai Metals Exchange (SHME) became the world's third largest such exchange only 1 year after its opening. In its first year SHME traded 8 million tons of nonferrous metals. Volume totaled $27 billion. The SHME planned to increase domestic brokers from the present 55 to 68. It served more than 1,000 customers in China and planned to include foreign members by yearend. Tin was one of six metals traded on the SHME along with aluminum, copper, nickel, pig iron, and zinc.

France.—The Government announced plans to privatize several long-time Government-owned organizations, including Europe's largest steelmaker, Usinor Sacilor SA. Usinor ranked as one of the world's largest tin users for its sizable tinplate operations.

Germany.—The two largest German steelmakers, Thyssen and Krupp Hoesch, announced the merger of their tinplate, electrical steels, and stainless steels flat products operations. Officials were clear that this was not a precursor to merging the two steel giants. Under the new system, Thyssen would run the merged tinplate and electrical steels operations, while Krupp Hoesch would run the stainless flat products operations. The division of authority paralleled the partners' relative strengths. Thyssen's Rasselstein subsidiary has long been the leader in German tinplate production (its 1993 output of 670,000 tons per year represented about 70% of Germany's tinplate manufacture), while Krupp Hoesch was Germany's largest factor in stainless flat products.

Th. Goldschmidt AG acquired the tin chemicals operations of Rhône-Poulenc at Clamecy, France, and conditionally acquired Pitt Metals & Chemicals, Inc. in Pittsburgh, PA. The Pitt transaction was pending U.S. Government approval. Goldschmidt viewed its new acquisitions as complementing its existing production facilities in Germany and broadening its technology base. The firm's offerings soon would include the major inorganic compounds used mostly in metal finishing, as catalysts in chemical processes, stabilizers, and intermediate chemicals. Goldschmidt reportedly favored inorganic tin compounds in its product mix because of their environmental record and ease of recycling.

Hong Kong.—The financially ailing Mainland Metals and Minerals Co. was absorbed by a group of creditors. The creditors group comprised five firms: Cheerglory Traders, Pacific Capital, ING Bank, BRI Finance, and Zhu Kuan Co. A Mainland representative indicated that these five creditors have suspended their own claims to their debts, settled a number of outstanding debts to other customers, and planned to inject further capital as and when necessary. Mainland's production had ceased before the takeover; the smelter began again operating around the clock and producing at the rate of 5,000 tons yearly.

Indonesia.—Government-owned tin producer P.T. Tambang Timah announced it was continuing with a program of restructuring designed to maintain profitability despite eroding tin prices. The first phase of the restructuring began a few years ago and eliminated noncore business and social commitments such as schools for employees' children. Then the company relocated its administrative departments from Jakarta to the island of Bangka, where most mining and smelting operations were located. Timah credited these moves with speeding up decision making and reducing overhead. Also, technical improvements were made to production equipment and supporting facilities. The second phase of Timah's restructuring involves staff development, education, training, and more effective use of human resources. Timah anticipated 1994 tin production to be similar to that of 1993. All of Timah's domestic tin mine production was smelted at the firm's Bangka and Mentok tin smelters, which have a total capacity of about 32,000 tons annually. Most of the output (95%) is exported, with 50% going to Asian consumers and the balance to the United States and Europe.

Renison Consolidated Goldfields Ltd. (Australia) announced plans to expand its tin mining operations in Indonesia. It planned to raise output at its 75%-owned Indonesian subsidiary, P.T. Koba Tin, from 7,500 tons yearly to 10,000 by commissioning another dredging unit. The new dredger was to be similar to the Merapin unit already operating and was to start operations in late 1995. The dredger was operating in Malaysia, and Renison calculated it could take 28 months to decommission it and transport it to Indonesia. The dredger represented an investment of $14 million and followed the discovery of 10 years worth of additional tin reserves in the Bemban area of Indonesia. Average tin grades were said to be high, and Renison expected to effect a reduction in its already low operating costs as a result of the investment.

Japan.—Nippon Steel Corp., the world's largest steelmaker and perhaps the world's largest tinplate producer, reportedly was rapidly increasing the quantity of used steel cans it purchases for recycling at its Kimitsu plant. Since the start of 1993, the weight of cans recycled was reported to have increased to more than 1,000 tons monthly. Nippon, which started recycling used steel cans at Kimitsu in 1984, planned to reach a level of 2,000 tons recycled within 1 or 2 years.

Malaysia.—Malaysia Mining Corp. (MMC), once the world's largest tin mining organization, announced the imminent cessation of all domestic tin mining operations because of low tin prices. MMC announced that it would concentrate on its more lucrative diamond and gold properties, often in other countries. It was reported that MMC had been losing money on its tin operations for several years. In the early 1950's, Malaysia had about 1,000 tin mines, compared with fewer than 100 in 1993. At the start of 1993 MMC operated 10 dredges. Some observers faulted the absence of a vigorous tin exploration program to seek new higher grade deposits as the older deposits became excessively worked down to lower grade status. Other observers noted that Malaysia's fast growing economy created a situation where much potential mining land was economically unviable for mining because the surface value (for other economic pursuits) was much higher. MMC retained 42% ownership in Malaysia Smelting Corp., which was one of the country's two large tin smelters.

The Zemex Corp. (United States) announced that it had sold its 70% ownership of Perangsang Pasifik Senderian Berhad, its tin dredging operation in Malaysia, to Americo Co., an Oklahoma-based oil and gas producer.

Zemex had been known for many years as Pacific Tin Corp., then based in New York, NY. In recent years Zemex relocated its headquarters, changed its name, and restricted its operations to focus on industrial mineral, metal, and metal powder markets.

A consortium of 10 Malaysian tin mining organizations announced it would travel to Vietnam to discuss with local parties a possible joint venture to mine tin in Vietnam. The consortium included Osborne & Chappel International, GB Mining, Foo Nyit Tse & Brothers, Gopeng Mining, & Selangor Dredging. This new interest in Vietnam may have originated from discouraging prospects in Malaysia. Malaysia had long been the world's leading tin producer but now ranked sixth in world tin mine production behind China, Bolivia, Indonesia, Brazil, and Peru in 1993.

Netherlands.—Hollandsche Metallurgische Industrie Billiton (HMIB) announced the cessation of making tin chemicals, anodes, and granules. Billiton closed its tin smelter at Arnhem in 1992 and hoped the restricted operation would be able to concentrate on the downstream market effectively. However, recessionary conditions throughout Europe impeded sales of such products, especially tin tetrachloride, which was used in the making of polyvinyl chloride (PVC). In 1993, 30 people worked at HMIB. Production was expected to cease in early 1994.

Russia.—The Government announced that tin could be exported without special documentation or quotas as part of the Government's liberalization of foreign trade. Officials at the Novosibirsk Tin Works declared they would keep their traditional ties with state trader Raznoimport, but would also forge their own direct trading links. Much of Novosibirsk's activities involved toll smelting deals for Portuguese and British tin mines. Novosibirsk reportedly was a 35,000-ton-per-year-capacity tin smelter currently operating at 60% of capacity. Like many metallurgical operations in Russia, it has been struggling with large price increases in energy and transport. Reports indicated that the Novosibirsk tin smelter was exporting to Europe freshly toll-smelted tin ingots as well as some material believed to be from old smelter inventory. This tin was reportedly mostly of three nines quality and was being offered at discounts of $30 to $70 per ton to the LME cash price. Toward yearend, plans were underway to privatize the smelter. Overseas investment in the smelter remained a future possibility.

South Africa, Republic of.—The Rooiberg Tin Co. announced that it would be monitoring the financial viability of its tin mining operations. Rooiberg had implemented a survival plan in 1992 to stave off possible closure while instituting a rehabilitation program. Under the plan, mining operations were refocused on high-grade ore reserves, and mine throughput was cut from 15,000 tons to 6,000 tons monthly. The company continued to operate at that level, which led to lower refined metal production at the Rooiberg smelter. Refined metal production was running at only 450 tons yearly, with a smelter capacity of 2,000 tons yearly. The smelter's output was consumed entirely in the domestic market. Earlier concerns that Rooiberg's higher-grade reserves would be exhausted soon were eased by the finding of new ore reserves. These new reserves gave the mine an operating expectancy of up to 5 years.

Thailand.—Once ranked in the top echelon of world tin producers, reports reflected the compression of mining activity in the country, a result of low tin prices. The Government's Department of Mineral Resources announced that 86 tin-mining operations were forced to stop production in 1991 and 1992, with a loss of 1,400 jobs. Thailand's largest tin smelter, Billiton's Thailand Smelting and Refining Co. (Thaisarco), reported that its use of domestic ore declined by 42%, to 2,840 tons, in the first half of 1993, while imports of tin concentrates rose by 155%; overall, ore consumption was down by 20% in the same period. Thaisarco's output was expected to reach 8,000 tons in 1993; 4,595 tons was produced in the first half. About 60% of this output was used domestically, while most tin exports went to Japan.

United Kingdom.—British Steel Corp. announced the commissioning of a wide tinplate coil line at its Trostre, Wales, Tin Mill. The $75 million line would allow the plant to produce tinplate coils in widths up to 122 centimeters, up from the current 99 centimeters. The Trostre plant would have the capability of producing up to 212,000 tons of the new, wider coil annually. The wider coils increasingly were preferred by beverage can makers. British Steel was Europe's second largest and the world's fourth largest steelmaker.

The Cookson Group, headquartered in London and the world's largest solder producer, announced it would reorganize its solder operations by merging two of its major U.S.-based firms: Federated-Fry Metals Inc., mostly an industrial solder producer, and Alpha Metals Co., primarily an electronic soldermaker. The new company would be called the Alpha-Fry Group and would continue to market all brand names currently available from each firm.

British Steel Corp. launched a new steel top for beverage cans, which stems from joint research work with Hoogovens (the Netherlands) and Rasselstein (Germany), two other large tinplate producers. The new top is designed to counter aluminum's position in the container market. The top, with a twin push-button operating system, was being introduced with a standard can body. But the three partners expected to have a 30% lighter body available next year. The brand name, "ECOTOP," was selected by British Steel to illustrate the environmental advantage it felt steel cans have over aluminum.

Current Research

In the United States, Dentsply International Corp., Milford, DE, a major supplier of dental alloys (amalgams), announced a collaboration between itself and the National Institute of Standards and Technology (NIST) to produce a mercury-free direct-filling alternative for conventional dental amalgams. Their joint work involved a process based on earlier NIST electrochemical powder technology. The alternate material involved the use of biocompatible metallic powders (e.g., silver-coated tin). The pairs of metals underwent fast diffusion to form an in situ intermetallic compound at body temperature. Although silver and tin were the principal ingredients, other formulations containing copper and gold also were being examined.

In the United States, Airco Gases Co., Murray Hill, NJ (a subsidiary of BOC Ltd., United Kingdom), announced it had three patents pending for the development of a controlled nitrogen atmosphere system for wave soldering applications. The system was said to virtually eliminate dross formation and to require less flux. Solder represented one of the major uses of tin.

In the United States, researchers at Rockefeller University, New York, NY, announced development of a new drug containing tin that appeared to cure babies suffering from jaundice, a common and potentially dangerous ailment in newborn infants. Tin-mesoporphyrin (SnMP) reportedly blocked the production of bilirubin, the yellow pigment from unprocessed bile that in instances of jaundice builds up in the blood faster than the baby's liver can process it. Severe cases of bilirubinemia can lead to brain damage or harm the central nervous system. The new drug was a synthetic chemical relative of heme, the iron-containing pigment in red blood cells. The SnMP molecule contained tin instead of iron.

In Japan, Sumitomo Light Metal Industries Ltd. announced development of a copper water supply tube with pure tin. The newly developed tube, marketed as Super Tin Coat (STC), was tested for 2 years in Hokkaido, Ibaragi Prefecture, with impressive results.

In the United Kingdom, the International Tin Research Institute (ITRI), funded by the Association of Tin Producing Countries (ATPC), announced it was progressing on several fronts in identifying potential new end uses for tin and developing existing technologies, as follows:

(1) For tinplate, ITRI was attempting to improve deposition techniques used in the passivation process that enhances corrosion resistance and lacquer adhesion.

(2) For solder, ITRI is investigating lead-free solders and higher grade pastes for miniature and surface-mounted electronic applications. Several low-lead or lead-free solders developed by ITRI with financial assistance from the British Government were being evaluated. ITRI hypothesized that if these solders, which contained about 90% tin, were to replace conventional 60% tin solders, world tin consumption in the solder category could increase by 20,000 tons yearly.

(3) In the categories of tin utilized for tinning and specialized alloys, which ITRI feels may account for 19% of world tin consumption, ITRI research focused on reducing the environmental impact of tin-nickel and tin-zinc coating and plating processes.

(4) In the field of tin chemicals, ITRI investigated the use of tin compounds in fire retardants, pigments, and paints; in all three fields, tin made inroads commercially. Tin-zinc compounds reportedly were less combustible and also emit less toxic fumes and tars than other retarding agents. ITRI projected the potential tin market could be quite large, perhaps tens of thousands of tons annually.

(5) In a new market, cooperation between ITRI and companies in Germany, Portugal, and Spain led to the development of a tin-only bottle capsule (primarily for wine) to capitalize on concerns about lead contamination in traditional capsules.

OUTLOOK

Domestic demand for primary tin is expected to grow slowly in the next few years, at a rate of perhaps 1% per year. However, new applications, especially those in which tin is substituted for toxic materials, could double that rate as early as 1996.

As long as the price of tin remains historically low, there appears to be little incentive to explore or develop domestic tin reserves. Thus, it is highly likely that domestic requirements for primary tin will continue to be met by imports and Government stockpile sales.

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[1] Can Manufactures Institute. Metal Can Shipment Report 1993. Washington, DC, 1993, pp. 1-4.

TABLE 1
SALIENT TIN STATISTICS

(Metric tons unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Production:					
Mine	W	W	W	W	W
Smelter	[e]1,000	—	—	—	—
Secondary[e]	14,340	17,187	[r]13,096	[r]13,747	13,449
Exports[1]	904	658	970	1,888	2,598
Imports for consumption:					
Metal	33,988	33,810	29,102	27,314	33,682
Ore (tin content)	216	—	1	—	—
Consumption:					
Primary	36,609	36,770	35,138	[r]34,983	34,973
Secondary	9,854	8,395	9,667	10,137	12,134
Stocks, yearend, U.S. industry	14,668	17,304	13,812	[r]10,715	10,865
Prices, average cents per pound:					
New York market	397.28	287.69	258.75	282.58	239.17
Metals Week composite	520.18	386.29	362.85	402.40	349.80
London	382.00	281.00	254.00	277.00	233.00
Kuala Lumpur	387.12	276.02	248.42	271.85	231.58
World: Production:					
Mine	[r]232,857	[r]218,057	[r]196,272	[r]178,365	[e]178,207
Smelter:					
Primary	[r]221,569	[r]223,310	[r]190,107	[r]186,585	[e]183,822
Secondary	[r]20,259	[r]17,983	[r]13,211	[r]8,710	[e]7,935
Undifferentiated	[r]3,896	[r]4,830	[r]1,722	[r]2,720	[e]1,235

[e] Estimated. [r] Revised. W Withheld to avoid disclosing company proprietary data; U.S. mine production for 1989-93 was negligible.

[1] Excludes reexports.

TABLE 2

U.S. CONSUMPTION OF PRIMARY AND SECONDARY TIN

(Metric tons)

	1989	1990	1991	1992	1993
Stocks, Jan. 1[1]	9,242	13,551	12,502	[r]12,038	8,556
Net receipts during year:					
Primary	37,760	38,473	36,126	[r]34,327	38,044
Secondary	10,901	9,501	1,622	2,279	3,470
Scrap	8,168	6,534	8,370	8,412	8,768
Total receipts	56,829	54,508	46,118	[r]45,018	50,282
Total available	66,071	68,059	58,620	[r]57,056	58,838
Tin consumed in manufactured products:					
Primary	36,609	36,770	35,138	[r]34,983	34,973
Secondary	9,854	8,395	9,667	10,137	12,134
Total	46,463	45,165	44,805	[r]45,120	47,107
Intercompany transactions in scrap	424	316	275	267	165
Total processed	46,887	45,481	45,080	[r]45,387	47,272
Stocks, Dec. 31 (total available less total processed)	19,184	22,578	13,540	[r]11,669	11,566

[r] Revised.

[1] Includes tin in transit in the United States.

TABLE 3

U.S. CONSUMPTION OF TIN, BY FINISHED PRODUCT

(Metric tons of contained tin)

Product	1992			1993		
	Primary	Secondary	Total	Primary	Secondary	Total
Alloys (miscellaneous)[1]	W	W	W	W	W	W
Babbitt	[r]625	291	[r]916	486	337	823
Bar tin	[r]919	W	[r]919	946	W	946
Bronze and brass	1,271	1,645	2,916	1,489	1,604	3,093
Chemicals	6,301	—	6,301	6,446	W	6,446
Collapsible tubes and foil	W	W	W	W	W	W
Solder	[r]11,537	6,924	[r]18,461	11,256	8,205	19,461
Tinning	[r]1,152	123	[r]1,275	1,249	W	1,249
Tinplate[2]	9,821	W	9,821	9,765	W	9,765
Tin powder	573	W	573	608	W	608
Type metal	W	W	W	W	W	W
White metal[3]	974	W	974	789	W	789
Other	1,810	1,154	2,964	1,939	1,988	3,927
Total	[r]34,983	10,137	[r]45,120	34,973	12,134	47,107

[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 4

U.S. INDUSTRY YEAREND TIN STOCKS

(Metric tons)

	1989	1990	1991	1992	1993
Plant raw materials:					
Pig tin:					
Virgin[1]	6,807	10,671	10,339	[r]6,831	7,542
Secondary	2,253	795	863	646	654
In process[2]	1,032	1,101	1,000	1,268	1,188
Total	10,092	12,567	12,202	[r]8,745	9,384
Additional pig tin:					
Jobbers-importers	3,536	2,467	742	1,117	679
Afloat to United States	1,040	2,270	868	853	802
Total	4,576	4,737	1,610	1,970	1,481
Grand total	14,668	17,304	13,812	[r]10,715	10,865

[r] Revised.

[1] Includes tin in transit in the United States.

[2] Data represent scrap only, tin content.

TABLE 5

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TIN, TIN MANUFACTURES, TINPLATE AND TERNEPLATE, AND TINPLATE SCRAP

Year	Miscellaneous tin and tin manufactures			Tinplate and terneplate		Tin compounds		Tinplate scrap	
	Tinfoil, tin powder, flitters, metallics, tin and manufactures, n.s.p.f.	Dross, skimmings, scrap, residues, tin alloys, n.s.p.f.							
	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991	$2,516	6,804	$33,132	284,783	$195,659	340	$2,698	10,109	$2,240
1992	2,333	10,567	57,875	[r]295,231	200,534	510	3,883	28,500	7,070
1993	5,299	8,280	25,006	237,356	160,714	431	3,145	12,559	1,424

[r] Revised.

Source: Bureau of the Census.

TABLE 6

U.S. EXPORTS OF TIN, TINPLATE, AND TERNEPLATE IN VARIOUS FORMS, INGOTS, PIGS AND TIN SCRAP

Year	Tinplate and terneplate		Ingots and pigs		Tin scrap and other tin bearing material except tinplate scrap[1]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1991	150,187	$89,677	970	$5,455	121,359	$85,708
1992	272,549	162,302	1,888	8,957	127,191	89,298
1993	200,794	120,068	2,598	11,377	92,585	63,240

[1] Includes rods, profiles, wire, powders, flakes, tubes, and pipes.

Source: Bureau of the Census.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF UNWROUGHT TIN METAL, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	300	$1,684	—	—
Belgium	1	10	1	$9
Bolivia	4,623	26,269	8,027	41,137
Brazil	8,167	49,597	11,366	57,749
Burma	21	112	40	215
Chile	521	2,883	714	3,149
China	5,389	31,136	4,202	22,395
Hong Kong	377	2,082	1,808	10,016
India	59	348	20	90
Indonesia	3,854	23,283	5,678	29,940
Malaysia	2,799	18,072	846	4,657
Mexico	212	1,310	572	2,945
Russia	—	—	40	213
Singapore	320	1,984	220	1,100
Thailand	427	2,783	—	—
United Kingdom	(1)	15	6	54
Other	244	1,455	143	828
Total	27,314	163,023	[2]33,682	174,497

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 8
TIN: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Argentina	405	[r]123	[r]—	[r]—	—
Australia[2]	7,709	7,377	5,700	6,400	[3]8,042
Bolivia	15,849	17,249	16,830	[r]16,516	[3]18,634
Brazil	50,232	[r]39,149	[r]29,253	[r]27,500	25,900
Burma[4]	501	653	518	[e]710	500
Burundi[e]	50	54	74	[r]110	50
Cameroon[e]	3	3	3	3	3
Canada	2,790	2,828	4,455	—	—
China[e]	40,000	42,000	[r]42,100	43,000	46,000
Czechoslovakia[5]	[r]468	[r]590	[r]15	[r]—	—
Germany: Eastern states	2,413	1,806	118	—	—
Indonesia	31,263	30,200	30,061	[r]29,400	29,000
Kazakhstan	—	—	—	[e]500	500
Laos[e]	[3]127	[3]500	300	300	300
Malaysia	32,034	28,468	20,710	14,339	[3]10,384
Mexico	[r]11	[r]5	[r]12	[r]1	1
Mongolia	1,200	320	[r]250	[r]190	150
Namibia	1,120	900	11	[r]11	—
Niger	71	38	20	[e]20	20
Nigeria[6]	[r]217	[r]192	[r]217	[r] [e]186	186
Peru	5,082	5,134	6,559	[r]10,195	13,700
Portugal	63	[r]1,300	[r]3,100	[r]3,000	5,300
Russia	—	—	—	[r] [e]6,000	5,000
Rwanda[e]	[r] [7]767	[7]734	730	[r]500	400
South Africa, Republic of	1,306	1,140	1,042	582	600
Spain	56	27	[r]12	[r]11	—
Tanzania[e]	15	15	6	5	5
Thailand	14,922	14,635	14,937	[r]11,484	7,000
Uganda[e]	10	25	25	[r] [3]30	30
U.S.S.R.[e] [8]	16,000	15,000	13,500	—	—
United Kingdom	3,846	3,400	2,326	[r] [e]2,000	1,500
United States	W	W	W	W	W
Vietnam[e]	850	850	800	[r]3,400	3,500
Zaire	2,346	2,221	[r]1,522	[r]1,020	700
Zambia	1	[r]1	6	[r]2	2
Zimbabwe[e]	1,130	1,120	1,060	[r]950	800
Total	[r]232,857	[r]218,057	[r]196,272	[r]178,365	178,207

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

[1] Contained tin basis. Table includes data available through July 19, 1994.

[2] Excludes tin content of copper-tin and tin-tungsten concentrates.

[3] Reported figure.

[4] Includes content of tin-tungsten concentrate.

[5] Dissolved Dec. 31, 1992.

[6] Concentrate gross weight reported, estimated 62% Sn content.

[7] Concentrate gross weight reported, estimated 70% Sn content.

[8] Dissolved in Dec. 1991.

TABLE 9

TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993•
Argentina:					
Primary	311	•180	[r]240	[r] •140	145
Secondary•	100	100	100	100	100
Total•	411	280	340	240	245
Australia:					
Primary	424	312	268	•250	250
Secondary•	300	200	300	250	250
Total•	724	512	568	500	500
Belgium: Secondary	5,976	6,063	4,426	•5,260	5,000
Bolivia: Primary	9,448	12,567	14,663	[r]14,393	16,700
Brazil:					
Primary	44,240	37,580	25,776	•30,000	30,000
Secondary•	250	250	250	250	250
Total•	44,490	37,830	26,026	30,250	30,250
Bulgaria:[2]	64	64	[r]22	[r]20	20
Burma: Primary	171	275	157	[r]189	150
Canada: Secondary•	200	200	200	200	200
China: Primary•	29,500	35,000	[r]36,400	[r]39,600	43,000
Czech Republic:[3] Primary and secondary	—	—	—	—	115
Czechoslovakia:[4] Primary	562	613	118	[r]115	—
Denmark: Secondary•	100	100	100	100	100
Germany: Primary and secondary	3,770	[r]3,362	700	[r]700	100
Greece: Secondary•	[r]800	[r]700	[r]200	[r]200	200
India: Secondary•	200	200	200	200	200
Indonesia: Primary	29,916	30,389	30,415	[r]31,915	30,000
Japan: Primary	808	816	716	821	800
Korea, Republic of: Primary•	800	800	600	400	400
Malaysia: Primary	50,874	[r]49,067	42,722	[r]45,598	42,000
Mexico: Primary	4,752	5,004	2,262	[r]1,907	2,000
Netherlands:					
Primary	4,529	[r]5,900	4,800	[r]—	—
Secondary•	[r]200	[r]200	200	[r]200	200
Total•	[r]4,729	6,100	5,000	[r]200	200
Nigeria: Primary	258	227	246	220	220
Norway: Secondary•	100	100	90	90	90
Portugal: Primary and secondary•	62	[5]1,404	[r]1,000	2,000	1,000
Russia:[6]					
Primary	—	—	—	[r] •6,000	5,000
Secondary	—	—	—	[r] •1,500	1,000
Total	—	—	—	[r] •7,500	6,000
Singapore: Primary•	[r]3,000	[r]2,500	[r]600	—	—
South Africa, Republic of:					
Primary	1,306	1,140	1,042	592	450
Secondary•	80	70	70	60	45
Total•	1,386	1,210	1,112	652	495

See footnotes at end of table.

TABLE 9—Continued
TIN: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Spain:[e]					
Primary	[5]1,767	600	[r]600	600	500
Secondary	200	200	200	200	200
Total	1,967	800	[r]800	800	700
Thailand: Primary	14,571	15,512	11,255	[r]10,679	9,000
U.S.S.R.:[e] [6] [7]					
Primary	18,000	16,000	13,000	—	—
Secondary	4,000	3,700	3,300	—	—
Total	22,000	19,700	16,300	—	—
United Kingdom:					
Primary	3,584	[r] [e]6,100	1,661	—	—
Secondary	7,184	[r] [e]5,900	3,575	100	100
Total	10,768	[r] [e]12,000	5,236	100	100
United States:					
Primary	1,000	—	—	—	—
Secondary	569	W	W	W	W
Total	1,569	W	W	W	W
Vietnam: Primary[e]	800	[r]1,800	[r]1,700	[r]2,400	2,500
Zaire: Primary[e]	100	90	70	[r]50	50
Zimbabwe: Primary	848	838	796	[r]716	[5]657
Grand total	[r]245,724	[r]246,123	[r]205,040	[r]198,015	192,992
Of which:					
Primary	[r]221,569	[r]223,310	[r]190,107	[r]186,585	183,822
Secondary	[r]20,259	[r]17,983	[r]13,211	[r]8,710	7,935
Undifferentiated	[r]3,896	[r]4,830	[r]1,722	[r]2,720	1,235

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

[1]Data for 1989 and 1990 are derived in part from UNCTAD. Wherever possible, total smelter output has been separated into primary (from ores and concentrates) and secondary (tin metal recovered from old scrap). This table reflects metal production at the first measurable stage of metal output. Table includes data available through July 19, 1994.

[2]May include some secondary metal.

[3]Formerly part of Czechoslovakia; data were not reported separately until 1993.

[4]Dissolved Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from the Czech Republic.

[5]Reported figure.

[6]All production in the U.S.S.R. from 1989-91 came from Russia.

[7]Dissolved in Dec. 1991.

TITANIUM

By Joseph M. Gambogi

Mr. Gambogi, a physical scientist with 11 years of Government and industry experience, has been a commodity specialist since 1988. Domestic survey data were prepared by Robin Kaiser, statistical assistant; and international data tables were prepared by David Mann, Section of International Data.

Titanium (Ti) is a lightweight metal well known for corrosion resistance and its high strength-to-weight ratio. Titanium comprises about 0.62% of the Earth's crust and occurs primarily in the minerals, anatase, brookite, ilmenite, leucoxene, perovskite, rutile, and sphene. Although titanium is best known for its use as a metal alloy, titanium is primarily used in the form of titanium dioxide (TiO_2), widely used as a white pigment in paints, paper, and plastics. Other minor uses of titanium minerals include ceramics, chemicals, welding rod coatings, heavy aggregate, and steel furnace flux.

Although the supply and demand of titanium products moved toward a balance in 1993, the past year was a year of consolidation in the global titanium industries. The TiO_2 pigment industry operated at capacity utilization rates estimated at less than 90%, and several pigment producers delayed capacity expansions or acquired existing operations rather than proceeding with planned expansions. Meanwhile, heavy-mineral producers scaled back production levels at various locations to better align themselves with demand by the pigment industry. In the titanium metal industry, depressed aerospace markets kept demand for titanium metal products to less than one-half of what it was just a few years ago. Several titanium metal producers closed reduction, melting, and fabrication facilities.

In 1993, the United States was a net importer of titanium concentrates and a net exporter of titanium pigment and metal products. Domestic consumption of titanium concentrates increased by 1.2% on a gross weight basis or 0.3% based on TiO_2 content. Production of TiO_2 pigment exceeded the 1992 level by 2.2%, while apparent consumption of TiO_2 pigment increased by 2.9%. Titanium ingot production decreased by 0.7%, while ingot consumption increased by 7.2%. Production of titanium sponge was withheld to avoid disclosing company proprietary data. *(See table 2.)*

DOMESTIC DATA COVERAGE

Consumption data for titanium raw materials are developed by the U.S. Bureau of Mines (USBM) from one voluntary survey of domestic operations. Of the 31 operations canvassed, 26 responded, representing more than 99% of the data in table 7. Data for nonrespondents were estimated based on prior-year consumption levels.

BACKGROUND

Definitions, Grades, and Specifications

Ilmenite is the most abundant titanium mineral, with the chemical formula $FeTiO_3$, and theoretical composition of 52.7% TiO_2 and 47.3% FeO. However, the term "ilmenite" also is used to include material that has been oxidized and leached during weathering, containing up to 70% TiO_2, about 25% to 30% iron oxides, and about 5% of oxides of other elements. When the alteration is extreme, the residual material is essentially amorphous to finely crystalline TiO_2 and is called leucoxene.

Rutile is essentially crystalline TiO_2, and commercial concentrates usually contain about 95% TiO_2. Synthetic rutile or rutile substitutes are derived from ilmenite by processes involving oxidation and reduction treatments followed by leaching of iron. Synthetic rutile concentrates approach rutile in chemical composition but, being residual leached grains, are porous and composed of very fine crystallites, while natural rutile grains are usually single crystals. Anatase also is crystalline TiO_2, but has a different crystal structure than rutile. Although research is ongoing, anatase is not a suitable feedstock for pigment production.

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 1993 were 80% TiO_2 slag from Sorel, Quebec; 85% TiO_2 slag from Richards Bay, Republic of South Africa; and 75% TiO_2 slag from Tyssedahl, Norway.

Titanium tetrachloride ($TiCl_4$), the intermediate compound from which titanium metal and chloride-process TiO_2 are manufactured, is a colorless to pale yellow liquid at room temperature, with a boiling point of 136° C.

Titanium sponge metal is the primary metal form obtained by vapor-phase reduction of $TiCl_4$ with magnesium or sodium metal. It is called sponge because of its appearance and high porosity. Most titanium ingot for forging into billet and mill products is obtained by melting sponge in a vacuum-arc furnace, with or without scrap titanium or alloying additions.

Titanium dioxide pigment is characterized by its purity, refractive index, particle size, and surface properties. The particle size is critical and must be closely controlled within the range of about 0.2 to 0.4 micron to develop optimum pigment properties. The superiority of TiO_2 as a white pigment is mainly due 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 is less reactive with paint vehicles in sunlight than anatase pigment and is preferred for use in outdoor paints. Anatase pigment has a bluer tone than the rutile type, is somewhat softer, and is used mainly in indoor paints and in paper manufacturing.

There are no rigid specifications for raw materials to be used as feed for making $TiCl_4$ for metal or pigment manufacture, or for ilmenite or slag to be used in the sulfate pigment process. However, certain impurities such as chromium, columbium, manganese, phosphorus, and vanadium can seriously impair pigment properties, so these impurities are an important consideration in the selection of concentrates for pigment production. Concentrates to be used for making $TiCl_4$ should be low in calcium and magnesium, which form high-boiling-point chlorides that cause trouble in fluid-bed chlorinators.

Industry Structure

On a gross weight basis, about 40% of the world's TiO_2 feedstocks are supplied by three titanium slag producers: Richards Bay Minerals (RBM), the Republic of South Africa; QIT Fer et Titane Inc., Canada; and Titania A/S, Norway. The remaining 60% of demand is supplied by producers of ilmenite and rutile concentrates (both natural and synthetic). Most of the production facilities for these concentrates are found in Australia, India, Malaysia, Norway, Sierra Leone, and the Republic of South Africa. Some of the largest producers of these feedstocks are Cable Sands Ltd., Consolidated Rutile Ltd. (CRL), Indian Rare Earths Ltd. (IREL), Renison Goldfields Consolidated Ltd. (RGC), Sierra Rutile Ltd., the TiWest joint venture, and Westralian Sands Ltd.

World TiO_2 pigment output in 1993 came from about 60 separate facilities ranging in annual capacity from a few thousand metric tons to nearly 300,000 tons. The world's four largest TiO_2 pigment producers are E. I. du Pont de Nemours & Co. Inc. (Du Pont), SCM Chemicals Inc., Tioxide Group PLC, and Kronos Inc. These four companies own or control about 60% of world capacity. Another 20% of world capacity is divided between Bayer AG, Ishihara Sangyo Kaisha, Kemira Oy, Kerr-McGee Chemical Corp., Sachtleben Chemie GmbH, and Thann et Mullhouse. The remaining 20% of world capacity was divided between about 20 other producers. An estimated 40% of the world's capacity is in North America while about 39% is in Europe (Eastern and Western).

There are 10 major producers of titanium sponge in the world. In Japan there are three producers: Sumitomo SiTix Corp. Ltd., Showa Titanium Co. Ltd., and Toho Titanium Co. Ltd. In the United States, there are two producers, Oregon Metallurgical Corp. (Oremet) and Titanium Metals Corp. of America (TIMET). The United Kingdom's one sponge producer is Deeside Titanium Co. China has one known producer in Shanghi. Within the former U.S.S.R., there are producers at Berezniki, Russia; Ust Kamenogorsk, Republic of Kazakhstan; and Zaporozhe, Ukraine.

The titanium mining and pigment industries are moderately integrated from raw materials to semifinished products. Most of the sponge metal producers do not own their own titanium mine. In the United States, one metal producer purchases mineral concentrates for the production of titanium sponge, while the other domestic producer purchases $TiCl_4$.

Technology

Exploration.—Hard-rock ilmenite deposits, because of their inherent magnetic properties, are readily amenable to the application of aero- and ground-magnetic geophysical surveys. These deposits generally respond to such surveys by reflecting abnormally positive magnetic intensities, although in some cases negative magnetic anomalies may result. Once such anomalies are mapped, further exploration may take place in the form of detailed geological observations and ultimately drilling to test the anomalies and delineate the associated ilmenite deposit.

If initial diamond drilling indicates an economic deposit, development drilling proceeds on a set grid pattern of about 100 meters. Intermediate holes are drilled to fill in major gaps in information on geologic structure or ore continuations. Drill cores are visually logged and split for chemical assay to determine TiO_2 and iron content.

Sand deposits of titanium minerals are mostly near continental margins where erosion of regional granitic and metamorphic rocks containing ilmenite and rutile has led to accumulation of these minerals in coastal plain sediments. Working and reworking of these sediments by ocean waves on beaches and in streams resulted in various degrees of sand sorting and concentration by particle size, density, and resistance to abrasion. Well-sorted sands are much more likely hosts for ilmenite, rutile, and other heavy minerals than are unsorted sands.

Titanium minerals are dark in color, and their concentration in predominantly quartz sands is often readily visible. Initial discovery has often been made through surface observation. In exploration, hand panning of samples has been a very useful exploration tool. Some titanium mineral ore bodies are detectable by ground or airborne magnetometer surveys or, if monazite or zircon is present, by low-level radiometric surveys.

Drilling to determine the extent of sand deposits in the first phase of development should be done to a depth of at least 15 meters and preferably 30 meters. The type of drill needed will depend on the nature of the ground, including the presence of clay, hardpan, roots, stumps, and other organic material, as well as the depth of the water table.

Approximate minimum requirements

for an economic sand deposit of titanium minerals include reserves of 300,000 to 1 million tons of TiO_2 content in rutile or ilmenite; and heavy-minerals content in the ore of 1% to 5%, depending on the mix of ilmenite, rutile, and other valuable minerals.

Mining and Concentration.—For mining sand deposits of titanium minerals, a dredge is usually used. This may be bucket-ladder type but is more likely to be suction type. The dredge floats in its own pond, digging forward and stacking tailings aft. Rough concentration, the separation of heavy minerals from the lighter quartz-feldspar-mica fraction, is usually accomplished by wet-gravity methods. The Humphreys spiral has been standard for this separation since its introduction about 1940, but pinched-sluice separators of various designs also have been used. The Reichert cone concentrator, which operates on the pinched-sluice principle, has been successful for large-tonnage operations. Flotation also has been used to some degree. For separating the minerals from stream-type deposits, jigs usually are chosen because they are the concentrating device least sensitive to extreme grain-size variation.

The final wet-mill concentrate is dried, usually in a rotary kiln, prior to further treatment. The subsequent flowsheet depends on the mineral assemblage to be treated. Ilmenite and rutile are usually removed together by electrostatic separation. The ilmenite-rutile conductor fraction of dried wet-mill concentrate is then subjected to high-intensity magnetic separation, yielding a final ilmenite product. The rutile fraction is further cleaned by screening and additional electrostatic separation. Zircon and monazite products are recovered from the nonconductor fraction of the wet-mill concentrate by a combination of gravity, electrostatic, and high-intensity magnetic separation.

Ilmenite is also mined from two hard-rock deposits, one in Canada, and one in Norway. The ore bodies are massive, and open pit mining is practiced. At Tellnes, Norway, the ore is crushed, ground, and subjected to wet-magnetic separation to recover magnetite. An ilmenite concentrate containing about 44.5% TiO_2 is recovered by flotation of the nonmagnetic portion, as was formerly done at the MacIntyre Development, Tahawus, NY, where ilmenite mining ceased in 1982. At Allard Lake, Quebec, ore at 32% to 36% TiO_2 is shipped from the mine to the beneficiation plant at Sorel, Quebec; some of the ore is shipped to steel companies as a substitute for fluorspar flux. For upgrading to slag, the ore is crushed and ground, concentrated by gravity methods, roasted to remove sulfur, mixed with a reducing agent, and smelted in an electric arc furnace. A high-purity pig iron is produced. The titanium is concentrated in the slag, known as Sorelslag, which contains 80% TiO_2. 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 aforementioned impurities, the Richards Bay slag is acceptable for manufacturing $TiCl_4$ and is also a feed material for the sulfate pigment process.

Materials made from ilmenite that have a TiO_2 content approaching that of natural rutile are known as synthetic rutile or beneficiated ilmenite. Processes to produce rutile substitutes from ilmenite fall into three general classes: those in which the iron is completely reduced to metal and separated from the reaction mass either physically or chemically, those in which iron is reduced to the ferrous state and chemically leached away from the titanium, and those in which the ilmenite is selectively chlorinated to remove iron and other impurities. Richards Bay slag also may be regarded as a rutile substitute because of its high grade (85% TiO_2) and suitability for the manufacture of $TiCl_4$.

Pigment Production.—Titanium dioxide pigment is produced commercially by two methods that require different raw materials. In the sulfate process, ilmenite or titanium slag is reacted with sulfuric acid, a portion of the iron sulfate formed may be crystallized and removed, and titanium hydroxide is precipitated by hydrolysis, filtered, and calcined. In the chloride process, rutile is converted to $TiCl_4$ by chlorination at 850° to 950° C in the presence of petroleum coke. All U.S. commercial chloride-process plants use fluid-bed chlorinators, although static-bed systems can be used for this purpose.

Titanium tetrachloride so prepared may be used either in making pigment, or with additional purification, for reduction to metal. In making pigment, the $TiCl_4$ is oxidized with air or oxygen at about 1,000° C, and the resulting fine-size TiO_2 is calcined at 500° to 600° C to remove residual chlorine and any hydrochloric acid that may have formed in the reaction. Aluminum chloride is added to the $TiCl_4$ to ensure that virtually all of the titanium is oxidized in the rutile crystalline form. Recoveries of TiO_2 in pigment are approximately 90% and 80% to 85% for chloride process and sulfate process plants, respectively.

Metal Production.—Feed materials needed for metal production are similar to those for chloride-process pigment because the formation of $TiCl_4$ is required in both cases. Titanium sponge is produced by reducing $TiCl_4$ with sodium or magnesium under an inert atmosphere at temperatures up to 1,040° C. Residual chlorides are removed by vacuum distillation, inert gas sweep, or after cooling and crushing, by leaching in very dilute acid. The sponge is compacted, usually with some scrap and alloying additions, and made into ingot by two or more successive melting operations.

Recycling.—Scrap titanium generally accounts for 40% to 50% of ingot production. Scrap is generated by producers of ingot and mill products and by consumers of mill products in fabricating finished products or components. It is estimated that up to 75% of titanium ingot metal becomes scrap during processing to finished parts.

Clean and well-segregated scrap, processed to remove impurities, is blended with sponge metal and alloying constituents and remelted to ingot. Remelting is mainly by vacuum-arc consumable-electrode processing. Cold-hearth melting (electron-beam and plasma-arc) also is used, especially for chips and turnings. Cold-hearth melting is very effective in ensuring removal of high-density inclusions, such as tungsten carbide tool particles, which settle out in the hearth area during melting. A substantial quantity of titanium scrap, particularly unprocessed turnings, is consumed directly or in making ferrotitanium for use in steel and other alloys.

Economic Factors

Tariffs.—The duties shown in table 1 reflect results of the Tokyo Round of Multilateral Trade Negotiations completed in 1979 under which tariffs on many items were reduced in several stages over the period January 1, 1980, to January 1, 1987. *(See table 1.)*

Depletion Provisions.—The depletion allowance for ilmenite and rutile is 22% when mined from domestic deposits and 14% from foreign deposits.

Operating Factors

Environmental Requirements.—Heavy-mineral sand mining presents few serious environmental hazards. The land is restored by returning the bulk of the sand after removal of the ore minerals. Dune areas can be left in nearly their original form, and the sand can be stabilized by seeding and replanting.

The major environmental problem in the titanium industry is the disposal of wastes from pigment-producing processes that use ilmenite, generating up to 3.5 tons of waste per ton of product. Solutions to this problem required the development of methods to neutralize and control the effluent now produced by the sulfate pigment process, mainly a solution of waste sulfuric acid and ferrous sulfate heptahydrate. Deep well disposal has been used for waste ferric chloride produced when ilmenite is used to make $TiCl_4$. In processes for making synthetic rutile, the effluent solutions are treated to regenerate the original leaching agent, such as hydrochloric acid, which is recycled, and to form useful byproducts such as sodium sulfate, ammonium sulfate, and iron oxide. In sulfate-process technology, there is a strong trend away from disposal of waste materials in streams or in the ocean. Both U.S. sulfate-process producers now are using waste treatment plants that neutralize acid effluent with limestone and lime, and produce gypsum and iron oxide byproducts.

Toxicity.—Titanium is a nontoxic material, as demonstrated by the use of TiO_2 in cosmetics and the use of titanium for making pacemakers and other implant devices for humans. However, some titanium compounds can be hazardous; for example, $TiCl_4$, which reacts violently with water or moisture in the air, forms TiO_2 and hydrochloric acid.

Energy Requirements.—According to a 1975 study for the USBM, energy requirements for alluvial mine production are about 5.1 million British thermal units (Btu) per ton of TiO_2 in concentrate. Production of pigment requires about 75 to 112 million Btu per ton of TiO_2, depending on the process and feed material used. Titanium sponge production uses from 408 to 466 million Btu per ton of metal, of which about 248 to 270 million Btu is required to regenerate the reductant and chlorine. The conversion of sponge metal to titanium ingot requires an additional 46 million to 57 million Btu per ton of titanium ingot.

ANNUAL REVIEW

Strategic Considerations

Security of Supply.—Dependence on foreign rutile sources for the production of titanium metal could be eased or eliminated in an emergency in two ways, using current commercial processing methods: (1) Synthetic rutile could be made from domestic ilmenite now being mined in Florida, or ilmenite that could be mined from other deposits; (2) Titanium tetrachloride for metal production could be made directly from ilmenite, as is done by Du Pont for TiO_2 pigment manufacture. Another possible solution to this problem is the development of new processes that utilize domestic ilmenite and perovskite that contain too much calcium and magnesium to be used directly for making $TiCl_4$. Availability of such processes would encourage production of domestic ilmenite. Titanium concentrates currently used to make $TiCl_4$ for metal production are mostly imported rutile and synthetic rutile, but domestic concentrates could be used for this purpose in an emergency, possibly at higher cost.

Stockpile.—The Defense Logistics Agency (DLA) began a modernization program in 1992. The National Defense Stockpile's (NDS) inventory in December contained 23,555 tons of specification metal and 9,857 tons of nonspecification material. In 1993, the Defense National Stockpile Center considered bids for the sale of 10,000 short dry tons (sdt) of rutile held in the NDS. However, only 1,218 sdt of material was sold in 1993. In June, DLA released its 1994 Annual Materials Plan, which included authorization to dispose of 20,000 sdt of rutile held in the stockpile. At the end of 1993, DLA held about 38,000 sdt in the stockpile.

Issues

Processing of some mineral sands by

certain methods results in the concentration of radioactive elements in the waste or byproduct streams. Monazite and xenotime, both rare-earth, thorium phosphates, are the usual minerals of consequence because 100% separation of a heavy-minerals deposit is impossible to obtain within economic considerations. Monazite inclusions within the mineral grains and/or ionic substitution of uranium, thorium, and radium within the mineral lattice result in some radioactive contamination. During the processing of titanium minerals, some concentration occurs in waste product streams. Generally, if the combined weight of uranium and thorium exceeds 0.05%, the materials are considered to be sources for these radioactive elements. Domestic requirements for licensing source material, definitions, exemptions, and other pertinent information are found in the Code of Federal Regulations, Energy, 10, Part 40 (10 CFR 40). The Environmental Protection Agency (EPA) is currently examining the generation and disposal practices for wastes that contain relatively low levels of naturally occurring radioactive materials. Consequently, mineral feedstock producers are closely examining the level of radioactive elements present in mineral deposits under development and are actively researching for remediation methods.

Although the United States has large reserves of titanium in the form of ilmenite, nearly all 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 $TiCl_4$ prefer rutile or synthetic rutile over ilmenite as plant feed material.

Production

Concentrates.—U.S. producers of ilmenite in 1993 were RGC (USA) Mineral Sands, Inc. at Green Cove Springs, FL; Du Pont at Starke and Highland, FL, both from mineral sands deposits; and P. W. Gillibrand Co., Simi Valley, CA, as a coproduct of its rock, sand, and gravel operations. RGC was the only U.S. producer of natural rutile. Kerr-McGee was the sole domestic producer of synthetic rutile at Mobile, AL.

Du Pont began dredging and mineral separation operations at its Maxville site in Florida. The new dredge was reported to have extended the mine life to the year 2010. The startup of dredging operations at Maxville coincided with a partial shutdown of the company's nearby Highland operations.[1]

Ferrotitanium.—Ferrotitanium was produced by Galt Alloys Inc., Canton, OH, and Shieldalloy Metallurgical Corp., Newfield, NJ. The two standard grades produced were 40% and 70% titanium.

Metal.—Titanium sponge metal was produced by two firms in Nevada and Oregon. Titanium ingot was produced by the two sponge producers and by nine other firms in seven States. About 30 companies are known to produce titanium mill products and castings. Production of ingot and mill products decreased by 0.7% and 1.0%, respectively. Production of titanium sponge was withheld to avoid disclosing company proprietary data. *(See tables 3 and 4.)*

Early in 1993, TIMET successfully commissioned a 10,000-ton-per-year expansion of titanium sponge capacity at its Henderson, NV, facility. The expansion was based on a Vacuum Distillation Process (VDP) developed by Toho Titanium Co. During the fourth quarter, TIMET and the United Steelworkers of America union failed to reach a contract agreement, and union employees began a strike at TIMET's Henderson facility. During the strike, which was unresolved at the end of 1993, TIMET continued to operate the facility with salaried employees and supplemental outside workers.[2]

Oremet began a restructuring and downsizing of its work force and was reported to be planning to reduce its salaried work force by 20%. However, Oremet did not expect production at its Albany, OR, facility to be affected. Depressed demand was cited as a driving force to reduce fixed costs and overhead.[3]

Titanium Dioxide Pigments.—Titanium dioxide pigments were produced by 5 companies at 11 plants in 9 States. Production of TiO_2 pigment exceeded the 1992 level by 2.2%. Capacity utilization for the domestic pigment industry was about 86%. *(See tables 5 and 6.)*

The Tioxide Group reached an agreement with NL Industries to acquire a 50% interest in NL's subsidiary Kronos' TiO_2 pigment facility at Lake Charles, LA. The agreement was reported to include an exchange of technologies between the two companies. The Lake Charles facility was recently commissioned with 80,000 tons per year of chloride-based capacity.[4]

Consumption and Uses

Concentrates.—On a gross weight basis, U.S. reported consumption of TiO_2 in concentrates increased 1.2% from the 1992 level. Titanium pigments accounted for 98% of total consumption. Based on TiO_2 content, consumption of concentrates was evenly divided between ilmenite, ruile, and titanium slag. *(See table 7.)*

Ferrotitanium.—Reported consumption of titanium in the form of ferrotitanium and scrap in steel and other alloys was 5,944 tons, a 20% increase from the 1992 level. Stainless, heat-resisting, and other alloy steel were the largest end-use categories of ferrotitanium and scrap. *(See table 9.)*

Metal.—Sponge and ingot consumption increased by 6.9% and 7.2%, respectively. Consumption of scrap for remelting increased by about 3% and supplied a calculated 50% of ingot feedstock. Net shipments of mill products increased by 2.9%, and casting shipments decreased by about 8%. Estimated U.S. mill product usage by application was as follows: commercial aerospace, 50%; military aerospace, 20%; and nonaerospace uses, 30%. Nonaerospace uses include those in the specialty chemical, pulp and paper, oil and gas, marine, and medical industries. *(See table 4.)*

Pigment.—Apparent domestic consumption of TiO_2 pigments was about 1.03 million tons, 2.8% more than in 1992. The paint, paper, and plastics industries were the largest consumers of pigment. Other consuming industries included ceramics, fabrics and textiles, floor coverings, printing ink, and rubber. *(See table 8.)*

Stocks

Consumer inventories of titanium concentrates decreased 6.2% on a gross weight basis, but increased 0.9% based on TiO_2 content. Producer stocks of TiO_2 pigments increased to about 116,000 tons, a 13.8% increase from that of 1992. Industry stocks of titanium sponge increased 51%, while stocks of titanium scrap decreased by about 9%. *(See table 10.)*

Markets and Prices

Overcapacity and depressed demand continued to affect prices in the titanium ore, pigment, and metal markets. Published prices for titanium concentrates, pigments, and metal products are presented in table 11. However, based on the customs value of imports for consumption, the average price for finished pigment was estimated to have decreased by about 2% compared with that of 1992. Similarly, prices for ilmenite, synthetic rutile, and natural rutile were estimated to have decreased by 12%, 4%, and 17%, respectively. Owing largely to increased imports from Russia and Ukraine, the average price for imported sponge was estimated to have decreased by 38%. In contrast to the rest of the titanium industry, the average price for titanium slag was estimated to have increased by about 9%. *(See table 11.)*

Foreign Trade

In March, the Department of Commerce (DOC) published the final results of its administrative review of an antidumping duty order on titanium sponge from Japan. The DOC concluded that the dumping margins for Showa Denko K.K. and Toho Titanium were 0% for the period November 1, 1990, to October 31, 1991. Although the antidumping orders were not removed, a 0% cash deposit rate was made effective on April 8, 1993. In November, the DOC published the preliminary results of another administrative review for Showa during the period November 1, 1991, to October 31, 1992. The DOC's preliminary determination was to revoke the antidumping duty order.[5]

The Office of the U.S. Trade Representative (USTR) reviewed the qualifications of Ukraine and Russia for designation under the Generalized System of Preferences (GSP) program. The GSP program grants qualified countries duty-free status for a limited level of imports. On September 30, 1993, GSP status was approved for Russia and was scheduled to become effective October 16, 1993. Under the GSP program, titanium mill products may enter the country duty free. However, imports of titanium sponge, ingot, and billet are not eligible for duty-free status under the GSP program.

Domestic producers of titanium requested the DOC begin an antidumping review of titanium sponge from the Republic of the Commonwealth of Independent States (C.I.S.). In their request, the producers stated the existing 83.96% antidumping margin was inadequate and named the major production sources and their agents in Kazakhstan, Russia, and Ukraine. The DOC planned to conduct an antidumping review covering the period from August 1, 1992, to July 31, 1993. *(See tables 12, 13, 14, and 15.)*

World Review

Capacity.—The capacity data in this report are for mines and benefication plants, sponge metal facilities, and TiO_2 pigment plants as of December 31, 1993. 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 temporarily closed facilities that, in the opinion of the author, can be brought into production within a short period of time 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 USBM estimates. *(See tables 3, 5, and 17.)*

Reserves.—U.S. reserves of ilmenite and rutile occur mainly in ancient beach sand deposits in Florida. Ilmenite concentrates from the U.S. sand deposits contain about 60% to 65% TiO_2, while those from rock deposits contain 45% to 50% TiO_2. Other U.S. resources include rock deposits of ilmenite in California, Minnesota, New York, and Wyoming, and sand deposits of ilmenite and/or rutile in Georgia, Idaho, New Jersey, North Carolina, Oregon, and South Carolina, as well as large quantities of accessory rutile in porphyry copper ores and mill tailings. The U.S. 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. Outside of the United States, major reserves are in Australia, Brazil, Canada, China, India, Norway, and the Republic of South Africa. *(See tables 16 and 18.)*

The USBM has compiled a computerized file of worldwide mineral deposit data called the Minerals Availability System (MAS). The MAS Advanced Deposit Information Tracking System contains location and descriptive information on mineral occurrences, mines, and mineral processing operations worldwide. Most of the reserve and resource data found in this report were derived from MAS reports. A public access version containing nonproprietary information contained in the MAS data base is available on request.

Australia.—ISK Mineral Sands was reported to have exhausted its Waroona mineral sands deposit near Perth, Australia. Owing to poor market conditions, ISK delayed the development of its Darndanup heavy-mineral deposit near Bunbury, Western Australia. The delay in developing Darndanup resulted in the closure of ISK's Picton mineral separation plant.[6]

Westralian Sands Ltd. (WSL) was planning to double its synthetic rutile capacity at its Capel facility in Western Australia. However, the company was waiting for an improvement in market conditions before proceeding with the project.[7]

At yearend, Tiwest, the Kerr McGee and Minproc Holdings Ltd. joint venture, suspended its synthetic rutile production at its Chandala, Australia, facility. Tiwest planned to suspend operations at Chandala for at least 6 months. During the shutdown, Kerr McGee planned to continue operating its synthetic rutile plant at Mobile, AL.[8]

RGC completed an upgrade of its Narngulu synthetic rutile facility and major modifications to its Eneabba West dredge. The company also conducted pilot-scale testing of a process to remove radionuclides from synthetic rutile.[9]

Brazil.—Du Pont America do Sul withdrew from a project to develop the Tapira anatase deposit. Following Du Pont's withdraw from the project, Companhia Vale do Rio Doce (CVRD) announced plans to develop the Tapira deposit with Andrade Guitierrez Quimica. CVRD estimated the reserves at Tapira to be more than 500 million tons.[10]

Canada.—Tiomin Resources Inc. announced the completion of pilot plant gravity separation testing on heavy-mineral concentrate produced at Natashquan, Quebec. Tiomin has contracted Mineral Deposits Ltd. to establish a design for a production-scale plant and produce a capital cost estimate.[11]

Tioxide planned to close its pigment production at Tracy, Quebec, and suspend its expansion at Becancour, Quebec. However, Tioxide planned to continue operating the finishing operations at Tracy. Tioxide recently appealed an order by the Canadian Government to stop the discharge of effluent from the Tracy facility into the St. Lawrence River.[12]

China.—A 15,000-ton-per-year pigment plant was reported to have been brought on-stream at Yumen, Ganzu Province. Another 15,000-ton-per-year facility was planned for completion in 1996 at Jinan, Shandong Province.[13]

France.—Cezus SA and TIMET formed an agreement where, over a 2-year period, TIMET would acquire Cezus' titanium business. During the 2-year takeover, TIMET would act as the exclusive agent for Cezus, and Cezus would manufacture titanium products solely on behalf of TIMET.[14]

India.—According to industry sources, Cochin Minerals & Rutile Ltd. began operation of a 10,000-ton-per-year synthetic rutile facility at Kerala. Ilmenite was supplied to the plant from a domestic source.

Japan.—According to the Japan Titanium Society, Japan's titanium sponge production and shipments during 1993 were 14,428 tons and 15,094 tons, respectively. Ingot production was 11,968 tons, and mill product shipments were 7,646 tons.

Toho Titanium completed a project to improve its sponge facility at Chigasaki, Japan. During the project, the batch size was increased from 1.6 tons to 7.4 tons. However, the plant's total capacity of 10,800 tons per year was reported not to have changed.[15]

Kazakhstan.—Two Japanese companies were reported to have agreed to help in the development of the Kara-Otel titanium ore deposit in Kazakhstan. The Kazakh Ministry of Industry also was reported to be interested in developing the Shokash and Obykhovskoe deposits.[16]

Mexico.—Du Pont opened a technical center north of Mexico City. The center was built to provide technical support for the Du Pont SA de CV pigment production facility in Altamira near Tampico in Tamaulipas State.[18]

Mozambique.—According to industry reports, Kenmare Resources PLC was moving forward in the development of the Congolone Mineral Sands Project. The ore body was reported to contain 3.25% heavy minerals and could yield 418,000 tons of ilmenite annually.

Netherlands.—TiO_2 pigment producer, TDF Tiofine BV, was purchased by Kemira Oy. Although the original Tiofine facility was a sulfate-route plant, the sulfate plant was closed in 1989 and replaced by a chloride facility in 1990. Tiofine's 45,000-ton-per-year chloride route facility at Botlek will be operated by Kemira Pigments.[19]

Norway.—RMI Titanium Co. and Permascand AB announced a joint venture to manufacture heavy walled titanium tubular products. A new production facility was planned for construction in Norway. The joint venture was intended to produce titanium tubular products sold primarily in the oil and gas, petrochemical, and pulp and paper industries. Pending the completion of the new facility, titanium tubular products were manufactured by Permascand in Sweden.[17]

Russia.—Lakokraska, a paint industry association, was seeking investors to expand pigment capacity in Russia. The first project planned for construction was a 50,000-ton-per-year sulfate route TiO_2 pigment plant in Yekaterinberg. The development of a heavy-mineral deposit in the Chelyabinsk region near Yekaterinberg was expected to provide an ilmenite feedstock for the plant. Meanwhile, a Russian oil investment corporation, Nipek, was planning the development of a titanium ore deposit in the Komi Republic of Russia.[20]

Sierra Leone.—CRL acquired a 50% interest in SRL from Nord Resources Corp. Under the acquisition agreement, CRL and Nord each held 50% in a new holding company called Sierra Rutile Holdings Ltd. that held 100% of the issued capital of SRL. SRL operation in Sierra Leone is a major source of rutile concentrate.[21]

South Africa, Republic of.—As part of a major corporate restructuring, the South African conglomerate, Gencor increased its interest in RBM from 25% to 50%. The remaining 50% interest was held by RTZ Corp. RBM operates Tisand Ltd., a heavy-mineral producer of ilmenite, rutile, and zircon, and Richards Bay Iron and Titanium Co., the world's largest producer of titanium slag. At yearend, RBM awaited a decision by the South African Government for the approval of the development of the Lake St. Lucia heavy-mineral deposit. Reserves at St. Lucia were estimated to be 276 million tons containing 9.74 million tons of ilmenite, 0.94 million tons of rutile, and 1.66 million tons of zircon.[22]

According to industry reports, Anglo American Corp. planned to commission its Namakwa Sands project in 1994. At full production, the project will produce 195,000 tons of slag, 38,000 tons of rutile, and 140,000 tons of zircon annually.

Taiwan.—Du Pont delayed plans to open a 60,000-ton-per-year pigment facility at Kuan Yin until the first quarter of 1994. The facility was originally scheduled to start up in October 1993. Oversupply of global production capacity was cited as the reason for the delay.[23]

United Kingdom.—At the end of 1993, the United Kingdom's sole titanium sponge producer, Deeside Titanium, closed its sponge facility. The company had an estimated production capacity of 5,000 tons per year, but recent production levels were reported to be well below capacity.[24]

Owing to poor market conditions, Tioxide reduced its sulfate-route TiO_2 pigment capacity at its Grimsby, United Kingdom, facility. Capacity at the sulfate-route plant was lowered from 100,000 tons per year to 70,000 tons per year. However, the company was reported to have plans to add chloride-route capacity at the Grimsby facility.[25]

Vietnam.—WSL was reported to be investing in the modernization and possible expansion of a heavy-minerals operation in Ha Tinh, Vietnam. The investment represented a 60% interest in the Hah Tinh operation. The remaining interest was held by the Provincial government and the Vietnamese Ministry of Heavy Industry. WSL planned to increase capacity at Ha Tinh from about 35,000 tons per year to 150,000 tons per year.[26] *(See table 19.)*

Current Research

The USBM is currently engaged in research to produce titanium at competitive cost. This research is being conducted under cooperative agreements with titanium producers, parts fabricators, members of the automotive industry, and the U.S. Army Tank Command. Much of the research is focused on developing technologies using three different approaches to produce titanium powder or granules suitable for powder metallurgy applications. The first approach is based on a liquid-liquid interaction of two streams of molten salt, one stream containing $TiCl_4$, the other stream containing magnesium or sodium. When the streams are combined, titanium powder is formed and is then separated using decantation and vacuum evaporation of the residual salt. The second approach involves a vapor-vapor phase reaction of $TiCl_4$ and gaseous magnesium. Titanium powder or granules that form during the reduction of $TiCl_4$ are separated using an electrostatic precipitator. The third approach involves a liquid-vapor reduction of gaseous $TiCl_4$ with molten magnesium or sodium.

OUTLOOK

Although global TiO_2 pigment capacity utilization was estimated to be below 90% in 1993, demand for titanium pigment is expected to grow annually between 3% and 4% for the period 1994-97. During the same period, some facilities are expected to close because they are not cost competitive or cannot meet environmental regulations. Subsequently, additional capacity may be needed within the next few years. Asia has been targeted as one area of high growth in demand and as a location for future pigment expansions. For several technological and environmental reasons, increased demand is expected to be met though expansions using chloride-route technology.

As it has in the past, total demand for titanium feedstocks is expected to follow that for titanium pigments. However, as a consequence of increased chloride route capacity and more stringent environmental restrictions, demand should increase at a higher rate for high-TiO_2 feedstocks, including high-grade ilmenite (60% TiO_2), natural and synthetic rutile, and titanium slag.

For the next few years, total demand for titanium metal is not likely to return to levels reached in the late 1980's. However, demand is expected to grow moderately and should be driven by increased consumption by commercial markets. Exports from Russia and Kazakhstan are expected to continue to affect the global market. Consequently, further consolidations in the titanium metal industry are likely.

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[1] Skillings Mining Review. Du Pont in Fla., Korean Co. Operating New Dredges. V. 82, No. 22, May 29, 1993, p. 5.

[2] American Metal Market. Titanium Prices Dropping as Timet Strike Continues. V. 101, No. 247, Dec. 27, 1993, p. 1.

[3] Oregon Metallurgical Corp. 1993 Annual Report, p. 2.

[4] Chemical Week. Tioxide Buying Stake in a Kronos TiO_2 Facility. V. 243, No. 6, Feb. 8, 1993, p. 3.

[5] Federal Register. Doc. 93-29321. V. 58, No. 228, Nov. 30, 1993, pp. 63155-63157.

[6] Industrial Minerals. ISK Minsands Development Shelved. No. 305, Feb. 1993, p. 9.

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TABLE 1
U.S. IMPORT DUTIES

Tariff item	HTS No.	Most favored nation (MFN) Jan. 1, 1993	Non-MFN Jan. 1, 1993
Ilmenite	2614.00.6020	Free	Free.
Titanium slag	2620.90.5000	do.	do.
Rutile concentrate	2614.00.6040	do.	do.
Synthetic rutile	2614.00.3000	5.0% ad valorem	30.0% ad valorem.
Waste and scrap metal	8108.10.1000	Free	Free.
Unwrought metal, including sponge	8108.10.5000	15.0% ad valorem	25.0% ad valorem.
Wrought metal:			
Articles of titanium	8108.90.3000	5.5% ad valorem	45.0% ad valorem.
Other	8108.90.6000	15.0% ad valorem	45.0% ad valorem.
Titanium dioxide pigments	3206.10.0000	6.0% ad valorem	30.0% ad valorem.
Titanium oxides	2823.00.0000	6.0% ad valorem	30.0% ad valorem.

Source: U.S. International Trade Commission.

TABLE 2
SALIENT TITANIUM STATISTICS

(Metric tons unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Ilmenite concentrate:					
Imports for consumption	411,751	345,907	213,886	294,585	301,447
Consumption[1]	659,584	688,948	738,089	684,882	693,940
Titanium slag:					
Imports for consumption	386,146	373,623	408,302	537,118	475,522
Consumption	414,830	390,537	341,379	539,323	545,809
Rutile concentrate, natural and synthetic:					
Imports for consumption	264,895	274,605	240,120	317,399	371,481
Consumption	366,143	369,454	368,643	[r]460,969	464,825
Sponge metal:					
Production	25,225	24,679	13,366	W	W
Imports for consumption	903	1,093	612	684	2,163
Consumption	24,927	23,207	13,594	14,165	15,140
Price, Dec. 31, per pound	$4.80-$5.30	$4.50-$5.00	$4.50-$5.00	$3.50-$4.00	$3.50-$4.00
Titanium dioxide pigment:					
Production	1,006,581	978,659	991,976	1,137,038	1,161,469
Imports for consumption	166,346	147,592	166,094	169,260	171,939
Consumption, apparent[2]	947,259	925,447	935,829	999,930	1,028,311
Price, Dec. 31, cents per pound:					
Anatase	102	99	99	99	99
Rutile	105	100	99	92 -95	92 -95
World production:					
Ilmenite concentrate[3]	4,353,115	4,071,611	3,411,295	3,580,854	3,578,560
Rutile concentrate, natural[3]	459,331	481,114	457,685	442,370	463,943
Titaniferous slag	1,765,000	1,886,000	1,509,000	1,637,000	1,545,000

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

[1] Includes consumption to produce synthetic rutile.

[2] Production plus imports minus exports plus stock decrease or minus stock increase.

[3] Excludes U.S. production data to avoid disclosing company proprietary data.

TABLE 3
U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1993

Company	Ownership	Plant location	Yearend capacity (metric tons)	
			Sponge	Ingot[1]
Howmet Corp., Titanium Ingot Div.	Pechiney, France	Whitehall, MI	—	2,300
A. Johnson Metals Corp.	Axel Johnson Group, Stockholm, Sweden	Morgantown, PA	—	[2]2,300
Lawrence Aviation Industries Inc.	Self	Port Jefferson, NY	—	1,400
Oregon Metallurgical Corp. (Oremet)	Oremet employees, 45%; public, 55%	Albany, OR	6,800	7,300
RMI Co.	USX Corp., 51%; public, 49%	Niles, OH	—	16,300
Teledyne Allvac	Teledyne Inc.	Monroe, NC	—	[3]7,300
Teledyne Wah Chang Albany	do.	Albany, OR	—	900
Titanium Hearth Technologies of America	A. Johnson Metals Corp., 50%; Titanium Metals Corp. of America, 50%	Morgantown, PA	—	[2]4,500
Titanium Metals Corp. of America	Tremont Corp., 75%: Union Titanium Sponge Corp, 25%	Henderson, NV	22,700	13,600
Viking Metallurgical Corp.	Quanex Corp.	Verdi, NV	—	[2]2,300
Wyman-Gordon Co.	Self	Worcester, MA	—	[4]3,200
Total			29,500	61,400

[1] Based on 7-day-per-week full production. Includes 55,000 tons vacuum-arc double-triple melt, of which triple melt generally ranged from 10% to 30%. The remaining 11,000 tons was single melt (electron-beam and plasma) capacity.

[2] Single melt only.

[3] Includes 2,300 tons of single melt capacity.

[4] Includes 1,400 tons of single melt capacity.

TABLE 4
COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND

(Metric tons)

Component	1989	1990	1991	1992	1993
Production:					
Sponge	25,225	24,679	13,366	W	W
Ingot	41,306	36,809	24,884	28,100	27,900
Mill products	29,946	25,619	22,263	19,054	18,871
Exports:					
Sponge	136	331	418	178	104
Other unwrought	1,173	3,102	[r]2,145	1,185	654
Scrap	5,474	5,487	[r]4,568	2,770	3,892
Ingot, slab, sheet bar, etc.	2,702	2,371	[r]1,699	1,455	857
Other articles of titanium	3,857	4,526	[r]3,300	2,431	2,387
Total[1]	13,342	15,816	[r]12,131	8,019	7,894
Imports:					
Sponge	903	1,093	612	684	2,163
Scrap	5,308	3,037	[r]2,666	6,257	5,519
Ingot and billet	190	162	[r]24	241	272
Other unwrought	119	213	175	128	168
Other wrought (mill products)	1,049	988	757	375	497
Other articles of titanium	200	279	[r]157	81	103
Total[1]	7,770	5,772	[r]4,391	7,766	8,722
Stocks, yearend:					
Government: Sponge (total inventory)	33,413	33,413	33,413	33,413	33,413
Industry:					
Sponge	2,114	3,267	2,852	1,929	2,905
Scrap	8,028	8,535	7,905	8,891	8,128
Ingot	3,548	3,725	2,826	2,352	2,427
Other	7	3	8	W	W
Total industry	13,697	15,530	13,591	13,172	13,460
Reported consumption:					
Sponge	24,927	23,207	13,594	14,165	15,140
Scrap	17,596	14,973	11,381	14,828	15,300
Receipts:					
Home	11,273	11,139	8,486	8,521	8,243
Purchased	12,583	9,710	7,313	12,665	9,868
Ingot	31,396	35,320	24,238	23,944	25,665
Mill products (net shipments):	24,997	23,923	15,600	16,074	16,540
Forging and extrusion billet	11,742	10,729	7,454	7,629	6,943
Rod and bar	3,566	3,499	2,141	2,484	2,153
Other[2]	9,689	9,695	6,005	5,961	7,444
Castings (shipments)	485	482	608	510	469

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

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

[2] Data for sheet and strip, plate, extrusions (other than tubing), pipe and tubing, and other have been combined to avoid disclosing company proprietary data.

TABLE 5
CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON DECEMBER 31, 1993[1]

Company	Plant location	Pigment capacity (metric tons per year): Sulfate process	Pigment capacity (metric tons per year): Chloride process
E.I. du Pont de Nemours & Co. Inc.:	Antioch, CA	—	40,000
	De Lisle, MS	—	245,000
	Edge Moor, DE	—	129,000
	New Johnsonville, TN	—	297,000
Kemira, Inc.	Savannah, GA	54,000	91,000
Kerr-McGee Chemical Corp.	Hamilton, MS	—	114,000
Kronos Inc.	Lake Charles, LA	—	100,000
SCM Chemicals Inc.	Ashtabula, OH	—	165,000
	Baltimore, MD	66,000	50,000
Total		120,000	1,231,000

[1] Table does not include Hitox Corp.'s Corpus Christi, TX, production capacity of about 16,400 tons per year of buff TiO_2 pigment that is produced by refining and fine grinding of synthetic rutile.

TABLE 6
COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND

(Metric tons unless otherwise specified)

Component	1990		1991		1992		1993	
	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content	Gross weight	TiO_2 content
Production[1]	978,659	913,275	991,976	926,506	1,137,038	[e]1,059,982	1,161,469	1,090,192
Shipments:[2]								
Quantity	1,116,431	1,045,748	1,124,194	1,052,350	1,261,812	1,178,902	1,285,773	1,202,644
Value thousands	$2,404,282	$2,404,282	$2,381,906	$2,381,906	[r]$2,535,255	[r]$2,535,255	$2,479,664	$2,479,664
Exports	202,288	[e]189,544	211,854	[e]197,872	270,422	[e]252,304	290,191	[e]272,373
Imports for consumption	147,592	[e]138,294	166,094	[e]155,464	169,260	[e]160,797	171,939	[e]161,382
Stocks, yearend	61,721	[e]57,597	72,108	[e]67,493	108,173	[e]102,764	123,079	[e]115,522
Consumption, apparent[3]	925,447	[e]863,196	935,829	[e]874,064	[r]999,811	[r]933,204	1,028,311	[e]965,173

[e] Estimated. [r] Revised.

[1] Excludes production of buff pigment.

[2] Includes interplant transfers.

[3] Production plus imports minus exports plus stock decrease or minus stock increase.

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

TABLE 7
U.S. CONSUMPTION OF TITANIUM CONCENTRATES

(Metric tons)

Year	Ilmenite[1] [2]		Titanium slag		Rutile (natural and synthetic)[3]	
	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]	Gross weight	TiO_2 content[e]
1989	659,584	419,743	414,830	335,395	366,143	345,989
1990	688,948	446,228	390,537	313,648	369,454	347,057
1991	738,089	476,640	341,379	273,976	368,643	335,872
1992:						
Alloys and carbide	(4)	(4)	(4)	(4)	—	—
Pigments	683,972	425,876	539,323	455,768	426,366	405,875
Welding-rod coatings and fluxes	(4)	(4)	—	—	(4)	(4)
Miscellaneous[5]	909	647	(6)	(6)	34,603	32,553
Total	[7]684,882	426,523	539,323	455,768	460,969	438,428
1993:						
Alloys and carbide	(4)	(4)	(4)	(4)	—	—
Pigments	693,207	434,097	545,809	453,500	432,915	405,784
Welding-rod coatings and fluxes	(4)	(4)	—	—	(4)	(4)
Miscellaneous[5]	733	451	(6)	(6)	31,910	30,223
Total	693,940	434,548	545,809	453,500	464,825	436,007

[e] Estimated.
[1] Includes a mixed product containing rutile, leucoxene, and altered ilmenite.
[2] Includes ilmenite consumed to produce synthetic rutile.
[3] Includes synthetic rutile made in the United States.
[4] Included with "Miscellaneous" to avoid disclosing company proprietary data.
[5] Includes ceramics, chemicals, glass fibers, and titanium metal.
[6] Included with "Pigments" to avoid disclosing company proprietary data.
[7] Data do not add to total shown because of independent rounding.

TABLE 8
U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS, TITANIUM DIOXIDE CONTENT, BY INDUSTRY

(Percentage)

Industry	1989	1990	1991	1992	1993
Ceramics	0.4	W	W	0.4	0.3
Coated fabrics and textiles	.4	0.2	W	.3	.4
Floor coverings	1.1	1.0	W	1.0	1.0
Paint, varnish, lacquer	50.0	48.9	46.6	44.7	46.0
Paper	25.8	26.5	26.4	26.2	26.2
Plastics	16.3	16.6	16.8	17.5	17.9
Printing ink	.8	1.6	1.8	1.7	1.5
Roofing granules	.3	.4	W	W	W
Rubber	1.4	1.5	1.8	1.8	1.9
Other	3.5	3.3	6.6	6.4	4.8
Total	100.0	100.0	100.0	100.0	100.0

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

TABLE 9

U.S. CONSUMPTION OF TITANIUM PRODUCTS[1] IN STEEL AND OTHER ALLOYS

(Metric tons)

	1989	1990	1991	1992	1993
Carbon steel	1,538	1,530	1,479	1,579	2,061
Stainless and heat-resisting steel	2,647	2,469	1,927	1,756	2,096
Other alloy steel (includes HSLA)	149	171	171	270	472
Tool steel	W	W	W	W	W
Total steel[2]	4,334	4,170	3,577	3,606	4,628
Cast irons	W	W	34	W	W
Superalloys	747	836	688	523	504
Alloys, other than above	873	973	665	738	455
Miscellaneous and unspecified	70	54	15	77	357
Total consumption[2]	6,023	6,032	4,979	4,943	5,944

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

[1] Includes ferrotitanium, titanium scrap, and other titanium additives.

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

TABLE 10

U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT, DECEMBER 31

(Metric tons)

	Gross weight	TiO_2 content
Ilmenite:[1]		
1991	250,762	146,129
1992	245,766	141,313
1993	173,351	105,262
Titanium slag:[1]		
1991	88,079	72,280
1992	138,509	112,487
1993	137,275	112,865
Rutile:[1]		
1991	208,030	196,526
1992	148,983	140,224
1993	189,784	179,411
Titanium pigment:[2]		
1991	72,108	[e]68,503
1992	108,173	[e]101,478
1993	123,079	[e]115,521

[e] Estimated.

[1] Consumer stocks.

[2] Bureau of the Census. Producer stocks only.

TABLE 11
PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS[1]

		1992	1993
Concentrates:			
Ilmenite, f.o.b. Australian ports	per metric ton	$58.00-$62.00	$61.00-$64.00
Rutile, bagged, f.o.b. Australian ports	do.	380.00-414.00	370.00-400.00
Rutile, bulk, f.o.b. Australian ports	do.	345.00-387.00	365.00-390.00
Rutile, large lots, bulk, f.o.b. U.S. east coast	do.	510.00-520.00	NA
Titanium slag, 80% TiO_2, Canada[e]	do.	264.00	276.00
Titanium slag, 85% TiO_2, Republic of South Africa[e]	do.	310.00	330.00
Metal:			
Sponge	per pound	3.50- 4.00	3.50- 4.00
Mill products:			
Bar	do.	7.50- 9.00	7.50- 9.00
Billet	do.	6.00- 7.50	6.00- 7.50
Plate	do.	8.50- 9.50	8.50- 9.50
Sheet	do.	7.50- 8.00	7.50- 8.00
Ferrotitanium:	do.	1.40- 1.50	1.15- 1.20
Scrap:			
Turnings, unprocessed	do.	.65- .80	.40- .45
Pigment:			
Titanium dioxide pigment, f.o.b. U.S. plants anatase	do.	.99	.99
Titanium dioxide pigment, f.o.b. U.S. plants, rutile	do.	.92- .95	.92- .95

[e] Estimated based on U.S. imports for consumption. NA Not available.

[1] Yearend.

Sources: American Metal Market, American Paint and Coatings Journal, Chemical Marketing Reporter, Industrial Minerals (London), Metal Bulletin, Metals Week, and industry contacts.

TABLE 12
U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS

Class	1991		1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Metal:						
Sponge	418	$2,604	178	$1,102	104	$748
Scrap	4,568	10,706	2,770	7,201	3,892	9,074
Other unwrought:						
Billet	513	8,087	509	9,652	240	4,793
Blooms and sheet bars	1,038	21,390	514	10,103	342	6,278
Ingot	149	2,437	432	5,828	275	4,012
Other	2,145	15,919	1,185	17,789	654	12,030
Wrought:						
Bars and rods	1,147	34,833	1,129	28,681	663	18,001
Other	2,153	78,227	1,302	52,346	1,723	54,677
Total[1]	12,131	174,203	8,019	132,702	7,894	109,613
Ores and concentrates	26,912	10,167	34,665	10,566	15,202	4,893
Pigment and oxides:						
Titanium dioxide pigments	168,362	276,229	231,734	362,606	261,017	363,303
Titanium oxides	43,492	76,683	38,688	57,766	29,175	41,862
Total[1]	211,854	352,912	270,422	420,372	290,191	405,165

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

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES, BY COUNTRY

Concentrate and country	1991		1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ilmenite:						
Australia	213,886	$24,071	264,459	$17,133	233,434	$12,504
India	—	—	220	194	40,095	2,606
Sierra Leone	—	—	21,397	2,415	27,918	3,316
South Africa, Republic of	—	—	8,505	578	—	—
Other	—	—	5	93	—	—
Total[1]	213,886	24,071	294,585	20,414	301,447	18,426
Titanium slag:						
Canada	73,346	19,084	67,642	17,848	88,350	24,200
Gabon	—	—	24,844	6,508	—	—
Norway	5,257	1,200	18,780	4,173	10,559	2,924
South Africa, Republic of	329,691	85,500	421,467	126,025	376,613	123,277
Other	8	8	4,386	1,388	—	—
Total[1]	408,302	105,792	537,118	155,943	475,522	150,401
Rutile, natural:						
Australia	57,388	33,170	76,728	34,676	79,866	29,607
Canada	113	60	33	53	14	14
Sierra Leone	76,368	33,545	76,155	33,606	55,113	21,001
South Africa, Republic of	40,460	19,773	28,156	12,783	139,639	50,813
Other	538	130	58	104	256	417
Total[1]	174,866	86,678	181,130	81,222	274,886	101,853
Rutile, synthetic:						
Australia	59,091	31,564	125,831	44,028	90,184	29,808
Malaysia	6,163	3,390	10,438	4,508	6,407	3,365
Other	—	—	—	—	5	2
Total[1]	65,254	34,953	136,269	48,536	96,595	33,175
Titaniferous iron ore:[2]						
Canada	27,012	1,593	32,381	1,564	66,253	2,854

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

[2] Includes materials consumed for purposes other than production of titanium commodities, principally heavy aggregate and steel-furnace flux.

Source: Bureau of the Census. Data adjusted by the U.S. Bureau of Mines.

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY COUNTRY

Country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
80% or more titanium dioxide:				
Australia	120	$190	642	$980
Belgium	4,308	7,015	1,590	2,493
Canada	38,815	65,669	33,639	57,472
China	1,640	1,512	1,768	1,636
Finland	3,365	5,848	4,752	7,594
France	3,411	5,526	5,383	8,585
Germany	17,058	32,694	14,639	28,618
Japan	6,197	11,464	5,478	10,755
Netherlands	54	82	100	151
Norway	6,061	10,392	5,468	9,381
Singapore	4,771	7,215	6,295	9,491
United Kingdom	2,148	3,716	3,318	5,029
Other	4,279	6,576	9,901	14,542
Total[1]	92,229	157,900	92,973	156,727
Other titanium dioxide:				
Belgium	352	624	193	376
Canada	4,536	8,387	6,155	10,505
France	10,314	15,577	9,507	14,391
Germany	1,796	6,717	3,013	9,584
Italy	605	1,149	532	900
South Africa, Republic of	5,013	7,363	6,867	9,889
Spain	10,465	16,514	7,071	10,462
United Kingdom	17,975	28,153	18,288	27,029
Other	2,029	4,204	2,700	5,106
Total[1]	53,085	88,690	54,326	88,242
Titanium oxide:				
Australia	36	55	144	263
Belgium	450	697	2,728	4,130
Canada	8,394	12,244	8,360	12,662
China	301	361	257	222
France	7,704	11,321	6,713	9,374
Germany	4,139	7,245	2,712	4,355
Japan	187	1,358	466	2,585
Mexico	40	60	—	—
Norway	970	1,633	1,243	2,054
United Kingdom	1,266	2,488	774	1,462
Yugoslavia	120	187	—	—
Other	338	608	1,243	1,970
Total[1]	23,946	38,254	24,640	39,077
Grand total[1]	169,260	284,843	171,939	284,046

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

Source: Bureau of the Census.

TABLE 15
U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY

Class and country	1991		1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought:						
Sponge:						
China	94	$600	230	$1,411	180	$1,316
Japan	357	3,484	321	2,907	338	2,834
Russia[1]	—	—	—	—	1,163	3,90
Ukraine[1]	—	—	—	—	292	72
U.S.S.R.[2]	91	399	84	387	—	—
United Kingdom	55	894	45	650	101	1,312
Other	15	74	4	9	89	375
Total[3]	612	5,451	684	5,363	2,163	10,473
Waste and scrap:						
Belgium	67	169	50	101	56	153
Canada	186	586	269	542	186	447
China	66	227	49	132	17	104
France	125	500	686	2,174	559	1,768
Georgia[1]	—	—	66	66	—	—
Germany	205	704	1,208	3,708	986	3,059
Japan	475	1,733	1,509	5,611	1,182	4,610
Russia[1]	—	—	189	420	578	1,624
Sweden	100	267	109	356	81	232
U.S.S.R.[2]	443	1,195	309	713	—	—
United Kingdom	815	2,694	1,451	4,591	1,501	4,755
Other	185	428	362	1,022	373	1,353
Total[3]	2,666	8,503	6,257	19,436	5,519	18,105
Ingot and billets:						
Japan	3	661	2	452	2	422
Russia[1]	—	—	—	—	109	578
United Kingdom	20	424	239	1,609	160	2,028
Other	1	10	—	—	(4)	6
Total[3]	24	1,095	241	2,062	272	3,034
Powder:						
Israel	22	522	30	700	19	441
Other	12	175	20	185	18	372
Total[3]	34	697	50	886	37	813
Other:[5]						
Japan	3	121	—	—	10	37
Netherlands	18	203	—	—	—	—
Switzerland	36	407	7	24	—	—
United Kingdom	63	751	18	72	36	167
Other	21	79	53	395	85	557
Total[3]	141	1,561	78	491	131	761
Wrought products and castings:[6]						
Canada	391	9,337	148	3,641	53	2,159

See footnotes at end of table.

TABLE 15—Continued

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

Class and country	1991 Quantity (metric tons)	1991 Value (thousand)	1992 Quantity (metric tons)	1992 Value (thousand)	1993 Quantity (metric tons)	1993 Value (thousand)
Wrought products and castings—Continued						
France	41	515	8	655	45	733
Germany	60	1,115	18	841	6	683
Japan	317	8,350	201	4,757	231	6,705
Russia[1]	—	—	—	—	33	299
Sweden	7	$431	19	$399	28	$680
United Kingdom	68	2,799	44	1,631	195	5,370
Other	30	1,466	18	905	9	608
Total[3]	914	24,014	456	12,830	600	17,237

[1] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[2] Dissolved in Dec. 1991; however, information is inadequate to formulate reliable estimates for individual countries.

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

[4] Less than 1/2 unit.

[5] Includes blooms, sheet, bars, slabs, and other unwrought.

[6] Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other.

Source: Bureau of the Census.

TABLE 16

U.S. TITANIUM RESERVES AND RESERVE BASE IN 1993

(Thousand metric tons of TiO_2 content)

	Reserves			Reserve base[1]		
	Ilmenite	Rutile	Total	Ilmenite and perovskite[2]	Rutile and anatase[3]	Total
Arkansas	—	—	—	—	200	200
California	—	—	—	600	—	600
Colorado	—	—	—	9,800	—	9,800
Florida	7,800	300	8,100	7,800	300	8,100
New York	—	—	—	7,900	—	7,900
Tennessee	—	—	—	5,600	900	6,500
Virginia	—	—	—	1,600	—	1,600
Total	7,800	300	8,100	33,300	1,400	34,700

[1] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves) and some of those that are currently subeconomic (subeconomic resources).

[2] Ilmenite except for the 9.8 million tons in Colorado perovskite.

[3] Rutile except for the 200,000 tons in Arkansas anatase.

TABLE 17

WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993

(Thousand metric tons of TiO_2 content of concentrates, gross weight of sponge (over 99% Ti), and gross weight of pigment (average about 95% TiO_2)

	Ilmenite	Rutile	Rutile, synthetic	Sponge metal	TiO_2 pigment		
					Sulfate[1]	Chloride[2]	Total
North America:							
Canada	[3]880	—	—	—	20	38	58
Mexico	—	—	—	—	—	90	90
United States	211	30	100	30	120	1,231	1,351
Total	1,091	30	100	30	140	1,359	1,499
South America: Brazil	[4]83	15	—	—	55	—	55
Europe:							
Belgium	—	—	—	—	28	40	68
Czech Republic	—	—	—	—	22	—	22
Finland	—	—	—	—	90	—	90
France	—	—	—	—	245	—	245
Germany	—	—	—	—	270	80	350
Italy	—	—	—	—	80	—	80
Kazakhstan	—	—	—	35	—	—	—
Netherlands	—	—	—	—	—	45	45
Norway	[5]450	—	—	—	27	—	27
Poland	—	—	—	—	36	—	36
Russia	—	—	—	35	—	—	—
Spain	—	—	—	—	65	—	65
Ukraine	250	30	—	15	100	—	100
United Kingdom	—	—	—	5	80	155	235
Yugoslavia	—	—	—	—	28	—	28
Total	700	30	—	90	1,071	320	1,391
Africa:							
Sierra Leone	35	194	—	—	—	—	—
South Africa, Republic of	[6]850	89	—	—	35	—	35
Total	885	283	—	—	35	—	35
Asia:							
China	90	—	—	7	25	—	25
India	239	21	43	—	12	22	34
Japan	—	—	43	29	274	54	328
Korea, Republic of	—	—	—	—	18	—	18
Malaysia	275	—	48	—	—	—	—
Singapore	—	—	—	—	—	36	36
Sri Lanka	80	7	—	—	—	—	—
Taiwan	—	—	—	—	—	—	10
Thailand	16	—	—	—	10	—	—
Total	700	28	134	36	339	112	451

TABLE 17

WORLD TITANIUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993

(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
Oceania: Australia	1,004	320	530	—	35	70	105
World total	4,463	706	764	156	1,675	1,861	3,536

[1] Sulfate process.

[2] Chloride process.

[3] Contained in 80% TiO_2 slag made from ilmenite.

[4] Mainly anatase.

[5] Contained in ilmenite and 75% TiO^2 slag made from ilmenite.

[6] Contained in 85% TiO_2 slag made from ilmenite.

Sources: Technical publications, Industrial Minerals; industry contacts; and U.S. Bureau of Mines estimates.

TABLE 18

WORLD TITANIUM RESERVES AND RESERVE BASE IN 1993

(Thousand metric tons TiO_2 content)

	Reserves			Reserve base[1]		
	Ilmenite	Rutile and anatase[2]	Total	Ilmenite and perovskite[3]	Rutile and anatase[2]	Total
North America:						
Canada	27,000	—	27,000	73,000	—	73,000
United States	7,800	300	8,100	33,300	1,400	34,700
Total	34,800	300	35,100	106,300	1,400	107,700
South America:						
Brazil	1,600	66,000	67,600	1,600	86,000	87,600
Europe:						
Finland	1,400	—	1,400	1,400	—	1,400
Italy	—	—	—	9,000	21,000	30,000
Norway	32,000	—	32,000	90,000	—	90,000
U.S.S.R.[4]	5,900	2,500	8,400	13,000	2,500	15,500
Total	39,300	2,500	41,800	113,400	23,500	136,900
Africa:						
Egypt	—	—	—	1,400	—	1,400
Madagascar	—	—	—	15,000	—	15,000
Mozambique	2,300	100	2,400	2,300	100	2,400
Sierra Leone	1,000	2,000	3,000	1,000	2,000	3,000
South Africa, Republic of	36,000	3,600	39,600	45,000	4,500	49,500
Total	39,300	5,700	45,000	64,700	6,600	71,300
Asia:						
China	30,000	—	30,000	41,000	—	41,000
India	31,000	4,400	35,400	31,000	4,400	35,400
Malaysia	—	—	—	1,000	—	1,000
Sri Lanka	3,600	800	4,400	3,800	800	4,600
Total	64,600	5,200	69,800	76,800	5,200	82,000
Oceania:						
Australia	24,000	5,300	29,300	66,000	42,000	108,000
World total	204,000	85,000	289,000	429,000	165,000	594,000

[1] The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

[2] Mainly anatase in Brazil; rutile elsewhere.

[3] Ilmenite except for 9.8 million tons in Colorado perovskite.

[4] As constituted before Dec. 31, 1991.

TABLE 19

TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE, AND TITANIFEROUS SLAG), BY COUNTRY[1]

(Metric tons)

Concentrate type and country	1989	1990	1991	1992	1993[e]
Ilmenite and leucoxene:[2]					
Australia:					
Ilmenite	1,696,000	1,602,000	1,363,000	[e]1,500,000	1,764,000
Leucoxene	18,000	19,000	18,000	[r][e]22,000	19,000
Brazil[3]	144,212	114,117	69,064	[e]70,000	70,000
China[e]	150,000	150,000	150,000	150,000	155,000
India	240,656	[e]280,000	311,537	[e]300,000	320,000
Malaysia	533,657	530,237	336,347	337,744	210,000
Norway	929,830	814,488	625,000	[r]708,000	700,000
Portugal[e]	111	[r]45	40	30	25
Sierra Leone	62,310	54,639	60,371	[r]60,331	[4]62,900
Sri Lanka	101,354	66,413	60,861	[r]33,283	[4]76,930
Thailand	16,985	10,674	17,075	[r]2,927	20,705
Ukraine[5]	—	—	—	[e]200,000	180,000
U.S.S.R.[e][6]	460,000	430,000	400,000	[r]—	—
United States	W	W	W	W	W
Total	4,353,115	[r]4,071,613	3,411,295	[r]3,384,315	3,578,560
Rutile:					
Australia	243,000	245,000	201,000	[r]190,000	190,000
Brazil	2,613	1,814	1,094	[e]1,100	1,100
India	9,931	[e]11,000	13,635	[e]10,000	13,900
Sierra Leone	128,198	144,284	154,800	[r]148,990	[4]152,000
South Africa, Republic of[e]	60,000	[4]64,056	75,000	[r]95,000	100,000
Sri Lanka	5,589	5,460	[r]3,085	[r]2,741	[4]2,643
Thailand	—	—	76	[r]281	300
Ukraine[5]	—	—	—	5,000	4,000
U.S.S.R.[e][6]	10,000	9,500	9,000	[r]—	—
United States	W	W	W	W	W
Total	459,331	481,114	[r]457,690	[r]453,112	463,943
Titaniferous slag:[7]					
Canada[e][8]	1,040,000	1,046,000	701,000	753,000	653,000
South Africa, Republic of[e][9]	725,000	840,000	[4]808,000	884,000	892,000
Total	1,765,000	1,886,000	1,509,000	1,637,000	1,545,000

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

[1] Table includes data available through Aug. 10, 1994.

[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] Excludes production of unbeneficiated anatase ore.

[4] Reported figure.

[5] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[6] Dissolved in Dec. 1991. All production in the U.S.S.R. from 1989-91 came from Russia and Ukraine.

[7] Slag is also produced in Norway but is not included under Titaniferous slag to avoid duplicative reporting. Beginning in 1988, about 25% of Norway's ilmenite production was used to produce slag containing 75% TiO_2.

[8] Contains 80% TiO_2.

[9] Contains 85% TiO_2.

TUNGSTEN

By Gerald R. Smith

Mr. Smith, a physical scientist with 30 years of research and commodity experience with the U.S. Bureau of Mines, has been the commodity specialist for tungsten since 1986. Domestic survey data were prepared by Dwayne Penn, statistical assistant; and the world production table was prepared by Jeremy Tidwell, international data coordinator.

The unique high-temperature properties of tungsten and its alloys can be utilized advantageously in the production of numerous end-use items. The high melting point, high density, good corrosion resistance, and good thermal and electrical conductivity properties of tungsten and its alloys and the excellent cutting and wear-resistant properties of its carbide continue to provide important items for consumption in the domestic and military sectors.

Total reported domestic consumption of tungsten in primary end-use categories increased by about 10% in 1993 compared with that of 1992. Demand generally increased in the cemented carbide end-use sectors that included the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries. Demand for mill products made from metal powder as well as demand for tungsten chemicals and directly reusable tungsten scrap also increased in 1993. Counter to these increases was a decrease in the use of ferrotungsten in steels, which included the tool, alloy, and stainless steel sectors. A gradual strengthening of the U.S. economy influenced the overall increase in demand for tungsten products during 1993.

The average Metal Bulletin (London) combined price for wolframite and scheelite concentrates, instituted in April 1992, declined about 38% in 1993 compared with that of 1992. The concentrate price trend for 1993 continued the downward trend that existed in 1992, increasing only slightly in the final 2 months of the year.

Prices for ammonium paratungstate (APT) on the world market decreased during 1993, consistent with the declining prices for concentrates. According to quotations in Metals Week, the average price for APT on the U.S. market, duty-paid and delivered to processing plants, decreased by 21% from an average of $58.42 per metric ton unit (mtu) in January to an average of $46.30 per mtu by yearend. Similarly, quotations for Chinese No. 1 Grade APT in Hong Kong declined by 25% during the year from an average price of $39.50 per mtu to an average of $29.50 per mtu. The average price of APT on the European free market decreased by 26%, from $47 per mtu to $35 per mtu, according to quotations published in Metal Bulletin (London).

As a result of the weak tungsten market, at least eight additional tungsten mine operators in the West, including two in the United States, were forced either to reduce concentrate production, to suspend production and place their mine on care-and-maintenance status, or to close their mines permanently.

The pattern of imports of tungsten materials by U.S. processors during 1993 showed a further shift away from tungsten concentrate and toward the intermediates ammonium paratungstate, tungsten oxide, and sodium tungstate. The shift continued a trend that began in 1991, subsequent to the imposition of the 151% antidumping tariff on imports of concentrate from China that effectively halted such imports. China, however, continued to be the dominant supplier of tungsten materials to the United States in 1993, providing about 44% of all imported tungsten materials.

A summary of the important U.S. and international statistics for 1993 and the previous 4 years are shown in table 1. *(See table 1.)*

DOMESTIC DATA COVERAGE

Domestic production data for tungsten are developed by the U.S. Bureau of Mines by means of two separate, voluntary surveys. These surveys are "Tungsten Ore and Concentrate" and "Tungsten Concentrate and Tungsten Products." Of the 14 mining and 15 processing operations to which survey requests were sent, response was received from 64% and 100%, respectively, of those operations surveyed. Production and stock totals for the survey respondents are shown in table 1.

BACKGROUND

Definitions

Tungsten, a silvery gray metal, has an atomic number of 74 and an atomic weight of 183.92. Its most outstanding physical property is its high melting point of 3,410° C, the highest of all metals. Tungsten is one of the heaviest elements, with a density of 19.3 grams per cubic centimeter at 20° C. It has good corrosion resistance, good thermal and electrical conductivity, and a low coefficient of expansion. At temperatures above 1,650° C, tungsten has the highest tensile strength of all metals.

Tungsten concentrate is sold in units of tungsten trioxide (WO_3). In the United States, sales are based on the short ton unit of WO_3. This is equivalent to 1% of a short ton, or 20 pounds of WO_3 and contains 7.19 kilograms (15.86 pounds) of tungsten. In most other countries, tungsten is sold in the mtu and contains 7.93 kilograms (17.48 pounds) of tungsten.

Natural or synthetic scheelite concentrate, in nodular form, is ideal for direct addition to steel melts because the calcium is removed as slag. Fine material in either synthetic or natural scheelite is not desirable because of high dust losses. Wolframite concentrate is not satisfactory for steelmaking because of the manganese and tin content.

Tungsten ores and concentrates are converted into the following intermediate products: APT, tungstic acid, sodium tungstate, tungsten metal powder, and tungsten carbide powder. Most of the APT is reduced to tungsten metal powder, which then is processed into tungsten carbide powder.

Tungsten alloys and tungsten mill products such as rod, wire, and sheet are produced from hydrogen-reduced tungsten metal powder. The tungsten carbide produced from powder is cemented, usually with cobalt, to form various cutting and wear-resistant tools and parts.

Tungsten chemicals (APT, tungstic acid, and sodium tungstate) are produced as coproducts at some tungsten processing plants and as primary products at others. When not processed further into metal powder, they generally are used in the chemical industry.

Products for Trade and Industry

Tungsten materials can be divided into four major classes, depending on use: (1) a carbide in cutting and wear-resistant materials, and welding and hard-facing rods; (2) mill products made from essentially pure metal; (3) an alloy constituent in high-speed and tool and die steels, superalloys, and nonferrous alloys; and (4) various chemicals and compounds for nonmetallurgical applications.

The extreme hardness of tungsten carbide at temperatures exceeding 1,000° C makes it a preferred metalworking material for cutting edges of machine tools subject to intense wear or abrasion and for metal surfaces in forming and shaping dies. The mining and petroleum industries use tungsten carbide in drill bits, in the cutting edges of earth-moving equipment, and in crushing machinery. Tungsten carbide is used widely in wear parts of transportation and electrical equipment.

In most applications, tungsten carbide generally is cemented with a powdered cobalt metal binder by compaction and sintering. The cobalt content can range from about 3 to 25 weight percent, with the higher content providing greater shock resistance at a sacrifice in hardness. Tantalum and/or titanium carbides are used in conjunction with tungsten carbide in certain cutting and chipping tools. Also, coatings such as titanium carbide, titanium nitride, and aluminum oxide on tungsten carbide are used extensively to increase the life of inserts for machining applications.

Mill products made from pure or substantially pure tungsten metal powder are used in significant quantities by the electrical and electronic industries. Tungsten wire is used as the filament in electric lamps and as cathodes for electronic tubes. Disks produced from tungsten rods or sheet are used in automotive distributor points, although this end use is declining as the number of automobiles with electronic ignition systems increases. They also are used as contact points in numerous manufactured products. Tungsten metal is employed as heat and radiation shielding, as electrodes for inert-gas welding, as components of X-ray and cathode-ray tubes, and as heating elements in high-temperature resistance furnaces. Tungsten metal is used by the aerospace industry because it retains its strength at elevated temperature in reducing or inert atmospheres. The use of tungsten as a heavy metal for counterweights and balances, especially by the aircraft industry, has been replaced, to a significant extent, by depleted uranium, which approaches the density of tungsten.

Cast tungsten carbide is used principally as a hard-facing material. In this application, carbide particles are applied by a welding process to provide an abrasion-resisting surface layer on the surface to be coated. The carbide may be initially in the form of rod or loose grains in a tube.

As an alloy constituent, tungsten is used primarily in the production of high-speed steels and tool and die steels. Hardness and oxidation resistance at elevated temperatures are the most important properties possessed by these steels, which are used for machinery and equipment in the metalworking, construction, and mining industries. Certain grades of stainless and other alloy steels contain tungsten to improve wear and abrasion resistance, shock resistance, corrosion resistance, and/or strength at high temperatures.

Tungsten is an important constituent in a wide variety of superalloys and nonferrous alloys. Tungsten-containing superalloys are being utilized increasingly in high-temperature applications for their high-temperature strength and oxidation resistance. Tungsten alloyed with copper or silver is used for electrical contacts to provide wear resistance with adequate electrical conductivity.

Nonmetallurgical applications of tungsten include chemicals used in textile dyes, paints, enamels, toners, and coloring glass. Certain tungsten compounds are luminescent and used as phosphors in pigments, X-ray screens, television picture tubes, and fluorescent lighting. Sodium tungstate is employed as a corrosion inhibitor and a fireproofing agent in textiles. APT is used in making catalysts for the refining of petroleum. Among other chemical applications, tungsten compounds are used in chemical-vapor deposition, as catalysts in other chemical processing, and as laboratory reagents.

The chief nonindustrial use of tungsten is in armor-piercing ordnance, but this has been replaced, in part, by depleted uranium.

ANNUAL REVIEW

Legislation and Government Programs

The fiscal year 1994 Defense Authorization Bill, passed by the U.S. Congress in November 1993 and signed by the President in early December 1993, contained no authority for the sale of tungsten from the National Defense Stockpile (NDS) for the period October 1, 1993, through September 30, 1994. Tungsten was last authorized for sale from the NDS in fiscal year 1989 when tungsten ore concentrate was used as payment material in support of the NDS ferroalloy upgrading program. At the beginning of fiscal year 1994, the NDS contained 37,336 metric tons of contained tungsten, of which approximately 93% was in the form of tungsten ore concentrates.

The antidumping tariff on imports of tungsten ore concentrates from China, initially imposed on October 28, 1991, was continued during 1993. Interested parties were afforded the opportunity to request administrative review of this antidumping order in an announcement published by the Department of Commerce, International Trade Administration (ITA) in the Federal Register, November 3, 1993. The ITA did not receive any requests for review of this order by the November 30, 1993, deadline. Accordingly, the imposition of the tariff will continue indefinitely. As is the procedure in such antidumping orders, the ITA will again afford the opportunity to request an administrative review during the next anniversary month of the antidumping order.

The Federal Trade Commission (FTC), in an announcement published in the Federal Register, November 15, 1993, requested comments on a proposal to add certain lamps to the list of products subject to the provisions of an existing Appliance Labelling Rule (16 CFR Part 305). Lamp products proposed to be subject to this rule, entitled "Rules Concerning Disclosures of Information About Energy Consumption and Water Use for Certain Home Appliances and Other Products Required Under the Energy Policy and Conservation Act," included general service fluorescent lamps; medium-base, compact fluorescent lamps; and incandescent reflector lamps. The action was taken pursuant to the Energy Policy Act of 1992, which directed the FTC to prescribe, by April 24, 1994, rules requiring such lamp products to be labeled with disclosures that will enable purchasers to select the most energy-efficient lamps that will meet their requirements. The proposed rule will serve to supplement rule 16 CFR 409, issued in 1970 to cover labeling requirements for general service incandescent electric lamps.

Strategic Considerations

Tungsten is an important strategic material necessary for defense purposes, including the industrial base. Currently, the heavy-metal alloys of tungsten, containing 3% to 10% nickel and small quantities of iron or copper, are used in several of the smaller diameter projectiles for penetrating armorplate. Cemented tungsten carbide parts, which exhibit excellent cutting and wear-resistant properties, are vital to the U.S. metalworking, machining, construction, transportation, mining, and oil and gas drilling industries. Tungsten mill products and powders are essential to the lamp and lighting industry as filaments and electrodes; to the electrical and electronic industries as wear-resistant, electrically conductive contact surfaces; and to the superalloy and steel industries as alloying components. The 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 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.

Issues

During 1993, prices for concentrates and intermediate materials continued to decline, causing at least eight additional tungsten mine operators in the West, including two in the United States, either to reduce concentrate production, to suspend production and place their mine on care-and-maintenance status, or to close their mines permanently. Although China remained the principal supplier of tungsten products to the world market during 1993, it, also, was not immune to the adverse market conditions. As a result of China's decision in late 1992 to eliminate Government subsidies to tungsten miners, numerous smaller mines reportedly were forced to close because they could not be operated economically. According to industry observers, this further increased the use of existing, but unknown, quantities of Chinese stocks of concentrate to meet domestic and world demand. By yearend 1993, many observers believed that stocks of Chinese concentrate nearly had been depleted. The quantity of tungsten materials available from Russia and certain other members of the Commonwealth of Independent States (C.I.S.) remained relatively small during 1993. Furthermore, uncertainties remained regarding the extent to which the C.I.S. might become a source of tungsten supply to the world market as it makes the transition to a market economy. Given all of these tungsten market factors, by yearend 1993 industry analysts believed a more balanced supply-demand condition was being approached.

Production

The already low tungsten mining activity in the United States further declined in 1993 as the continuing low prices for concentrate and the growing use of intermediate tungsten materials made mining uneconomical and impractical. The sole producer of tungsten concentrate in 1993 was U.S. Tungsten Corp., a division of Strategic Minerals Corp., at its Pine Creek Mine, Bishop, CA. Major processors of tungsten materials in 1993 were Buffalo Tungsten Inc., Depew, NY; General Electric Co., Euclid, OH; Osram Sylvania, Inc. (formerly GTE Products Corp.), Towanda, PA; Kennametal Inc., Latrobe, PA, and Fallon, NV; Teledyne Firth Sterling, LaVergne, TN; and Teledyne Advanced Materials (formerly Teledyne Wah Chang Huntsville), Huntsville, AL. Net production statistics for tungsten metal powders, carbides, and chemicals are shown in table 2. *(See table 2.)*

Curtis Tungsten Inc., operator of the Andrew Tungsten Mine near Los Angeles, CA, declared a force majeure in 1993, citing low tungsten concentrate prices, and did not produce any concentrate during the year.

U.S. Tungsten Corp., Bishop, CA, continued to produce a limited quantity of concentrate during 1993. As with its mine production, operations at its APT conversion facility were limited because of the low prices existing in the tungsten market.

GTE Corp., Stamford, CT, completed the sale of its North American lamp and lighting business to Osram, a Siemans AG company based in Munich, Germany, in early 1993. Included in this sale was GTE Products Corp., Towanda, PA, a tungsten processor and producer of a variety of tungsten materials and end-use items. Additionally, GTE Corp. completed the sale of its GTE Valenite cemented carbide division, Troy, MI, to Cincinnati Milacron Inc., Cincinnati, OH, effective February 1, 1993. The new company, named Valenite Inc., became a wholly owned subsidiary of Cincinnati Milacron.

Kennametal Inc., Latrobe, PA, a producer of tungsten carbide for use in cemented carbides, completed purchase of the cemented carbide tool and tooling system manufacturing business of Hertel AG, Furth, Germany, in the fourth quarter of 1993. According to a Kennametal executive, it was anticipated that the shared resources of the two companies would provide substantial opportunities for improved operating efficiency in Europe.

General Electric Co. (GE) announced on October 4, 1993, that it was discontinuing production of tungsten carbide powder at its Euclid, OH, facility. As a result, the company would no longer be a market supplier of the carbide, which is used to produce cutting and wear-resistant components for a variety of applications. GE planned to focus on the production of tungsten metal powder, both for internal consumption in the manufacture of wire for its lamp and lighting business, and for supply to end-use consumers in various specialty applications.

Consumption and Uses

Total reported domestic consumption of tungsten in primary end-use categories (table 3) increased by about 10% in 1993 compared with that of 1992. Demand generally increased in the cemented carbide end-use sectors that included the combined cutting tool, mining tool, oil drilling equipment, and wear-resistant component industries. Demand for mill products made from metal powder, as well as demand for tungsten chemicals and directly reusable tungsten scrap, also increased in 1993. Counter to these increases was a decrease in the use of ferrotungsten in steels that included the tool, alloy, and stainless steel sectors. *(See table 3.)*

Reported consumption of obsolete tungsten scrap, reprocessed either chemically or physically for reuse, decreased to 2,158 tons of contained tungsten in 1993 from 2,638 tons in 1992. Increased competition associated with the continued low prices for primary and intermediate tungsten materials likely contributed to the decline in demand for this form of scrap.

Gradual strengthening of the U.S. economy influenced the overall increase in demand for tungsten products during 1993. A slow economic recovery in the major industrial sectors of auto, aerospace, and construction, where a significant quantity of tungsten is consumed as cemented carbide components, was begun in 1993. Demand for cemented carbide components in the oil drilling industry fluctuated during 1993. The number of operating oil drilling rigs in the United States rapidly declined from a yearly high of 928 in early January to a yearly low of 600 rigs in mid-March, then gradually increased to 883 rigs by yearend 1993, according to figures reported by the International Association of Drilling Contractors and Baker Hughes Inc.

Markets and Prices

The average Metal Bulletin (London) combined price for wolframite and scheelite concentrates, instituted in April 1992 (table 4), declined to $34.56 per mtu tungsten oxide from an average $55.36 per mtu in 1992. The concentrate price trend for 1993 continued the downward trend that existed in 1992, increasing only slightly in the final 2 months of the year. *(See table 4.)*

Prices for APT on the world market decreased during 1993, consistent with the declining prices for concentrates. According to quotations in Metals Week, the average price for APT on the U.S. market, duty-paid and delivered to processing plants, decreased by 21% from an average of $58.42 per mtu in January to an average of $46.30 per mtu by yearend. Similarly, quotations for Chinese No. 1 Grade APT in Hong Kong declined by 25% during the year from an average price of $39.50 per mtu to an average of $29.50 per mtu. The average price of APT on the European free market, decreased by 26%, from $47 per mtu to $35 per mtu, according to quotations published in Metal Bulletin (London).

Foreign Trade

Comprehensive lists of U.S. export and import trade statistics by material quantity and value and by country of destination and origin are shown in tables 5 through 13. Import tariff rates for the various materials are shown in table 14. *(See tables 5 through 14.)*

The pattern of imports of tungsten materials by U.S. processors during 1993 showed a further shift away from tungsten concentrate and toward the intermediates ammonium paratungstate, tungsten oxide, and sodium tungstate. The shift continued a trend that began in 1991, subsequent to the imposition of the 151% antidumping tariff on imports of concentrate from China that effectively halted such imports. In addition, as concentrate prices declined during this period, other concentrate producers were forced to close their mines or reduce production, further decreasing the supply of concentrate to the market. In 1993, concentrate represented a 36% share of the combined imports of concentrate and intermediates from all sources, compared with a 63% share in 1992 and an 87% share in 1990, prior to the antidumping tariff. The share of these combined imports of concentrate and intermediate materials provided by China as intermediate materials was 51% in 1993.

Total U.S. imports of all tungsten materials increased by 13% in 1993 compared with those of 1992. China continued to be the dominant supplier, providing about 44% of all imported tungsten materials. China's share of the total quantity of tungsten materials imported by the United States was up about 18 percentage points compared with that of 1992. The total quantity of tungsten materials imported from China increased from 1,820 tons of contained tungsten in 1992 to 3,280 tons in 1993. Of the total tungsten imports from China in 1993, the percentage imported as intermediate products was 74%, unchanged from that of 1992. Major suppliers of concentrates to the United States in 1993 included Bolivia (44%), Peru (17%), Portugal (14%), and Rwanda (8%).

World Review

Capacity.—Rated capacity for mines and mills as of December 31, 1993, was approximately 42,000 tons of contained tungsten. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure.

Mine capacity for tungsten is based on published reports, maximum production statistics, and estimates. The latter is utilized particularly for certain countries where capacity information is either incomplete or unavailable. Estimated annual mine production capacity declined by about 12% in 1993 compared with that of 1992. Some of this decline was attributed to an estimated lower capacity in the C.I.S., associated with the transition to a market economic system within the individual republics of the former U.S.S.R. Decline in mine capacity was attributed further to the apparent closure of additional smaller, inefficient mines in China, as well as to production declines at some larger mines, following the discontinuation of Government subsidies to tungsten mines during the last quarter of 1992.

Australia.—Poseidon Ltd., owner of the Mount Carbine wolframite mine in Queensland, sold most of the equipment at the mine during 1993, effectively closing the mine permanently. Efforts to find a buyer for the mine were unsuccessful, considering the depressed state of the tungsten concentrate market in 1993. Earlier poor market conditions had forced the closure of the Mount Carbine facility and subsequent placement on care-and-maintenance status in late 1986, about 1 year after Poseidon had purchased a controlling interest in the mine from Queensland Wolfram Pty. Ltd. Concentrate was produced from the open pit portion of the mine during the early 1980's, but plans to recover concentrate from the underground portion of the mine had to be cancelled when the closure occurred in 1986.

Annual concentrate production and consumption statistics for the world are shown in tables 15 and 16, respectively. *(See tables 15 and 16.)*

Austria.—The Mittersill Tungsten Mine, Mittersill, was forced to close because of the depressed tungsten market. Wolfram Berbau and Huttengesellschaft, operator of the mine, disclosed that the mine was placed on care-and-maintenance status at the end of February 1993. Until market conditions improved, concentrates were expected to be obtained from the spot market, as necessary, to supplement the company's existing concentrate stocks in support of its tungsten metal powder production operation. According to the operators, the concentrate production portion of the company's integrated facility for making the tungsten powder had become uneconomical in light of the existence of low-priced tungsten intermediate materials on the world market.

China.—According to published reports, China began a more centralized procedure to control the issuance of export licenses for tungsten concentrates and intermediate products, effective April 1, 1993. Under the revised procedure, licenses were to be obtained from the main office of the Ministry of Foreign Economic Relations and Trade (MOFERT) in Beijing through the head offices of China National Nonferrous Metals Import and Export Corp. (CNIEC) and China National Minerals and Metals Import and Export Corp. (Minmetals). Prior to this new ruling, licenses were issued directly to Provincial branches of CNIEC and Minmetals by local branch offices of MOFERT. The previous, less restricted licensing procedures likely contributed, in part, to overproduction, resulting in lower market prices, particularly when coupled with declining worldwide demand for tungsten. In related action, the Chinese limited the number of tungsten materials for which the Provincial branches of CNIEC and Minmetals could receive export licenses to that of blue oxide and sodium tungstate. Export licenses for tungsten concentrates and the remaining intermediate products, excluding tungsten metal powder and tungsten carbide powder, were then planned to be issued to the head offices of CNIEC and Minmetals.

The cemented carbide industry in China continued to expand, according to a report presented to the delegates at the sixth International Tungsten Symposium held in Guangzhou, China, in November 1993. A member of the Zhouzhou Cemented Carbide Co., Hunan Province, China, stated that carbide production had passed the 5,000-ton-per-year mark in

1993. China nearly doubled its cemented carbide production in the 1980's, increasing from 2,400 tons in 1980 to 4,740 tons in 1990.

Commonwealth of Independent States.—During 1993, there were increased efforts by the republics of the former U.S.S.R to market a variety of tungsten-containing materials and products. Metallurgical operations that were formerly staffed and funded to meet the defense and aerospace requirements, as well as the domestic needs for mining and metalworking, were continuing their plans to provide quality tungsten merchandise to the market. The merchandise expected to be marketed included tungsten oxide, and metal and carbide powders, as well as a number of wrought shapes, such as rod, wire, tube, strip, and foil, and certain end-use products, consisting of cemented carbide cutting tools, drill bits, and wear parts.

International Tungsten Industry Association (ITIA).—The International Tungsten Industry Association (ITIA) held its sixth International Tungsten Symposium in Guangzhou, China, November 2-4, 1993. Speakers from eight countries presented a wide range of papers covering subjects, including tungsten supply, demand, pricing, trade patterns, recycling, and mining, as well as technological developments in process control, extractive metallurgy, and end-use applications. Information provided by the China Tungsten Industry Association on tungsten production and consumption in China generated particular interest at the symposium. According to a published report, the information presented by the Chinese at the meeting still left a number of questions unanswered regarding the actual production and consumption statistics. There seemed to be general agreement among the attendees, however, that production of both concentrate and intermediate products was down appreciably and that the inventories of these materials also had declined recently. The actual inventory levels still remained uncertain. In an attempt to provide an explanation for its international pricing structure, Chinese officials cited a number of factors, in addition to production costs, that affected this structure. These included the maintenance of unspecified production levels to avoid unemployment, the sale of stockpiled material worldwide, the decline in sales to Eastern Europe and the C.I.S., the existence of domestic competition for the tungsten market, and the desire by consumers to acquire less expensive tungsten materials.

Japan.—Japan reportedly closed its last tungsten mine in September 1993. The mine, in Yamaguchi prefecture and owned by Tanaka Kogyo, supplied a portion of Japan's demand for tungsten, but for most of 1993 it operated well below capacity. Falling market prices for the intermediate tungstates made it more economical and practical to import additional quantities of the intermediates, mainly from China, than to domestically produce and process the concentrate.

Peru.—Minera Regina ceased production of concentrate from tailings at its Palca XI tungsten mine southeast of Lima at the end of July 1993. The company began producing concentrate from tailings in the first quarter of 1993, after persistent low prices for concentrate resulted in the termination of all new mining at the facility. As a result of this closure of the tailings processing unit, Minera Regina subsequently invoked force majeure and temporarily suspended shipments of concentrate to its customers.

Portugal.—The Panasquiera tungsten mine near Fundao was closed at the end of 1993. According to a spokesperson from the parent company, Minorco SA of Portugal, the relentless decline in the tungsten market was the reason for the closure. Efforts to continue operation of the mine through a management buy-out initiative were unsuccessful. Purchase of the mine by another company remained a possibility. Production at the Panasqueira Mine had been reduced to about 30% of capacity by late 1993. The Panasquiera Mine was the last operating tungsten mine in Europe following the placement of Austria's Mittersill Mine on care-and-maintenance status at the end of February 1993. There reportedly were no plans to place the Panasquiera Mine on care-and-maintenance status.

Russia.—Russia was approved for Generalized System of Preferences (GSP) trade status, effective October 16, 1993, following the signing of a proclamation by the President on September 30, 1993, to carry out this action. Under GSP, imports of numerous Russian materials were permitted to enter the United States duty free rather than be assessed the duty that presently exists under most-favored-nation trade status. Tungsten materials affected by the new GSP status included concentrates, ferrotungsten, carbide powder blends, and certain forms of waste and scrap.

United Nations Conference on Trade and Development (UNCTAD).—The Second Meeting of the Intergovernmental Group of Experts on Tungsten (IGE) was held in Geneva, Switzerland, November 8-10, 1993. A representative from the UNCTAD Secretariat's office provided an overview of the status of the world tungsten industry. A pessimistic picture of the current situation and short-term outlook for the tungsten market was presented in this overview. Significant production decreases that had occurred recently were tempered by declining demand, leaving the tungsten market in a continued weak position. Poor performance of the world economy and changing structural conditions in both the economy and industry were significant factors affecting demand. In addition, there were major geographical shifts in the international source of supply. The latter contributed to an abundant availability of tungsten materials in recent years that provoked an associated market instability. Prospects for recovery in the tungsten market were contingent on a significant strengthening of the world economy. The need to improve transparency in the statistics provided by the member IGE countries to UNCTAD again was expressed during this meeting. With regard to the examination of statistics, it was stated that the task before the IGE was to update, revise, and strengthen these statistics. Despite efforts to make the UNCTAD statistics as complete as possible, significant gaps that could only be remedied by member countries remained.

The IGE again discussed the matter of submission of project proposals for funding under UNCTAD's Common Fund for Commodities. The fund supports developmental activities within the individual commodities embraced by UNCTAD. At the first meeting of the IGE, a decision had been made to request the Secretary General of UNCTAD to submit for funding, on its behalf, two separate proposals, one from the Chinese delegation entitled "Development of the Rare Earth Doped Cemented Carbide and its Mechanism Research," and one from the ITIA entitled "Health and Environmental Effects Testing of Tungsten Materials." The IGE's recommendation for financing of these proposals was approved on a technical and market basis, provided that no written statement to the contrary, with explanation, was received from any member of the IGE by the Secretary General of UNCTAD by February 11, 1993. Subsequently, the Secretary General of UNCTAD received two letters, one from the delegation from the United Kingdom expressing objections to China's proposal and one from the Chinese delegation expressing objections to the ITIA's proposal. Both delegations contended that the proposals did not fulfill the criteria for financing under UNCTAD's Common Fund. Prior to the second meeting of the IGE, the Director General of the Common Fund for Commodities rejected both of the IGE's project proposals submitted for funding. The chairman of the second meeting suggested that the Chinese delegation resubmit its proposal at the third meeting and stressed that other delegations also consider submitting proposals at this meeting.

A provisional agenda for the third meeting of the IGE was adopted. Essentially, the IGE agreed that its future activities should again include the following: a review of the current market situation, short-term outlook, and medium- to long-term perspectives; a consideration of project proposals submitted by Governments and industry for possible financing under UNCTAD's Common Fund for Commodities; and a consideration of other ways, means, and measures to improve the functioning and stability of the tungsten market through strengthened international cooperation between Governments and industries of producing and consuming countries.

Current Research

Russian scientists developed a method for depositing tungsten films in a glow discharge system using tungsten chlorides. Glow discharge is a luminous electrical discharge process without sparks through a gas. The process was said to enable the deposition of films with controlled grain size, texture, and composition at temperatures that avoided significant interaction between substrate and coating. Excellent results were obtained with tungsten films deposited on a variety of articles that were subsequently exposed to ion radiation, thermocycling, and high temperatures.[1]

The service life of crucibles used for melting rare-earth metals was increased significantly through the development of a new tungsten alloy containing 20% yttria. Excellent corrosion resistance was exhibited by the new alloy prepared by pressure sintering. This corrosion resistance, combined with improved flexural strength of the tungsten, permitted crucibles to be made with greater durability than conventional types made of tantalum. Using the new alloy, infiltration of crucible material into the molten rare-earth metals was reduced to 10% of that occurring with a tantalum crucible, thereby increasing by tenfold the service life of the crucible.[2]

A technique was developed to impart wear-resistant properties equivalent to that of cemented tungsten carbides to the surface of ordinary steels and stainless steels. In this surface reforming technique, the base metal steel is diffused to form an adherent bond with a cemented tungsten carbide layer while sintering the tungsten carbide target material in a vacuum. Preparation of coated steel, wear-resistant parts with greater variations in size, shape, and machining method and at lower cost than solid, wear-resistant cemented carbide parts were said to be possible.[3]

Dense, complex electronic components consisting of tungsten and copper were prepared without the need of an infiltration step using a new W-Cu powder called Tungstar developed by Sylvania Chemicals and Metals, Towanda, PA. The components can be produced with copper uniformly dispersed throughout solely by utilizing pressing and sintering steps. Elimination of the infiltration step simplifies the manufacture of components such as heat sinks and also permits the creation of smaller parts. Content of the copper in the components can range from 1% to 50% depending upon the thermal and electrical characteristics required in the practical use of the component.[4]

A new thermochemical processing method for preparing high surface area powders, starting from homogeneous precursor compounds, was developed. The method was applied successfully to the synthesis of novel nanostructured tungsten- and tungsten carbide (WC)-base materials. Nanostructured WC-cobalt powders were consolidated by low-pressure plasma spraying and by cold compaction and liquid-phase sintering. The use of vanadium carbide (VC) as a grain growth inhibitor was essential to mitigate the WC grain growth during liquid-phase sintering. Theoretically dense, VC-doped WC-cobalt materials prepared by this method displayed superior hardness, and wear and cracking resistance.[5]

A method was discovered to extend the life of an Earth satellite using a fine, doped tungsten heating element in association with the thruster burns that are used to periodically correct the satellite's orbit. Under normal conditions, solar winds, lunar gravity, the Earth's magnetic field, and other forces regularly move a satellite out of its prescribed orbit. During a satellite's average life of 15 years, most of the onboard thruster fuel is burned during these orbit corrections. In the new method described, the tungsten heating element effectively adds energy to the exhausting propellant during each thrust motor burn, thereby extending the useful period of the onboard fuel and, therefore, the life of the satellite.[6]

OUTLOOK

Based on reported consumption of all tungsten products during the first 5 months of 1994, the total annual demand for tungsten materials in the United States in 1994 was estimated to be about 8,000 tons of contained tungsten. This would represent an increase in consumption of approximately 6% compared with the 7,581 tons reported for 1993. The economic recovery rate in 1994 is expected to exceed slightly the modest gains the economy experienced in 1993. As a result, overall demand for cutting and wear-resistant components integrally associated with the metalworking, machining, construction, transportation, mining, and oil and gas drilling industries is expected to increase moderately in 1994. In particular, the consumption of cemented carbide tool bit inserts is expected to increase as the automobile market grows and the requirement for machined automobile parts correspondingly rises. In the short term, demand for tungsten in the lighting, electrical, and electronic sectors is expected to continue to increase slowly, although there could be a significant erosion of this demand, should the recent breakthroughs in the development of tungsten-free light bulbs begin to capture a portion of the lighting market. The general rate of growth in tungsten demand will continue to be dampened by the effects of substitution in the cutting and wear-resistant component industries as well as by technological improvements within the industry that result in a more efficient use of tungsten.

The sources of future supplies of tungsten concentrate and intermediate materials for U.S. consumption became less certain by the end of 1993 as producers were forced either to decrease production or to close their operations as a result of a continuing poor market. China, the traditional major supplier of tungsten to the market, experienced a significant production decline, with a further decline possible in the short term. Additionally, China was believed to have nearly exhausted its supply of concentrate stocks. Consequently, a more balanced tungsten supply-demand condition began to emerge at the end of 1993. In the short term, the tungsten market is expected to correct for the transition from an oversupply of tungsten to one that more closely balances its supply and demand, effectively allowing for the entrance of more producers into the market.

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TABLE 1
SALIENT TUNGSTEN STATISTICS

(Metric tons of tungsten content unless otherwise specified)

		1989	1990	1991	1992	1993
United States:						
Concentrate:						
Mine production		W	W	W	W	W
Mine shipments		W	W	W	W	W
Value	thousands	W	W	W	W	W
Consumption		7,725	[1]5,878	[1]5,309	4,313	[2]2,866
Shipments from Government stocks		466	—	—	—	—
Exports		203	139	21	38	63
Imports for consumption		7,896	6,420	7,837	2,477	1,721
Stocks, Dec. 31:						
Producer		10	16	26	44	44
Consumer		1,261	1,077	1,778	702	592
Ammonium paratungstate:						
Production		7,831	[r] [1]6,327	[r] [1]5,856	[r]5,764	[1]4,733
Consumption		8,493	8,787	[3]8,897	7,013	6,969
Stocks, Dec. 31: Producer and consumer		915	896	578	333	420
Primary products:						
Net production		8,749	[4]4,677	8,980	[r]8,451	9,406
Consumption		7,990	8,496	7,981	6,906	7,581
Stocks, Dec. 31:						
Producer		1,562	[5]1,459	[5]1,667	[5]1,508	[5]1,482
Consumer		761	793	796	601	716
World: Concentrate:						
Production		[r]51,038	[r]51,805	[r]48,567	[r]37,452	[e]29,509
Consumption		[r]54,912	[r]45,255	[r]40,300	[r]32,605	[e]31,006

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

[1] Excludes 2 months of "Withheld" data.

[2] Excludes 3 months of "Withheld" data.

[3] Excludes 1 month of "Withheld" data.

[4] Includes only hydrogen-reduced metal powder and chemicals.

[5] Excludes tungsten carbide-cast and crystalline.

TABLE 2
NET PRODUCTION[1] AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES

(Metric tons of tungsten content)

	Hydrogen-reduced metal powder	Tungsten carbide powder		Chemicals	Total
		Made from metal powder	Cast and crystalline		
Net production 1993	4,661	4,745	W	W	9,406
Net production 1992	[r]4,008	[r]4,443	W	W	[r]8,451
Producer stocks, Dec. 31, 1993	816	519	W	147	1,482
Producer stocks, Dec. 31, 1992	753	611	W	144	1,508

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

[1] Gross production less quantity used to make other products in table.

TABLE 3

REPORTED CONSUMPTION AND STOCKS OF TUNGSTEN PRODUCTS IN THE UNITED STATES IN 1993, BY END USE

(Metric tons of tungsten content)

End use	Ferro-tungsten[1]	Tungsten metal powder	Tungsten carbide powder	Tungsten scrap[2]	Other tungsten materials[3]	Total
Steel:						
Stainless and heat-resisting	39	—	—	4	—	43
Alloy	40	—	—	—	—	40
Tool	377	—	—	W	W	388
Superalloys	W	W	37	165	W	282
Alloys (excludes steels and superalloys):						
Cutting and wear-resistant materials	—	259	4,805	(4)	—	5,064
Other alloys[5]	W	W	—	W	—	291
Mill products made from metal powder	—	1,434	—	—	—	1,434
Chemical and ceramic uses	—	W	(4)	—	W	37
Miscellaneous and unspecified	W	—	—	—	W	2
Total	474	1,729	[6]4,842	455	83	[7]7,581
Consumer stocks, Dec. 31, 1993	29	33	[6]567	87	(8)	716

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

[1] Includes scheelite, natural and synthetic.

[2] Does not include that used in making primary tungsten products.

[3] Includes tungsten chemicals and others.

[4] Included in "Tungsten carbide powder: Cutting and wear-resistant materials."

[5] Includes welding and hard-facing rods and materials and nonferrous alloys.

[6] Based on reported consumption plus information from secondary sources on companies not canvassed; includes estimates.

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

[8] Included in "Tungsten scrap."

TABLE 4

MONTHLY PRICE QUOTATIONS OF TUNGSTEN CONCENTRATE IN 1993

Month	Metal Bulletin (London), European market, 65% WO_3 basis, c.i.f.[1]				Metals Week, U.S. spot quotations, 65% WO_3 basis, c.i.f. U.S. ports, including duty[2]			
	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
January	40.00	50.00	45.00	40.82	42.00	45.00	43.50	47.95
February	35.00	50.00	42.63	38.67	42.00	45.00	43.50	47.95
March	31.00	44.00	37.50	34.02	38.00	45.00	42.00	46.30
April	28.00	43.00	36.38	33.00	38.00	43.00	40.50	44.64
May	27.00	41.00	33.94	30.79	38.00	43.00	40.50	44.64
June	27.00	39.00	33.00	29.94	38.00	43.00	40.50	44.64
July	25.00	39.00	32.44	29.43	38.00	43.00	40.50	44.64
August	20.00	35.00	27.75	25.17	28.00	43.00	35.63	39.27
September	20.00	37.00	27.89	25.30	28.00	40.00	34.00	37.48
October	26.00	39.00	32.13	29.15	28.00	40.00	34.00	37.48
November	27.00	39.00	33.00	29.94	28.00	40.00	34.00	37.48
December	27.00	39.00	33.00	29.94	28.00	40.00	34.00	37.48

[1] Combined wolframite and scheelite quotations. Low and high prices are reported semiweekly. Monthly averages are arithmetic averages of semiweekly low and high prices. The average annual price per metric ton unit of WO_3, of all semiweekly low and high prices was $34.56 for 1993. The average equivalent price per short ton unit of WO_3 was $31.35 for 1993.

[2] Low and high prices are reported weekly. Monthly averages are arithmetic averages of weekly low and high prices. The average annual price per short ton unit of WO_3, of all weekly low and high prices was $38.55 for 1993. The average equivalent price per metric ton unit of WO_3 was $42.49 for 1993.

TABLE 5

U.S. EXPORTS OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1992		1993	
	Tungsten content[1] (metric tons)	Value (thousands)	Tungsten content[2] (metric tons)	Value (thousands)
Austria	3	$25	—	—
Canada	—	—	3	$14
France	—	—	1	3
India	10	75	1	6
Israel	2	13	—	—
Korea, Republic of	—	—	1	3
Mexico	1	9	2	8
Netherlands	21	157	55	269
Singapore	1	5	—	—
South Africa, Republic of	—	—	1	4
Taiwan	—	—	1	3
Total[3]	38	284	63	309

[1] Calculated based upon an estimated value of $58 per metric ton unit WO_3.

[2] Calculated based upon an estimated value of $39 per metric ton unit WO_3.

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

Source: Bureau of the Census.

TABLE 6

U.S. EXPORTS OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Belgium	30	$410	—	—
Germany	34	183	2	$28
Japan	406	2,760	164	2,183
Total	470	[1]3,354	166	2,211

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

Source: Bureau of the Census.

TABLE 7

U.S. EXPORTS OF TUNGSTEN CARBIDE POWDER, BY COUNTRY

Country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Argentina	1	$52	2	$45
Australia	3	120	8	435
Austria	23	384	27	366
Belgium	27	516	11	227
Brazil	7	188	8	168
Canada	316	7,148	373	7,868
Chile	(1)	3	—	—
Denmark	40	413	169	1,120
Finland	1	74	1	81
France	11	282	14	208
Germany	98	3,059	226	3,269
India	(1)	21	(1)	4
Ireland	(1)	19	4	191
Israel	5	365	4	389
Italy	35	1,109	58	1,907
Japan	34	795	83	1,119
Korea, Republic of	(1)	9	1	54
Luxembourg	4	104	3	54
Malaysia	(1)	4	—	—
Mexico	3	159	2	124
Netherlands	6	177	52	716
Singapore	2	144	5	192
South Africa, Republic of	14	149	14	162
Spain	1	12	—	—
Sweden	20	215	84	1,199
Switzerland	9	405	12	742
Taiwan	7	227	4	181
United Kingdom	43	1,816	78	1,504
Venezuela	3	107	3	100
Other	1	22	2	59
Total[2]	715	18,098	1,250	22,484

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 8

U.S. EXPORTS OF TUNGSTEN AND TUNGSTEN ALLOY POWDER, BY COUNTRY

Country	1992			1993		
	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)	Gross weight (metric tons)	Tungsten content[1] (metric tons)	Value (thousands)
Australia	12	10	$112	7	6	$63
Austria	23	19	336	5	4	73
Belgium	11	9	171	1	1	24
Brazil	3	3	175	17	14	17
Canada	40	31	945	36	29	792
Finland	1	1	64	1	1	28
France	4	3	180	1	1	66
Germany	123	99	2,962	104	83	2,456
Hong Kong	1	1	44	2	2	36
Israel	78	62	1,045	121	97	807
Italy	4	3	145	6	5	252
Japan	10	8	164	9	7	198
Korea, Republic of	(2)	(2)	3	1	1	29
Mexico	3	3	89	5	4	115
Netherlands	18	14	181	81	65	661
Singapore	(2)	(2)	3	32	26	455
South Africa, Republic of	(2)	(2)	6	1	1	18
Spain	1	1	11	(2)	(2)	7
Sweden	(2)	(2)	17	23	18	23
Switzerland	2	1	106	5	4	123
Taiwan	26	21	623	23	18	653
Turkey	2	1	38	1	1	16
United Kingdom	33	26	905	34	27	926
Other	1	1	56	1	1	21
Total[3]	395	316	8,380	516	416	7,859

[1] Tungsten content estimated by multiplying gross weight by 0.80.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 9

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Tungsten and tungsten alloy wire:				
Argentina	(1)	$24	1	$6
Belgium	1	47	—	—
Brazil	5	532	4	247
Canada	12	1,134	5	368
China	4	290	1	102
France	2	265	(1)	51
Germany	1	206	3	189
Hong Kong	6	603	1	99
India	22	1,285	17	1,034
Italy	3	306	1	166
Japan	9	1,296	7	898
Korea, Republic of	5	279	3	170
Mexico	4	332	4	230
Netherlands	(1)	72	(1)	17
Poland	(1)	14	(1)	11
Switzerland	(1)	4	(1)	6
Taiwan	7	475	8	440
United Kingdom	1	241	1	150
Venezuela	(1)	6	(1)	—
Other	7	466	9	642
Total	89	7,877	65	4,826
Unwrought tungsten and alloy in crude form, waste and scrap:				
Australia	8	130	32	284
Belgium	—	—	(1)	4
Canada	6	164	11	189
Chile	11	258	4	61
France	(1)	5	—	—
Germany	146	1,435	144	1,265
Israel	—	—	3	39
Japan	1	25	—	—
Mexico	1	29	17	365
Spain	1	15	10	62
Sweden	2	22	5	42
Taiwan	—	—	2	732
United Kingdom	9	169	28	150
Other	2	48	7	63
Total[2]	186	2,302	263	3,256
Other tungsten metal:				
Australia	1	130	2	165
Belgium	(1)	6	(1)	7
Brazil	1	101	2	251
Canada	4	271	9	437
Colombia	(1)	69	1	221
France	(1)	66	1	314

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Other tungsten metal—Continued:				
Germany	4	$250	6	$445
Hong Kong	2	301	4	699
India	1	90	2	119
Ireland	66	3,635	1	69
Italy	10	949	2	134
Japan	8	2,937	6	1,948
Korea, Republic of	2	380	2	139
Mexico	9	814	8	818
Netherlands	1	199	(1)	124
Singapore	1	228	2	432
South Africa, Republic of	1	76	1	81
Sweden	1	80	(1)	12
Switzerland	(1)	67	(1)	120
Taiwan	6	498	9	784
Thailand	1	59	1	65
United Kingdom	21	1,797	10	722
Venezuela	(1)	11	(1)	56
Other	4	804	3	350
Total[2]	144	13,817	70	8,511
Ferrotungsten and ferrosilicon tungsten:				
Belgium	33	79	—	—
Canada	1	9	1	8
Mexico	19	45	—	—
Total[2]	53	132	1	8
Wrought tungsten:				
Australia	(1)	3	—	—
Canada	40	1,180	40	1,264
France	11	329	6	379
Germany	3	183	5	181
India	4	169	8	424
Israel	29	96	10	147
Italy	1	76	4	283
Japan	25	904	12	1,107
Korea, Republic of	—	—	7	598
Mexico	30	185	1	78
Netherlands	10	77	(1)	39
Philippines	3	67	—	—
Saudi Arabia	—	—	19	1,494
Singapore	2	58	2	67
Spain	8	193	6	220
Taiwan	—	—	1	223
United Kingdom	14	242	6	391
Venezuela	—	—	1	21
Other	6	289	3	299
Total[2]	185	4,052	131	7,215

See footnotes at end of table.

TABLE 9—Continued

U.S. EXPORTS OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992 Tungsten content (metric tons)	1992 Value (thousands)	1993 Tungsten content (metric tons)	1993 Value (thousands)
Other tungsten compounds:[3]				
Argentina	(1)	$3	—	—
Brazil	3	46	11	$152
Canada	—	—	6	22
Colombia	—	—	(1)	3
Israel	(1)	3	—	—
Japan	18	64	—	—
United Kingdom	5	36	3	36
Total[2]	27	152	20	213

[1] Less than 1/2 unit.
[2] Data may not add to totals shown because of independent rounding.
[3] Includes only other tungstates.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS FOR CONSUMPTION OF TUNGSTEN ORE AND CONCENTRATE, BY COUNTRY

Country	1992 Tungsten content (metric tons)	1992 Value (thousands)	1993 Tungsten content (metric tons)	1993 Value (thousands)
Bolivia	658	$4,380	762	$3,393
Brazil	36	200	—	—
Burma	232	1,390	55	245
Canada	33	130	—	—
China	15	130	—	—
France	(1)	3	—	—
Japan	—	—	31	142
Mexico	65	369	48	137
Netherlands	24	79	47	161
Peru	613	3,897	299	1,453
Portugal	574	4,424	240	1,546
Russia	—	—	1	4
Rwanda	31	222	132	399
Thailand	61	275	34	168
Uganda	46	168	73	195
United Kingdom	91	599	—	—
Total[2]	2,477	16,265	1,721	7,843

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

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PARATUNGSTATE, BY COUNTRY

Country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
China	287	$1,858	934	$5,082
Germany	64	547	109	1,003
Hong Kong	—	—	115	346
Japan	—	—	(1)	12
Korea, Republic of	16	107	—	—
Netherlands	12	135	—	—
Sweden	—	—	17	39
Total[2]	378	2,647	1,176	6,481

[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. IMPORTS FOR CONSUMPTION OF FERROTUNGSTEN, BY COUNTRY

Country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Austria	—	—	27	$152
China	356	$1,826	516	2,220
France	—	—	1	3
Germany	1	9	(1)	5
Hong Kong	37	253	78	285
Mexico	19	100	31	161
United Kingdom	1	5	—	—
Total[2]	414	2,194	652	2,827

[1] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 13
U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Waste and scrap:				
Australia	—	—	1	$2
Austria	—	—	19	90
Belgium	13	$75	4	30
Brazil	41	201	31	154
Canada	16	99	6	28
China	39	263	74	408
France	16	80	23	89
Germany	323	1,683	241	1,089
Ireland	—	—	46	276
Israel	147	755	85	254
Italy	3	16	41	161
Japan	310	1,763	197	1,109
Korea, Republic of	146	502	8	48
Mexico	13	56	1	5
Netherlands	58	449	36	250
Pakistan	—	—	75	132
Portugal	—	—	13	66
Russia	—	—	10	60
Singapore	42	161	41	133
South Africa, Republic of	56	318	61	277
Switzerland	7	58	—	—
United Kingdom	271	1,247	235	889
Other	4	11	1	6
Total[1]	1,503	7,737	1,250	5,558
Unwrought tungsten, except alloys, alloys, and in lumps, grains, and powders:				
Belgium	4	185	2	104
Canada	12	562	12	369
Germany	16	829	17	745
Hungary	—	—	10	55
Japan	14	727	14	1,165
Korea, Republic of	3	83	—	—
Russia	—	—	4	17
South Africa, Republic of	15	60	1	23
Sweden	(2)	6	—	—
Uganda	27	61	—	—
United Kingdom	56	684	30	322
Other	1	40	5	131
Total[1]	148	3,237	95	2,930
Unwrought tungsten, ingots, shot alloys and other:				
Austria	3	120	(2)	19
Belgium	61	321	—	—

See footnotes at end of table.

TABLE 13—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Unwrought tungsten, ingots, shot, alloys and other—Continued:				
China	9	$219	(2)	$2
Germany	—	—	6	234
South Africa, Republic of	—	—	120	61
Other	(2)	16	4	5
Total[1]	73	675	130	320
Wrought tungsten-wire, plate, sheet, strip, foil, and other:[3]				
Austria	14	1,759	15	1,697
Belgium	1	178	1	397
China	4	158	10	581
France	(2)	12	(2)	122
Germany	5	1,179	6	905
Israel	23	1,324	27	1,407
Japan	95	11,973	76	10,681
Mexico	11	2,301	6	1,193
Netherlands	2	245	5	593
Russia	(2)	10	(2)	10
United Kingdom	2	382	3	322
Other	8	803	8	570
Total[1]	163	20,325	158	18,480
Calcium tungstate:				
China	—	—	158	531
Germany	5	247	3	176
Japan	—	—	(2)	17
Total[1]	5	247	161	723
Tungsten oxides:				
China	742	5,928	[4]1,085	5,063
Germany	1	22	[4]234	737
Hong Kong	13	90	[4]44	188
Russia	—	—	[4]38	315
United Kingdom	—	—	[4](2)	61
Other	—	—	(2)	5
Total[1]	757	6,040	1,401	6,370
Other metal-bearing materials in chief value of tungsten:				
China	1	50	4	101
Germany	(2)	7	—	—
Hong Kong	1	35	—	—
Total[1]	3	92	4	101
Chlorides of tungsten:				
China	—	—	[4]41	192

See footnotes at end of table.

TABLE 13—Continued

U.S. IMPORTS FOR CONSUMPTION OF MISCELLANEOUS TUNGSTEN-BEARING MATERIALS

Product and country	1992		1993	
	Tungsten content (metric tons)	Value (thousands)	Tungsten content (metric tons)	Value (thousands)
Chlorides of tungsten—Continued:				
Other	—	—	(2)	$12
Total	—	—	41	204
Sodium tungstate:				
China	324	$1,917	405	1,593
France	—	—	—	—
Germany	(2)	32	24	105
Hong Kong	10	67	—	—
Japan	1	130	(2)	29
Zambia	—	—	(2)	2
Total[1]	334	2,146	429	1,729
Tungsten carbide:				
Austria	39	538	57	761
Canada	12	448	31	833
China	52	866	53	1,053
France	10	791	3	63
Germany	105	2,127	99	1,687
Hong Kong	8	72	3	41
Japan	(2)	14	1	303
Korea, Republic of	37	621	17	318
Luxembourg	(2)	12	—	—
Mexico	24	1,039	9	344
Sweden	84	2,572	13	364
United Kingdom	12	485	3	60
Other	5	69	3	65
Total[1]	389	9,653	291	5,891

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

[2] Less than 1/2 unit.

[3] Quantity estimated from reported gross weight.

[4] All or part of these data have been referred to the Bureau of the Census for verification.

Source: Bureau of the Census.

TABLE 14

U.S. IMPORT DUTIES ON TUNGSTEN

Item	HTS No.	Rate of duty effective Jan. 1, 1993	
		Most favored nation (MFN)	Non-MFN
Tungsten ores and concentrates	2611.00.0000	$0.375 per kilogram on tungsten content	$1.10 per kilogram on tungsten content.
Tungsten oxides	2825.90.3000	10% ad valorem	45.5% ad valorem.
Tungstic acid	2825.90.6010	3.7% ad valorem	25% ad valorem.
Chlorides of tungsten	2827.39.4000	10% ad valorem	45.5% ad valorem.
Ammonium tungstates	2841.80.0010	10% ad valorem	49.5% ad valorem.
Calcium tungstate	2841.80.0020	10% ad valorem	49.5% ad valorem.
Other tungstates	2841.80.0050	10% ad valorem	49.5% ad valorem.
Tungsten carbide	2849.90.3000	10.5% ad valorem	55.5% ad valorem.
Other tungsten compounds	2850.00.1000	10% ad valorem	45.5% ad valorem.
Mixtures of inorganic compounds, chief value tungsten	3823.90.3500	10% ad valorem	45.5% ad valorem.
Ferrotungsten and ferrosilicon tungsten	7202.80.0000	5.6% ad valorem	35% ad valorem.
Tungsten powders	8101.10.0000	10.5% ad valorem	58% ad valorem.
Tungsten waste and scrap	8101.91.1000	4.2% ad valorem	50% ad valorem.
Unwrought tungsten	8101.91.5000	6.6% ad valorem	60% ad valorem.
Wrought tungsten—bar, rod, sheet, etc.	8101.92.0000	6.5% ad valorem	60% ad valorem.
Wrought tungsten—wire	8101.93.0000	6.5% ad valorem	60% ad valorem.
Wrought tungsten—other	8101.99.0000	5.5% ad valorem	45% ad valorem.

Source: U.S. International Trade Commission.

TABLE 15
TUNGSTEN: WORLD CONCENTRATE PRODUCTION, BY COUNTRY[1]

(Metric tons of tungsten content)

Country	1989	1990	1991	1992	1993[e]
Argentina	20	6	[r]8	[r][e]8	9
Australia	1,371	1,086	237	[r][e]160	100
Austria	1,517	1,378	1,314	[r][e]1,500	300
Bolivia	1,118	1,014	1,065	[r]851	320
Brazil	679	316	223	[r]205	250
Burma[2]	233	351	275	[e]375	270
China[e] [3]	30,200	32,000	[r]31,800	[r]25,000	20,000
Czechoslovakia[e] [4]	[r]75	[r]84	[r]13	[r]—	—
India	12	[r][e]10	[r]11	[r][e]11	3
Japan	296	[r]260	279	[r]347	65
Kazakhstan[e]	—	—	—	500	500
Korea, North[e]	500	1,000	1,000	1,000	1,000
Korea, Republic of	1,701	1,361	780	[r]247	200
Malaysia	—	—	2	3	2
Mexico	170	183	194	[r]162	160
Mongolia	[r]600	500	300	[e]260	250
New Zealand[e]	5	—	—	—	—
Peru	970	1,536	[r]1,232	[r]802	800
Portugal[e]	[r][5]1,376	[r]1,400	1,400	1,200	1,000
Russia[e]	—	—	—	[r]4,000	3,500
Rwanda	[6]105	[6]156	[e]175	[e]175	175
Spain	58	[r]10	[r]—	[r]—	—
Sweden[e]	80	—	—	—	—
Tajikistan[e]	—	—	—	200	150
Thailand	603	290	230	[r]70	85
Uganda[e]	4	4	4	[r][5]66	60
U.S.S.R.[e] [7]	9,300	8,800	8,000	—	—
United Kingdom	28	42	9	[e]10	10
United States	W	W	W	W	W
Uzbekistan[e]	—	—	—	300	300
Zaire	16	17	[e]15	[r]—	—
Zimbabwe[e]	1	1	1	[r]—	—
Total	[r]51,038	[r]51,805	[r]48,567	[r]37,452	29,509

[e] Estimated. [r] Revised. W Witheld to avoid disclosing company proprietary data; not included in "Total."

[1] Table includes data available through July 5, 1994.

[2] Includes content of tin-tungsten concentrate.

[3] Based upon data published in the Yearbook of Nonferrous Metals Industry of China, 1992 and 1993.

[4] Dissolved on Dec. 31, 1992.

[5] Reported figure.

[6] Gross weight reported, estimated to contain 54% W (68% WO_3).

[7] Dissolved in Dec. 1991.

TABLE 16

TUNGSTEN: WORLD CONCENTRATE CONSUMPTION, BY COUNTRY[1]

Country	1989	1990	1991	1992	1993
Argentina	50	29	30	30	30
Australia[e]	50	50	50	50	50
Austria[e]	1,800	1,800	1,600	1,500	700
Belgium	2	—	—	—	—
Brazil	701	363	137	[e]150	100
Bulgaria[e]	50	50	—	—	—
Canada	300	290	255	(2)	—
China[3,4]	[r]19,000	[r]19,000	[r]17,000	[r]17,000	20,000
Czechoslavakia[e]	1,700	[r]950	400	300	300
Germany:					
Eastern states[e]	300	300	(2)	(2)	—
Western states[5]	2,576	749	[e]350	[e]250	—
Hungary[e]	500	200	[r]10	[r]10	10
India	212	217	[e]200	[r][e]200	200
Italy[5]	[e]10	[e]10	—	—	—
Japan	1,538	1,440	1,276	[r]891	850
Kazakhstan[6]	—	—	—	[3]500	[3]500
Korea, North[3]	1,000	1,500	1,500	1,000	1,000
Korea, Republic of[e]	2,000	1,950	[r]1,800	[r]1,400	200
Mexico	[e]5	[e]5	—	—	—
Netherlands	[e]350	[e]200	—	—	—
Russia[6]	—	—	—	[r][3]4,000	[3]3,500
South Africa, Republic of	153	114	161	[e]150	150
Spain[5]	[e]20	[e]20	—	—	—
Sweden	320	380	202	261	95
Tajikistan[6]	—	—	—	[3]200	[3]150
U.S.S.R.[3,7]	14,500	10,000	10,000	—	—
United Kingdom[e]	50	50	20	50	5
United States	7,725	[8]5,878	[8]5,309	4,313	[9]2,866
Uzbekistan[6]	—	—	—	[3]300	[3]300
Total	[r]54,912	[r]45,255	[r]40,300	[r]32,605	31,006

[e] Estimated. [r] Revised.

[1] Source, unless otherwise specified, is Tungsten Statistics, UNCTAD Committee on Tungsten.

[2] Revised to zero.

[3] Estimated by the U.S. Bureau of Mines.

[4] Combined internal consumption plus that which was processed to intermediate products and subsequently exported.

[5] Apparent consumption, production plus imports minus exports.

[6] Formerly part of the U.S.S.R.; data were not reported separately until 1992.

[7] Dissolved in Dec. 1991.

[8] Reported figure; excludes 2 months of "withheld" data.

[9] Reported figure; excludes 3 months of "withheld" data.

VANADIUM

By Henry E. Hilliard

Mr. Hilliard, a physical scientist with more than 20 years of U.S. Bureau of Mines experience, has been the commodity specialist for vanadium since 1986. Domestic survey data were prepared by Sherwood Jordan, statistical assistant; and international data tables were prepared by Jeremy Tidwell, international data coordinator.

Vanadium is a member of a group of elements, including columbium and molybdenum, which, when present in small amounts in alloys, can have a significant effect on their properties. Manufacturers of automobiles and machinery recognized this as far back as the early 1900's, incorporating steels containing vanadium for toughness and fatigue resistance of axles, crankshafts, gears, and other critical components. Vanadium improves the properties of alloys because it reacts with carbon and nitrogen to form refractory carbides and carbonitrides, which act as precipitation strengtheners and grain refiners. For some time, about 95% of vanadium used has been consumed by the ferrous and nonferrous alloy industries.

In addition to its metallurgical uses, vanadium has a wide range of chemical applications. The catalytic activity of vanadium oxide enables the controlled catalytic oxidation of naphthalene and o-xylene to phthalic anhydride and of butane and benzene to maleic anhydride to take place. Both compounds are essential monomers in the production of polyesters and plastics. The first use of a vanadium catalyst in the production of sulfuric acid was employed in the United States in 1926. Since that time, vanadium oxide catalysts have replaced platinum as the catalyst of choice for producing sulfuric acid. Vanadium catalysts have the advantages of superior resistance to poisoning and being relatively abundant and inexpensive compared to platinum. Sulfuric acid has been an important item of commerce for more than 200 years and has been known since the Middle Ages.

The lingering economic downturn that had been dampening U.S. vanadium demand in recent years was still very much in evidence in 1993. The pickup experienced in the rest of the economy had not yet reached the vanadium industry. The heavily steel-dependent vanadium industry found that the recovery that occurred in the domestic economy was not enough to return the industry to the good health it enjoyed during the second half of the 1980's. There were signs, however, that the worst was probably over. Most major markets for downstream vanadium products perked up in 1993, and production of vanadium pentoxide (V_2O_5) started growing again after stagnating in 1992. *(See figure 1.)* As the tables and graphs of this report illustrate, the vanadium industry's performance for the past 4 years, in terms of demand and production, though certainly disappointing when measured against conditions of the late 1980's, held up relatively well for a period of recession. Production never declined significantly, though it essentially stopped growing in 1992, and shipments dipped only slightly, falling off less than 10% in 1992, a loss that was recovered in 1993. Just as the industry never fell sharply into recession, the overall message of 1993 seems to be that it would not rebound quickly to prosperity.

DOMESTIC DATA COVERAGE

Domestic consumption data for vanadium are developed by the U.S. Bureau of Mines from a voluntary survey of all known domestic consumers. In 1993, there were 83 responses to the consumption survey, representing 81% of the total canvassed. These 83 respondents are estimated to have accounted for 95% of total domestic consumption, or about 3,121 metric tons. The estimated consumption of nonrespondents, derived using their past consumption relationships, trends, and data from nonsurvey sources, was about 164 tons. The consumption quantity of 3,973 tons shown in table 1 is the U.S. Bureau of Mines estimate of total U.S. (reported) vanadium consumption.

BACKGROUND

Definitions, Grades, and Specifications

The term ferrovanadium as used by the U.S. Bureau of Mines includes vanadium-carbon-iron-nitrogen proprietary alloys as well as the conventional forms of ferrovanadium. Some of the more common commercial products are listed in table 2. A standard specification for ferrovanadium has been developed by the American Society for Testing Materials (ASTM).[1]

Aluminum-vanadium master alloys contain fixed ratios of vanadium to aluminum and are used in the manufacture of titanium alloys. Amounts of vanadium up to 1 weight percent (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. The Ti-6Al-4V alloy presently accounts for more than 50% of the titanium-base alloy market.

Products for Trade and Industry

Vanadium is usually traded on the international market in the form of technical-grade V_2O_5 and 50% to 80% FeV. Most world exports of vanadium raw material are in the form of vanadium-bearing iron slag from China and the Republic of South Africa. The U.S. and Western European converters are the major importers of these raw materials. U.S. and Western European converters are the major exporters of downstream vanadium products such as vanadium oxides and FeV to the many small consuming countries. These converters also compete for the major markets for pentoxide and FeV in Japan and the Republic of Korea. Trade in ferrovanadium is dominated by the major European and U.S. converters. A large part of this trade is within Europe, but exports also are made to many other consuming countries. *(See table 8.)*

Industry Structure

The vanadium industry has a five-tiered structure with facilities on six continents. As expected, mines and oilfields form the base of the structure (figure 1). Since 1979, an estimated 83% of world production has come from vanadiferous magnetite (Fe_3O_4). The principal sources of the magnetite ore were China, the Republic of South Africa, and Russia. World vanadium production for 1987-91 is shown in table 14. The other 17% of the vanadium was recovered from other pertroliferous materials and spent catalysts.

The second tier is a set of economically unrelated facilities that include (1) pig iron plants with slag recovery units, (2) elemental phosphorus smelters, and (3) generators of petroleum residues, fly ash, and spent catalysts that contain vanadium either as the active material or as a contaminant.

The third tier consists of (1) acid leaching plants with solvent extraction circuits and (2) salt roasting operations. Technical-grade V_2O_5 and NH_4VO_3 are the principal products at this level.

To have an easily marketable product, it is customary at this point to either convert the oxides into an alloy or upgrade their purity to greater than 98.5 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 a considerable distance from the mills and slag plants and frequently blend feed materials to improve recovery.

Of the more than 30 privately owned vanadium companies, only 1, the Republic of South Africa's Highveld Steel & Vanadium Corp., 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 Strategic Minerals Corp. (Stratcor), have extensive operations on the second, third, and fourth tiers. Shieldalloy traditionally used Highveld slag as its starting material for low vanadium grades of ferrovanadium.

The fifth tier is composed of producers of vanadium specialty alloys, high-purity vanadium metal, primary vanadium chemicals, and vanadium catalysts. Reading Alloys Inc., Akzo Chemical Co., and Teledyne Wah Chang Albany illustrate the diversity of operations at this level.

The Republic of South Africa is the world's largest producer of ore and vanadium-bearing slag. Its annual production of more than 17,000 tons is approached only by production in Russia. The bulk of Russian production has been traditionally consumed internally or by other Eastern European countries. In 1993, vanadium products of Russian origin began appearing in the United States, Europe, and Japan. Other major producers include China and the United States. Canada, Japan, and Western Europe are heavily dependent on imports of vanadium slag and pentoxide from the Republic of South Africa.

Geology-Resources

Vanadium is found in many parts of the world, usually in association with other minerals. There are few ores from which vanadium can be economically extracted as a single product. It is, therefore, often extracted as a byproduct or coproduct in the production of other elements, such as iron, phosphorus, or uranium. Increasing amounts are being recovered from petroleum residues and spent catalysts. The world also has extensive subeconomic resources of vanadium contained in oil sands, carbonaceous shale, and bauxite.

The crustal abundance of vanadium is estimated to be 100 to 150 parts per million (ppm), about twice that of copper, 10 times that of lead, and almost 100 times that of molybdenum.[2] As a result, trace vanadium mineralization occurs in a wide range of geologic provinces and environments. At the same time, ore deposits of vanadium are rare because much of the vanadium in igneous rocks occurs dispersed in the relatively insoluble trivalent state and substitutes for ferric iron in chromite, ferromagnesian silicates, ilmenite, and magnetite. Because of the substitutional phenomenon at the atomic level, vanadium is more abundant in mafic (those high in magnesium and iron) than silicic rocks. Gabbros and norites typically contain 200 to 300 ppm vanadium compared with 5 to 80 ppm for granites. When mafic rocks weather in a humid climate, the vanadium remains in the trivalent state or is weakly oxidized to the relatively insoluble tetravalent state. In either case, the vanadium is captured along with aluminum in the residual clays. Subsequent leaching of the clays can produce bauxite and lateritic iron ores that contain 400 to 500 ppm vanadium. When mafic rocks are intensely oxidized in an arid climate, some of the vanadium is converted to the pentavalent state. The pentavalent cation is considerably more soluble than the trivalent cation, is readily dissolved by ground water, and can be transported over long distances. This transport phenomenon can be observed in arid parts of Western Australia where carnotite precipitates from ground water in calcreted drainage systems.[3] At Yeelirrie, for example, thin films of carnotite were formed in the voids and cavities of river fill when ground water percolated through a tertiary river channel.

Organic materials frequently play a key role in the depositional process by helping to create a reducing environment. At many locations on the Colorado Plateau, carnotite, tyuyamunite, and other secondary uranium-vanadium minerals replace fossil logs and other carbonized plant debris. Some of the best examples of this phenomenon can be seen in the Monument Valley and White Canyon districts where uranium-vanadium ores have been deposited in paleochannels of the Shinarump Member of the Upper Triassic Chinle Formation. Fossils in the Shinarump indicate that the stream channels were cut into the underlying Moenkopi mudstones and then filled with sands, pebbles, and plant debris before the end of the Triasssic Period 195 million years ago. Although the uranium-vanadium ores are associated with plant remains, the two elements were precipitated from aqueous solutions percolating through the stream channels long after the host sandstones and conglomerates had formed. The genesis and age of the mineralization remain controversial.

The role of vanadium during the formation of fossil fuels is obscure. There appears to be a relationship between the relatively high concentration of vanadium in coal and petroleum and the burial and subsequent degradation processes that apparently formed the fuels from organisms. The structures of the vanadyl porphyrins found in crude oil are approximately identical to the structures of chlorophyll (magnesium-centered porphyrins present in green plants) and hemoglobin (iron-centered porphyrins present in the red corpuscles of blood). The ratio of vanadium to nickel in crude oil is a function of the oxidation-reduction potential (Eh), the hydrogen ion activity (pH), and sulfide activity of the environment in which the oil source rocks were deposited. The two metals both form stable metallo-organic complexes in the high molecular weight fractions of crude oil.[4] Cleavage of these vanadium and nickel bonds will not occur unless the crude oil is subjected to a temperature greater than 300° C. As a result, the vanadium-to-nickel ratio remains constant for a specific reservoir even when the lower molecular weight components migrate away. The ratio is therefore useful in identifying unmetamorphosed crude oil from different depositional facies of the same source rock.

Technology

Mining.—In the United States, vanadium is recovered as a principal mine product from Arkansas clay, as a coproduct from carnotite ores, and from ferrophosphorus slag as a byproduct in the production of elemental phosphorus. Increasingly, vanadium also is being recovered from petroleum refinery residues, fly ash, and spent catalysts. In China and the Republic of South Africa, vanadium is recovered as a byproduct of pig iron production from titaniferous magnetite.

Processing.—The steel industry accounts for more than 80% of the world's consumption of vanadium as an additive to steel. It is added to the steelmaking process as a ferrovanadium alloy, which is produced commercially by the reduction of vanadium pentoxide or vanadium-bearing slag with aluminum, carbon, or ferrosilicon.

The first stage in the processing of vanadium-bearing ore is the production of an oxide concentrate. The ore is crushed, ground, screened, and mixed with a sodium salt. This mixture is roasted at about 850° C to convert the oxides to water-soluble sodium metavanadate. The vanadium is extracted by leaching with water and precipitated at pH 3 as sodium hexavanadate (red cake) by the addition of sulfuric acid. The red cake is fused at 700° C to yield a dense, black product that is sold as technical-grade vanadium pentoxide. Technical-grade vanadium pentoxide contains a minimum of 86 wt % pentoxide and a maximum 8 wt % sodium oxide. The red cake may be purified further by dissolving it in an aqueous solution of sodium carbonate. Aluminum, iron, and silicate impurities precipitate from solution upon pH adjustment. Ammonium metavanadate is then precipitated by the addition of ammonium chloride. The precipitate is calcined to give a vanadium pentoxide product of greater than 99.8% purity.

Vanadium is extracted as a coproduct with uranium from carnotite by direct leaching of the ore with sulfuric acid. An alternative method is roasting the ore followed by countercurrent leaching with dilute sulfuric acid. In some cases, the first leach may be with a sodium carbonate solution. The uranium and vanadium are then separated from the pregnant liquor by liquid-liquid extraction techniques.

More recently spent catalysts have become a major source of vanadium. The catalyst may be either oxidation catalyst used in the production of sulfuric acid and maleic anhydride or hydroprocessing catalyst used in petroleum refining. Vanadium is recovered by first roasting the material in a controlled atmosphere to solubilize the vanadium and other trace metals; e.g., molybdenum and nickel. It is then milled, leached, and filtered to enable the separation of solids from the solution containing vanadium. The solutions go through various precipitation steps prior to the precipitation of vanadium as ammonium metavanadate, which is then decomposed and fused to form V_2O_5 or used directly to make other vanadium chemicals. AMAX Metals Recovery Inc., Braithwaite, LA, uses a somewhat different process to recover cobalt, molybdenum, nickel, and vanadium from alumina-based spent catalysts. The process developed by AMAX in the early 1980's uses a two-stage caustic leach process, one to solubilize vanadium and molybdenum, and the other to solubilize alumina. This process separates the spent catalysts into four products: molybdenum trisulfide, vanadium pentoxide, alumina trihydrate, and a nickel-cobalt concentrate.

In China and the Republic of South

Africa, vanadium is concentrated in slag resulting from the production of pig iron from magnetite ore. The ore, containing 1.5% to 2.5% vanadium pentoxide, is partially reduced with coal in rotary kilns. The ore is then melted in an enclosed furnace that produces a slag containing most of the titanium and pig iron containing most of the vanadium. After the titanium-bearing slag is removed, the molten pig iron is blown with oxygen to form a slag containing 12 to 24 wt % vanadium pentoxide. The slag is separated from the molten metal and then may be used as a high-grade vanadium raw material in the usual roast-leach process.

In the aluminothermic process for preparing ferrovanadium, a mixture of technical-grade pentoxide, aluminum, iron scrap, and a flux are charged into an electric furnace, and the reaction between aluminum and pentoxide is initiated. The reaction is highly exothermic, producing very high temperatures. The temperature can be controlled by adjusting the particle size of the reactants and the feed rate of the charge and by using partially reduced pentoxide or by replacing some of the aluminum by a milder reductant. Ferrovanadium containing up to 80 wt % vanadium can be produced by this method.

Ferrovanadium also can be prepared by the thermit reaction, in which vanadium and iron oxides are coreduced by aluminum granules in a magnesia-lined steel vessel or in a water-cooled crucible. The reaction is initiated by a barium peroxide-aluminum ignition charge. This method also is used to prepare vanadium-aluminum master alloys for the titanium industry.

The production of ferrovanadium by the reduction of vanadium concentrates with silicon involves a two-stage process in which technical-grade vanadium pentoxide, ferrosilicon, lime, and flurospar are heated in an electric furnace. An iron alloy containing about 30% vanadium but undesirable amounts of silicon is produced. The silicon content of the alloy can be reduced by adding more pentoxide and lime to effect the extraction of most of the silicon into the slag phase. An alternative process involves the formation of a vanadium-silicon alloy by the reaction of vanadium pentoxide, silica, and coke in the presence of a flux in an arc furnace. The molten metal reacts with vanadium pentoxide yielding ferrovanadium. The silicon reduction method has not been used extensively.

A process developed by Foot Mineral Co., Cambridge, OH (now Shieldalloy Metallurgical Corp.), has been used to produce tonnage quantities of ferrovanadium. This process involves the reaction of vanadium-bearing iron slag with silica, flux, and a carbon reductant followed by refinement by vanadium pentoxide. The reaction takes place in a submerged electric arc furnace yielding a ferrovanadium alloy containing about 40 wt % vanadium, 3.5 wt % silicon, 3.8 wt % manganese, 0.1 wt % carbon, and the remainder iron.

Substitutes

Various metals, such as columbium, manganese, molybdenum, titanium, and tungsten, are, to some degree, interchangeable with vanadium. So far there are no substitutes for vanadium in the all-important aerospace titanium alloys, which were used in jet engine mountings and wing structures. High-purity vanadium compounds were used as catalysts in the production of sulfuric acid, maleic anhydride, and in pollution control technology where it was required to remove hydrogen sulfide gas from flu gases (Stretford Process). In only a few chemical applications could platinum or nickel replace vanadium catalyst.

Economic Factors

Prices.—The U.S. producer price of ferrovanadium (FeV) declined by more than 25% over the past 12 months from an average of $5.28 per pound vanadium content to an average of $3.95 per pound. Similarly, vanadium pentoxide prices fell from $1.68 per pound in January to $1.28 per pound at the end of the year. The decline of vanadium prices was attributed to lower grade material of Russian origin forcing down the price of higher grades. The free market price for Russian V_2O_5 was about $1.50 per pound in January 1993. That was $0.05 to $0.15 below the free market price for Chinese and South African (Highveld) material.

Tariffs.—U.S. import duties on selected vanadium items as of January 1, 1993, are listed in table 3. The tariff listing includes rates for both most-favored-nation (MFN) and non-MFN status.

Operating Factors

Environmental Requirements.—Because some segments of the geochemical cycle of thorium and uranium coincide with the vanadium cycle, the environmental considerations of vanadium mining are frequently linked to the management of radioactive mine wastes. In addition to careful placement and containment of tailings ponds, special attention must be given to preventing or limiting radioactive contamination of ground water aquifers and to the impoundment and long-term storage of mill tailings and mine waste to control radon daughter exhalation.

In 1982, the U.S. Environmental Protection Agency (EPA) published a regulation dealing specifically with the mining of vanadium ores and uranium-radium-vanadium ores.[5] Under these rules, the concentration of uranium in mine drainage must be less than 4 milligrams per liter per day for 30 consecutive days. In addition, the U.S. Nuclear Regulatory Commission has issued two regulatory guides dealing with personnel monitoring at uranium mills and processing facilities. The two guides delineate techniques for performing a bioassay on workers routinely exposed to airborne yellowcake (U_3O_8) or airborne uranium ore dust.[6]

In October 1983, EPA published rules dealing with the stabilization and long-term control of mill tailings at inactive uranium-vanadium processing sites.[7] These rules, which took effect on December 6, 1983, required uranium-vanadium mill operators to install plastic liners or other protective barriers under their tailings piles to prevent uranium, its radioactive daughter products, and nonradioactive toxic substances such as selenium from contaminating ground waters. Each tailings pond was required to have an earthen cover to minimize emissions and prevent erosion of the sandy surface by wind and rain. The rules also limited radon release from the surface of the pile to 20 picocuries per square meter per second.

Toxicity.—Vanadium compounds are irritants chiefly to the conjunctiva and respiratory tract. Prolonged exposure may lead to respiratory irritations with mucus discharge and lower respiratory tract irritation with bronchitis and chest pains.[8] Other noted effects of vanadium and its compounds have included contact dermatitis, conjunctivitis, and discoloration of the tongue. Vanadium in high concentrations may alter metabolic processes in animals and humans. The reported toxic effects of exposure to vanadium compounds have been acute, never chronic. Toxic effects vary with the compound involved; e.g., vanadium oxytrichloride ($VOCl_3$) liberates hydrogen chloride gas, and the oral lethal dose (LD_{50}) for V_2O_5 dust in rats is 23 milligrams per kilograms of body weight.[9] The lethal dose value is used to express the toxicity of many compounds and is determined by experiment. As used here, it is milligrams of V_2O_5 per kilogram of body weight (taken by mouth) that is lethal to 50% of the experimental animals.

Vanadium metal and its alloys pose no particular health or safety hazard, but they do react violently with certain materials, including bromine trifluoride (BrF_3), chlorine, and some strong acids. The toxicity of vanadium alloys depends on other components in the alloy.

The adopted threshold limit values for time weighted averages for airborne vanadium, including oxide and metal dusts of vanadium, is 0.5 milligram per cubic meter; the value for fumes of vanadium compounds is 0.05 milligram per cubic meter. These limits are for normal 8-hour workday and 40-hour workweek exposures. The short-term exposure limit is 1.5 milligrams per cubic meter for dust.[10] The ammonium salts of vanadic acid and vanadium pentoxide have been listed as toxic constituents in solid wastes under the Resource Conservation and Recovery Act.[11]

ANNUAL REVIEW

Legislation and Government Programs

There was a glut of uranium fuel in the domestic commercial market in 1993, much of it attributed to the Russians, who have been exporting commercial-grade uranium for several years. At least in part because of Russian inroads, U.S. uranium oxide (U_3O_8) production declined from about 17,000 tons in 1980 to less than 4,000 tons in 1990. At the same time, coproduction of vanadium pentoxide from uranium-vanadium ores declined from 5,000 tons to 1,200 tons. Meanwhile, imports from Russia and other republics of the former U.S.S.R. rose from near zero to more than 2,700 tons per year. The U.S. Department of Commerce made a preliminary finding in 1992 that Russia was "dumping" uranium in the United States at unfairly low prices. Consequently, Russia and five other former Soviet republics accepted strict quotas imposed by the U.S. Department of Commerce that essentially exclude them from the U.S. market until the price of uranium rises $3 or more above its yearend price of about $10 per pound. At the end of 1991, when U.S. producers decided to take action, uranium imports from the former U.S.S.R. were about 3 million pounds per month. Under the new agreement, Kazakhstan, Russia, Ukraine, and Uzbekistan were excluded from the U.S. market until the price of uranium rose to $13. At $13, they could ship 2.9 million pounds per year. The quota was to rise with price. At $21, the quotas would be lifted. The $13 threshold, however, was never reached in 1993, so Russia and the other former Soviet republics were unable to export uranium to the United States. By late 1993 the Russians began pressing for a more liberal uranium policy, and by the end of 1993 the Commerce Department accepted terms that would allow Russia to export up to 42 million pounds of uranium to the United States over the next 10 years. The new terms required that every pound of Russian vanadium imported must be matched with a newly mined pound of U.S. uranium, and the blend must be sold to utilities for at least the prevailing market price. Final action on the deal was expected in early 1994.

Strategic Considerations

Vanadium is classified as a strategic and critical material because of the significant import dependence of the United States for its vanadium supply and because of the essential use of vanadium in equipment for defense, energy, and transportation.

Steel producers in the market economy countries (MEC) of Japan, the United States, and Western Europe shared a common concern about lack of economically viable domestic vanadium raw materials. Also, MEC vanadium supply was from only a few sources, chiefly China and the Republic of South Africa and from just three or four suppliers in these countries. China was expected to soon become a net importer of vanadium, leaving only South Africa and perhaps the Commonwealth of Independent States as the only major sources. Japan and Western Europe are more heavily dependent on imports than the United States.

Stockpile

The purpose of the National Defense Stockpile (NDS) is to ensure the supply of critical materials for military and civilian needs in the event of a national defense emergency. The vanadium inventory consists entirely of V_2O_5, which represents 651 tons of contained vanadium. At the current annual rate of U.S. consumption, that is about a 3-month supply. Although the goal for vanadium in the National Defense Stockpile at the end of 1992 was about 7,000 tons of contained vanadium, it was reduced to zero in 1993. There is no FeV in the stockpile. No date has been set for the disposal of vanadium in the stockpile. By law, the NDS cannot be used for economic or budgetary purposes.

Issues

Prior to about 1984-85, more than one-half of the vanadium mined in the United States was recovered as a coproduct with uranium from sandstone mined on the Colorado Plateau. Companies recovering vanadium from uranium ores were hurt by the downturn in nuclear powerplant construction in the aftermath of the Three Mile Island nuclear reactor accident and the subsequent reduced demand for enriched uranium. Worldwide recession, high interest rates, and the cancellation of powerplant construction in the United States caused the Nuclear Exchange Corp. (Nuexco) exchange value of uranium oxide (U_3O_8) to decline from $40.75 per pound in early 1980 to less than $10 per pound in 1991. The exchange value is Nuexco's judgment of the price at which transactions for significant quantities of uranium concentrates could be concluded on a specified date. Value is based on bids to buy and offers to sell, as well as recently completed and pending transactions.

A direct result of the price decrease was mill closing and decommissioning, personnel cutbacks, and canceled development and expansion plans. This unstable situation had the potential for creating a much higher degree of dependence by the United States on imports of vanadium raw materials. However, some of the slack was taken up by increased recovery of vanadium from petroleum residues, including spent petroleum catalysts. Recovery of vanadium from this source began during the 1973 and 1978 Arab oil embargoes. After being cut off from light crude from the Middle East, refiners were forced to process crude oils with high-sulfur and high-metal content. The trend toward heavier, sour crude led to the production of large volumes of petroleum coke that contained high concentrations of metals. This material has become an important source of vanadium, and in some instances, molybdenum and nickel. At the same time, the combustion of increasingly metalliferous fuel oils at powerplants created a second source of feed materials in the form of fly ash and boiler scale. More V_2O_5 produced in the United States is now being recovered from refinery residues, fly ash, boiler scale, and spent catalysts than ever before. In 1993, the United States recovered 2,700 tons of vanadium oxides from petroliferous materials.

Production

Vanadium is often considered to be an uncommon element, but actually its abundance in the Earth's crust is comparable to or greater than that of copper, nickel, and zinc. Although there is a plentiful supply of vanadium, it is one of the most expensive elements to recover. In most cases, whether vanadium occurs as a primary ore, a coproduct, or in petroleum, the vanadium content of the material usually runs 1.5% V_2O_5 or less. V_2O_5 is the principal starting material for the production of all vanadium compounds. Therefore, when one speaks of vanadium production or the supply side of the industry, only those involved in the production of V_2O_5 should be included.

At yearend, there were five companies producing V_2O_5 in the United States. Of these, one was a totally integrated company that produced V_2O_5, vanadium chemicals, FeV, and other vanadium alloys. The others produced mainly V_2O_5 from a variety of raw materials.

Consumption, Uses, and Stocks

Vanadium has been used as an alloying element in steel since 1902, when it was first added to tool steels used for high-speed machining operations. It was found that vanadium prevented grain growth in tungsten-bearing steels and enabled the steels to maintain their hardness at the high temperatures generated in tool steels during high-speed machining. Vanadium is also widely used in high-temperature steels used in steam powerplants. Chromium-vanadium steels are used for steel pipes and headers, and molybdenum-vanadium steels are used for rotors in turbines because of the high creep resistance produced by vanadium carbides.

Metallurgical applications accounted for more than 95% of vanadium consumption, with about 83% for steelmaking. Relatively small quantities of vanadium were used for alloying with nonferrous metals, mostly aluminum. Nonmetallurgical applications included catalysts, ceramics, and vanadium chemicals. The dominant nonmetallurgical use was in catalyst. Much less was consumed in ceramic and electronics (batteries).

Reported yearend consumers' and producers' stocks of vanadium oxides, metal, alloys, and chemicals totaled 1,019 tons of contained vanadium; there was 1,084 tons in stocks at yearend 1992.

Foreign Trade

Overall exports of vanadium products were essentially unchanged in 1993. Canada and Mexico were the leading importers of U.S. materials. Most countries imported almost exclusively V_2O_5. Canada, the Republic of Korea, and Venezuela also imported substantial quantities of FeV.

Imports for consumption of downstream vanadium compounds increased by more than 36% in 1993; imports of raw material slag, ash, residues, and spent catalysts were up by more than 40%.

World Review

Industry Structure.—Vanadium was traded on the world market in vanadium-bearing slag, petroleum residues, technical-grade V_2O_5, and FeV. The Republic of South Africa was the largest producer with more than 60% of the MEC market. Most of the Republic of South Africa's exports of vanadium were in the form of vanadium-bearing iron slag. Japan and Western Europe were the chief importers of this material. The United States imported slag from the Republic of South Africa and fly ash, petroleum residues, and spent catalyst from many other sources. The large importers of vanadium raw materials; e.g., slag, were the chief exporters of V_2O_5, FeV, and other downstream vanadium products. This trade was dominated by a few large West European converters who competed not only within Europe, but also exported to many large and small consumers outside of Europe. Reliable statistics from Russia were not available, but it is believed to be second only to the Republic of South Africa in vanadium production. Most Russian trade was thought to be with other East European countries. However, significant quantities of Russian and Czech material began to find its way into the world market.

Capacity.—The data in table 12 are rated capacity for mills producing vanadium oxides as of December 31, 1993. Included in this data is capacity to produce vanadium-bearing slag and petroleum coke. Rated capacity is defined as the maximum quantity of product that can be produced on a normally sustainable, long-term operating rate, based on the physical equipment of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgement of the author, can be brought back into production within a short period with minimum capital expenditure.

Canada.—A mineral deposit that may have sufficiently high concentration of vanadium and titanium for commercial development has been discovered in Manitoba. The deposit was discovered on land owned by the Cross Lake First Nation Indian band. The site is about 80 kilometers southeast of Cross Lake Village. An agreement was worked out between Gossan Resources and Cross Lake First Nation wherein Gossan owns 51% of the claim and Cross Lake Mineral Exploration owns 49%. Gossan officials said that intense exploration would begin in January 1994. Mining could start as early as mid-1995. According to Gossan officials, total deposits of iron, titanium, and vanadium could reach 40 million tons. Manitoba Government officials stated that the ore concentrations were likely to be sufficient for commercial development, because a major international mining company had expressed interest in developing the deposit. Estimated startup cost reportedly was C$250 million.

Czech Republic.—Czech-based Mníšek Ferozliatinárske Zavody, Š. P., announced plans to expand FeV production in 1994. The action follows an earlier agreement with a group of Japanese companies to form a joint venture to produce FeV. The group included Nissho Iwai. According to company officials, the joint venture, called Nikom, will produce 1,300 tons of FeV in 1993 and 1,500 tons in 1994. Nikom plans to sell most of its production in the Far East with the remainder going to Europe. Mníšek owns a V_2O_5 plant that supplied feed for its FeV operations. Vanadium-bearing iron slag for the V_2O_5 plant was imported from Russia. Vanadium pentoxide capacity was estimated at 3.5 to 4 million pounds per year. Ferrovanadium capacity was estimated at 1,500 tons per year and could easily be expanded to 2,000 to 3,000 tons per year.

United States.—Stratcor, Danbury, CT, announced an agreement under which it will exclusively market FeV from Russia's largest FeV producer, Tulachermet Corp., in North America. Tulachermet produces 52% FeV low in aluminum, which, according to Stratcor, will be advantageous to continuous casting operations and producers of low aluminum products. The agreement resulted in the curtailment of FeV production at the company's Niagara Falls, NY, plant. About one-half of the 80 workers at the New York plant were laid off. The plant has an annual capacity of about 4,000 tons per year FeV. Stratcor also formed an alliance with Bear Metallurgical Corp., Butler, PA, to toll convert V_2O_5 produced by U.S. Vanadium Corp. U.S. Vanadium, located in Hot Springs, AR, is a subsidiary of Stratcor. The Hot Springs plant will be expanded to supplement specialty vanadium chemicals and vanadium-aluminum operations at Niagara Falls.

An expansion at Stratcor subsidiary Vametco in Brits, Republic of South Africa, produced FeV to be marketed in Japan and Europe. The Vametco expansion totally integrated the facility, bringing total vanadium capacity to about 10 million pounds per year, including FeV, Nitrovan, and V_2O_5.

OUTLOOK

U.S. vanadium prices continued to decline in 1993 despite an apparent increase in demand. The failure of prices to improve may have been caused by market oversupply through all of 1993. There were indications that market conditions would improve in 1994-95. The tool steel industry is a relatively large consumer of vanadium. The Association of Manufacturing Technology, based in McLean, VA, reported that orders for U.S.-made machine tools hit a 5-year high in 1993. The Association said December 1993 tool orders were up more than 37% at $319 million, compared with November's $232 million, and up 55% from December 1992's $206 million. The gain in machine tool orders is considered an indicator of economic activity. The increase in machine tool orders this year should show up in stronger demand for vanadium beginning in fourth quarter 1994 and continuing in 1995. Another boost in demand for vanadium could come in 1994 as the automotive industry increases its demand for automotive alloys that contain vanadium. U.S. auto production increased by more than 5% in 1993 and is expected to increase by more than 9% in 1994.

More than 95% of the demand for vanadium is driven by steel and nonferrous metallurgical applications. This dependence of the vanadium industry on the demand for steel products is not likely to change in the near future. The remaining demand is driven by chemicals applications. The reader is referred to the outlook section of the Iron and Steel Annual Report for more information on the short-term outlook for the steel industry. An excellent analysis of the chemical industry was published in the June 1993 issue of Chemical & Engineering News.

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[4] Lewan, M. D. Factors Controlling the Proportionality of Vanadium to Nickel in Crude Oils. Cosmochim. Acta, v. 49, No. 11, Nov. 1984, pp. 2231-2238.

[5] U.S. Code of Federal Regulations. Title 40—Protection of Environment; Chapter I—Environmental Protection Agency; Part 440—Ore Mining and Dressing Point Source Category; July 1, 1984, pp. 302-304, 312-313.

[6] U.S. Atomic Energy Commission. Applications of Bioassays for Uranium. Regulatory Guide 8.11, June 1974, 31 pp. U.S. Nuclear Regulatory Commission. Bioassay at Uranium Mills. Regulatory Guide 8.22, July 1978, 5 pp.

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[9] Sax, N. I. Dangerous Properties of Industrial Materials. 5th ed., Van Nostrand Reinhold, 1979, p. 1082.

[10] National Institute for Occupational Safety and Health. Criteria for a Recommended Standard. Occupational Exposure to Vanadium. Dep. Health Education and Welfare. Washington, DC, Publ. No. 77-22, Aug. 1977, 142 pp.

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OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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Iron and Steel. Ch. in Minerals Yearbook, annual.
Vanadium. Ch. in Mineral Commodity Summaries.
Vanadium. Reported monthly in Mineral Industry Surveys.

Other Sources

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Metalworking News.
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TABLE 1

SALIENT VANADIUM STATISTICS

(Metric tons of contained vanadium unless otherwise specified)

		1989	1990	1991	1992	1993
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]		2,389	2,308	2,250	1,352	[e]2,867
Consumption		4,646	4,081	3,293	[r]4,079	3,973
Exports:						
Ferrovanadium		399	271	94	213	219
Oxides and hydroxides, other		1,080	976	1,110	1,113	895
Vanadium pentoxide (anhydride)		1,171	819	700	26	126
Other compounds (gross weight)		688	1,472	816	2,015	989
Imports (general):						
Ferrovanadium		527	262	428	603	1,649
Oxides and hydroxides, other		106	271	110	103	19
Ore, slag, ash, and residues		4,210	3,826	882	838	1,454
Vanadium pentoxide, anhydride		133	83	145	253	70
World: Production from ore, concentrate, slag[4]		[r]32,967	[r]30,906	[r]28,162	[r]25,933	[e]25,200

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

[1] Recoverable vanadium contained in uranium and vanadium ores and concentrates received at mills, plus vanadium recovered from ferrophosphorus derived from domestic phosphate rock.

[2] Produced directly from all domestic ores and ferrophosphorus slag; includes metavanadates.

[3] Includes vanadium recovered from fly ash, residues, and spent catalysts.

[4] Excludes U.S. production.

TABLE 2
CHEMICAL SPECIFICATIONS FOR COMMERCIAL FORMS OF FERROVANADIUM

Alloy	Composition, weight-percent (maximum unless otherwise specified)							
	Vanadium	Carbon	Nitrogen	Aluminum	Silicon	Phosphorus	Sulfur	Manganese
50% to 60% ferrovanadium	50.0-60.0	0.2	—	2.0	1.0	0.05	0.05	—
70% to 80% ferrovanadium	70.0-80.0	—	—	1.0	2.5	.05	.10	—
80% ferrovanadium	77.0-83.0	.5	—	.5	1.25	.05	.05	0.50
Proprietary alloys:								
Carvan (Stratcor)	82.0-86.0	10.5-14.5	—	.1	.10	.05	.10	.05
Ferovan (Shieldalloy)	42.0 min.	.85	—	—	7.0	—	—	4.50
Nitrovan (Stratcor)	78.0-82.0	10.0-12.0	6.0 min.	.1	.1	.05	.01	.05

TABLE 3
U.S. IMPORT DUTIES, JANUARY 1, 1993

Tariff item[1]	HTS No.	Most favored nation (MFN)	Non-MFN
Ores and concentrates	2615.90.6090	Free	Free.
Slag	2619.00.9030	Free	Free.
Ash and residues	2620.50.0000	Free	Free.
Vanadium pentoxide anhydride	2825.30.0010	16.0% ad valorem	40% ad valorem.
Vanadium oxides and hydroxides, other	2825.30.0050	16.0% ad valorem	40% ad valorem.
Vanadates	2841.90.1000	11.2% ad valorem	40% ad valorem.
Ferrovanadium	7202.92.0000	4.2% ad valorem	25% ad valorem.
Aluminum-vanadium master alloys	7601.20.9030	Free	10.5% ad valorem.
Waste and scrap	8112.40.3000	Free	Free.

[1] Specific import classes only.

Source: U.S. International Trade Commission.

TABLE 4
U.S. VANADIUM PENTOXIDE PRODUCERS

Producer	Plant location	Capacity (metric tons pentoxide per year)
AMAX Metals Recovery Inc.	Braithwaite, LA	1,800
Gulf Chemical & Metallurgical Corp.	Freeport, TX	1,400
Kerr-McGee Chemical Corp.	Soda Springs, ID	2,000
UMETCO Minerals Corp.	Blanding, UT	6,800
U.S. Vanadium Corp.	Hot Springs, AR	6,800

TABLE 5
U.S. CONSUMPTION AND CONSUMER STOCKS OF VANADIUM MATERIALS, BY TYPE

(Kilograms of contained vanadium)

Type	1992		1993	
	Consumption	Ending stocks	Consumption	Ending stocks
Ferrovanadium[1]	[r]3,580,121	[r]326,642	3,607,756	297,501
Oxide	14,716	7,584	W	9,203
Ammonium metavanadate	W	W	2,170	1,896
Other[2]	[r]484,429	[r]57,714	362,651	20,666
Total	[r]4,079,266	[r]391,940	3,972,577	[3]329,267

[r] Revised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Includes other vanadium-iron-carbon alloys as well as vanadium oxides added directly to steel.

[2] Consists principally of vanadium-aluminum alloy and small quantities of other vanadium alloys and vanadium metal.

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

TABLE 6
U.S. CONSUMPTION OF VANADIUM IN 1993, BY END USE

(Kilograms of contained vanadium)

End use	Quantity
Steel:	
Carbon	1,413,087
Stainless and heat resisting	32,517
Full alloy	788,696
High-strength low-alloy	981,104
Tool	373,349
Unspecified	10,427
Total	[1]3,599,179
Cast irons	21,021
Superalloys	13,166
Alloys (excluding steels and superalloys):	
Cutting and wear-resistant materials	339
Welding and alloy hard-facing rods and materials	W
Magnetic alloys	W
Other alloys	308,921
Chemical and ceramic uses:	
Catalysts	W
Pigments	W
Miscellaneous and unspecified	29,951
Grand total	3,972,577

W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

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

TABLE 7

PRODUCERS OF VANADIUM ALLOYS OR METAL IN THE UNITED STATES IN 1993

Producer	Plant location	Products[1]
Bear Metallurgical, Corp.	Butler, PA	FeV.
KB Alloys Inc.	Henderson, KY	VAl, ZrVAl.
Do.	Wenatchee, WA	Do.
Reading Alloys Inc.	Robesonia, PA	NiV, VAl, V.
Shieldalloy Metallurgical Corp.	Cambridge, OH	FeV, Ferovan.[2]
Do.	Newfield, NJ	FeV.
U.S. Vanadium Corp.	Niagara Falls, NY	FeV, VAl, Nitrovan.[2]
Teledyne Wah Chang Albany	Albany, OR	V, VAl.

[1] FeV, ferrovanadium; V, vanadium metal; VAl, vanadium-aluminum alloy; ZrVAl, zirconium-vanadium-aluminum alloy; NiV, nickel-vanadium alloy.

[2] Registered trademark for proprietary products.

TABLE 8

U.S. EXPORTS OF VANADIUM IN 1993, BY COUNTRY

Country	Ferrovanadium (gross weight)		Aluminum-vanadium master alloy[1] (gross weight)		Vanadium compounds (contained weight)			
					Pentoxide (anhydride)[2]		Oxides and hydroxides, other	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Australia	—	—	3,562	$68	—	—	—	—
Belgium	—	—	—	—	5,227	$50	19,489	$81
Brazil	—	—	2,169	29	—	—	—	—
Canada	217,659	$1,866	152,956	1,998	—	—	626,736	2,919
Chile	—	—	—	—	1,281	12	—	—
Egypt	—	—	1,440	20	—	—	—	—
France	—	—	752	13	—	—	3,247	265
Finland	—	—	—	—	1,068	12	—	—
Germany	—	—	85	14	92,434	380	—	—
Hong Kong	—	—	248	3	—	—	—	—
Japan	—	—	13,209	166	—	—	36,288	143
Korea, Republic of	—	—	6,184	84	—	—	—	—
Kuwait	—	—	—	—	3,266	24	—	—
Malaysia	—	—	195	3	—	—	—	—
Mexico	58,820	551	588,859	7,655	820	17	13,270	38
Netherlands	—	—	8,552	313	—	—	16,048	115
Pakistan	—	—	—	—	5,085	80	—	—
Romania	—	—	3,409	44	—	—	—	—
South Africa, Republic of	—	—	78,926	273	16,777	136	64,528	288
Sweden	14,366	359	—	—	—	—	89,812	535
Taiwan	—	—	1,860	21	—	—	—	—
United Kingdom	—	—	2,317	46	—	—	—	—
Venezuela	—	—	568	7	—	—	25,214	158
Total[4]	290,845	2,776	865,291	10,757	125,958	710	894,632	4,545

[1] Includes vanadium metal.

[2] May include catalysts containing vanadium pentoxide.

[3] Excludes vanadates.

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

Source: Bureau of the Census.

TABLE 9
U.S. IMPORTS OF FERROVANADIUM, BY COUNTRY

Country	1992			1993		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Austria	191,275	135,707	$1,594	208,994	159,552	$1,524
Belgium	[1]79,333	[1]42,887	444	106,590	73,856	539
Canada	446,884	364,895	4,418	478,834	386,619	3,560
Czech Republic	60,619	49,091	563	—	—	—
Germany	—	—	—	390,256	178,925	1,121
Japan	—	—	—	5,401	2,816	24
Russia	20,046	10,588	83	1,366,269	693,388	4,415
Switzerland	—	—	—	50,000	39,527	308
Tajikistan	—	—	—	30,250	24,563	199
Ukraine	—	—	—	78,170	40,840	304
United Kingdom	—	—	—	91,700	48,932	394
Total	798,157	603,168	7,102	2,806,464	1,649,018	12,388
Imports for consumption:						
Austria	188,992	135,307	1,594	208,994	159,552	1,524
Belgium	[1]68,000	[1]46,701	[1]534	71,590	46,080	328
Canada	446,884	364,895	4,418	478,834	386,619	3,560
Czech Republic	43,309	34,999	409	—	—	—
France	—	—	—	16,481	8,608	82
Germany	—	—	—	390,256	178,925	1,121
Japan	—	—	—	40,401	30,592	235
Russia	20,046	10,588	83	1,346,414	688,222	4,379
Switzerland	—	—	—	50,000	39,527	308
Ukraine	—	—	—	78,170	40,840	304
United Kingdom	—	—	—	91,700	48,932	394
Total	767,231	592,490	7,038	2,772,840	1,627,897	12,235

[1] Bureau of the Census was unable to verify this data.

Source: Bureau of the Census.

TABLE 10

U.S. IMPORTS OF VANADIUM PENTOXIDE (ANHYDRIDE), BY COUNTRY

Country	1992			1993		
	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)	Gross weight (kilograms)	Vanadium content (kilograms)	Value (thousands)
General imports:						
Canada	4	3	$2	1,840	1,052	$17
China	131,800	114,419	591	—	—	—
Germany	862	410	31	683	580	13
South Africa, Republic of	179,403	137,908	891	108,000	68,198	350
Total[1]	312,069	252,740	1,515	110,523	69,830	381
Imports for consumption:						
Canada	4	3	2	1,840	1,052	$17
China	71,800	57,910	330	—	—	—
Germany	862	410	31	683	580	13
South Africa, Republic of	196,423	147,633	1,001	108,000	68,198	350
Total[1]	269,089	205,956	1,364	110,523	69,830	381

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

Source: Bureau of the Census.

TABLE 11
U.S. IMPORTS OF VANADIUM-BEARING ASH, RESIDUES, SLAG AND OTHER MATERIALS, BY COUNTRY[1]

Material and country	1992 Gross weight (kilograms)	1992 Vanadium pentoxide content (kilograms)	1992 Value (thousands)	1993 Gross weight (kilograms)	1993 Vanadium pentoxide content (kilograms)	1993 Value (thousands)
Slag:[2]						
South Africa, Republic of	1,063,648	255,276	$1,797	1,317,405	316,177	6$1,526
Ash and residues:						
Barbados	—	—	—	60,000	18,000	8
Canada	1,467,898	693,136	955	951,754	439,047	533
Chile	16,827	5,385	4	—	—	—
Dominican Republic	20,735	11,819	16	98,122	80,000	60
Germany	1,016,561	222,275	182	582,293	202,228	142
Israel	388,931	105,012	208	231,740	77,271	104
Italy	163,180	39,165	84	606,440	250,490	180
Jamaica	—	—	—	20,370	7,130	18
Mexico	122,101	56,830	111	2,086,079	1,012,700	461
Netherlands	15,240	4,572	13	33,518	12,694	8
Netherlands Antilles	142,552	32,931	34	43,725	9,182	5
Portugal	—	—	—	64,000	16,000	85
Spain	27,480	5,491	8	—	—	—
United Kingdom	16,750	3,350	4	197,668	56,023	42
Venezuela	90,000	27,000	48	120,032	60,257	63
Total[3]	3,488,255	1,206,966	1,669	5,095,741	2,241,022	1,710
Other (includes spent catalyst):						
Argentina	18,091	9,046	5	15,315	7,658	5
Canada	48,231	22,927	25	32,644	15,943	21
France	—	—	—	159,028	14,173	54
United Kingdom	5,465	984	6	—	—	—
Total	71,787	32,957	36	206,987	37,774	80

[1] General imports.
[2] As adjusted by the U.S. Bureau of Mines.
[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 12

WORLD VANADIUM PENTOXIDE ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1993[1]

(Metric tons of contained vanadium)

Country	Rated capacity[2]
Austria	1,500
Canada	770
Chile	2,300
China	8,200
South Africa, Republic of	27,200
Russia	9,500
United States	11,000
Venezuela	2,500
Other	550
Total	63,520

[1] Includes V_2O_5 in vanadiferous iron slags and petroleum refinery residues.

[2] Includes capacity of operating plants as well as plants on standby basis.

TABLE 13

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing: Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	Other[1]
United States:						
Akzo Chemical Co.	Weston, MI					E
AMAX Metals Recovery Inc.	Braithwaite, LA	x				
Bear Metallurgical Corp.	Butler, PA		x			
Cotter Corp.	Canon City, CO	x				
Gulf Chemical & Metallurgical Corp.	Freeport, TX	x				
Kerr-McGee Chemical Corp.	Soda Springs, ID	x		x		
Reading Alloys Inc.	Robesonia, PA				x	C
Shieldalloy Metallurgical Corp.	Cambridge, OH		x	x	x	B,E
U.S. Vanadium Corp.	Hot Springs, AR	x				
Do.	Niagara Falls, NY		x		x	A,E
Teledyne Wah Chang Albany	Albany, OR					C,D
UMETCO Minerals Corp.	Blanding, UT	x				
Canada:						
Carbovan Inc.	Fort McMurray, Saskatchewan	x				
Masterloy Products Ltd.	Gloucester, Ontario		x			
Germany:						
Gesellschaft fur Electrometallurgie mbH	Nuremburg		x		x	
Belgium:						
Sadacem (Langerbruggekaai Plant)	Ghent		x			
Spain:						
Ferroastur SA	Poligono de Maqua, Aviles		x			

See footnotes at end of table.

TABLE 13—Continued

VANADIUM: WORLD PROCESSING FACILITIES

Country and plant	Location	Vanadium processing				
		Vanadium pentoxide	Ferro-vanadium	Ammonium metavanadate	Aluminum-vanadium alloy	Other[1]
Sweden:						
Metals & Powders						
Trollhatten AB (Sandvik AB)	Trollhatten		x			
United Kingdom:						
Ferroalloys & Metals Ltd.	Glossop, Derbyshire		x			
London & Scandinavian Metallurgical Co. Ltd.	Rotherham, South Yorkshire		x			
Murex Ltd.	Rainham, Essex	x	x	x		
South Africa, Republic of:						
Highveld Steel & Vanadium Corp.	Witbank	x		x		
Transvaal Alloys Pty. Ltd.	Roos Senekal, Transvaal	x				
Union Steel Corp.	Vereeniging	x				
Vametco Minerals Corp.	Bushveld Complex	x		x		A
Vansa Vanadium SA Ltd.	Steelpoort, Eastern Transvaal					
Japan:						
Awamura Metals Industry Co.	Uji, Kyoto		x			
Japan Metals and Chemical Co.	Oguni, Yamagata		x			
Nippon Denko KK	Hokuriku, Toyama		x			
NKK Corp.	Toyama, Toyama		x			
Shinko Chemical Co. Ltd.	Saki, Osaka	x				
Taiyo Mining & Industrial Co.	Ako, Hyogo	x	x			
China:						
Chengde Plant	Hebei	x				
Emei Ferroalloy Plant	Sichuan		x			
China Titanium Plant	Zunyi, Guizhou	x				
Jinzhou Ferroalloy Plant	Liaoning	x	x			
Nanjing Ferroalloy Plant	Jiangsu	x	x			
Shanghai Plant	Shanghai		x			
Russia:						
Chusovskoy Metallurgical Zavod	Chusovoy	x	x			
Novo-Tagilskiy	Nizhniy-Tagil	x	x			
Novo-Tulskiy Metallurgical Zavod	Tula	x	x			
Serovskiy Metallurgical Zavod	Serov	x	x			

[1] A, Nitrovan, proprietary product; B, Ferovan, proprietary product; C, Vanadium metal producer; D, Vanadium-zirconium alloy producer; and E, Unsupported vanadium catalyst.

TABLE 14
VANADIUM: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons of contained vanadium)

Country	1989	1990	1991	1992	1993[e]
Production from ores, concentrates, slag:[2]					
China (in vanadiferous slag product)[e]	4,500	4,500	4,500	4,700	5,000
Hungary[e]	300	300	200	200	200
Russia[3]	—	—	—	[e]7,000	6,000
South Africa, Republic of:[4]					
Content of pentoxide and vanadate products[e]	7,270	7,100	[r]6,500	[r]6,300	6,500
Content of vanadiferous slag product[e,5]	11,300	10,000	[r]8,460	[r]7,730	7,500
Total[6]	18,567	17,106	[r]14,962	[r]14,033	14,000
U.S.S.R.[e,3,7]	9,600	9,000	8,500	—	—
United States (recoverable vanadium)	W	W	W	W	W
Total	[r]32,967	[r]30,906	[r]28,162	[r]25,933	25,200
Production from petroleum residues, ash, spent catalysts:[8]					
Japan (in vanadium pentoxide product)[e]	868	700	889	870	870
United States (in vanadium pentoxide and ferrovanadium products)	2,389	2,308	2,250	1,347	[9]2,867
Total	3,257	3,008	3,139	2,217	3,737
Grand total	[r]36,224	[r]33,914	[r]31,301	[r]28,150	28,937

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

[1] In addition to the countries listed, vanadium is also recovered from petroleum residues in Germany, and several other European countries, but available information is insufficient to make reliable estimates. Table includes data available through July 28, 1994.

[2] Production in this section is credited to the country that was the origin of the vanadiferous raw material.

[3] All production in the U.S.S.R. from 1989-91 came from Russia.

[4] Includes production for Bophuthatswana.

[5] 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.

[6] Data may not add to reported totals shown because of independent rounding of estimated detail.

[7] Dissolved in Dec. 1991.

[8] 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.

[9] Reported figure.

FIGURE 1

U.S. VANADIUM PENTOXIDE PRODUCTION, 1989-93

(Metric tons of vanadium content)

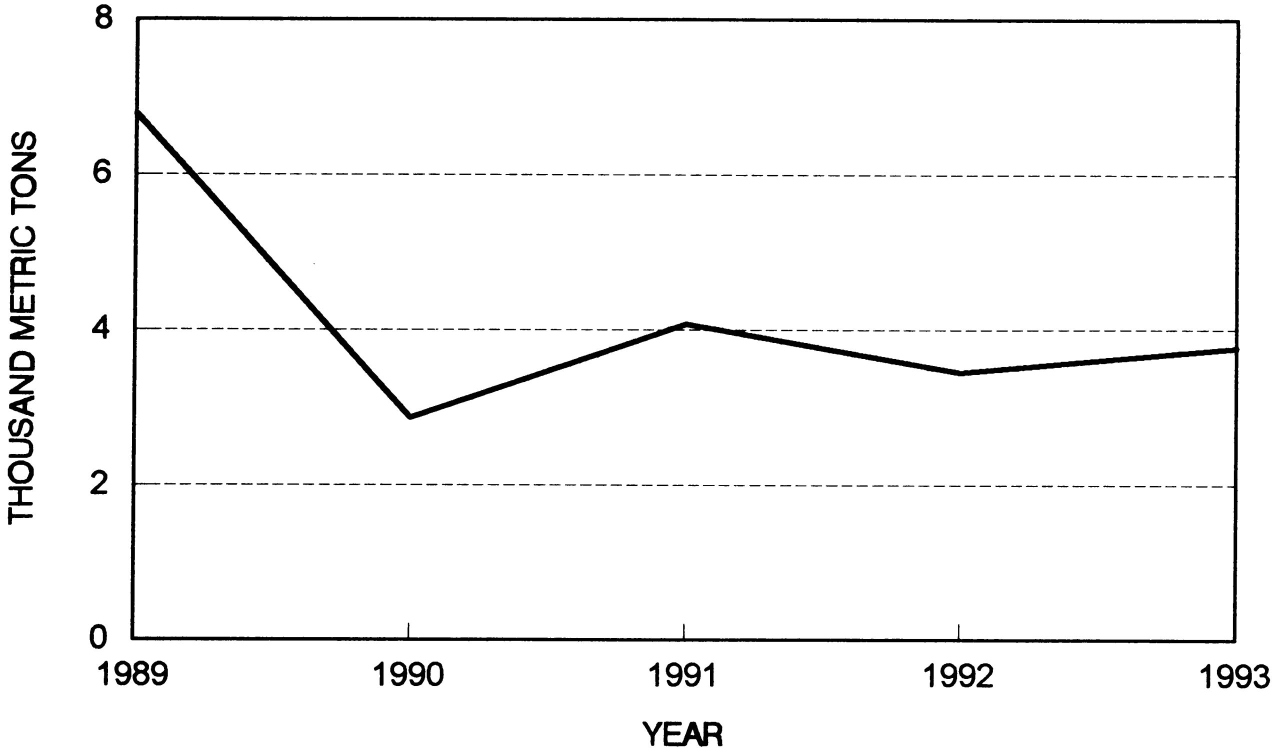
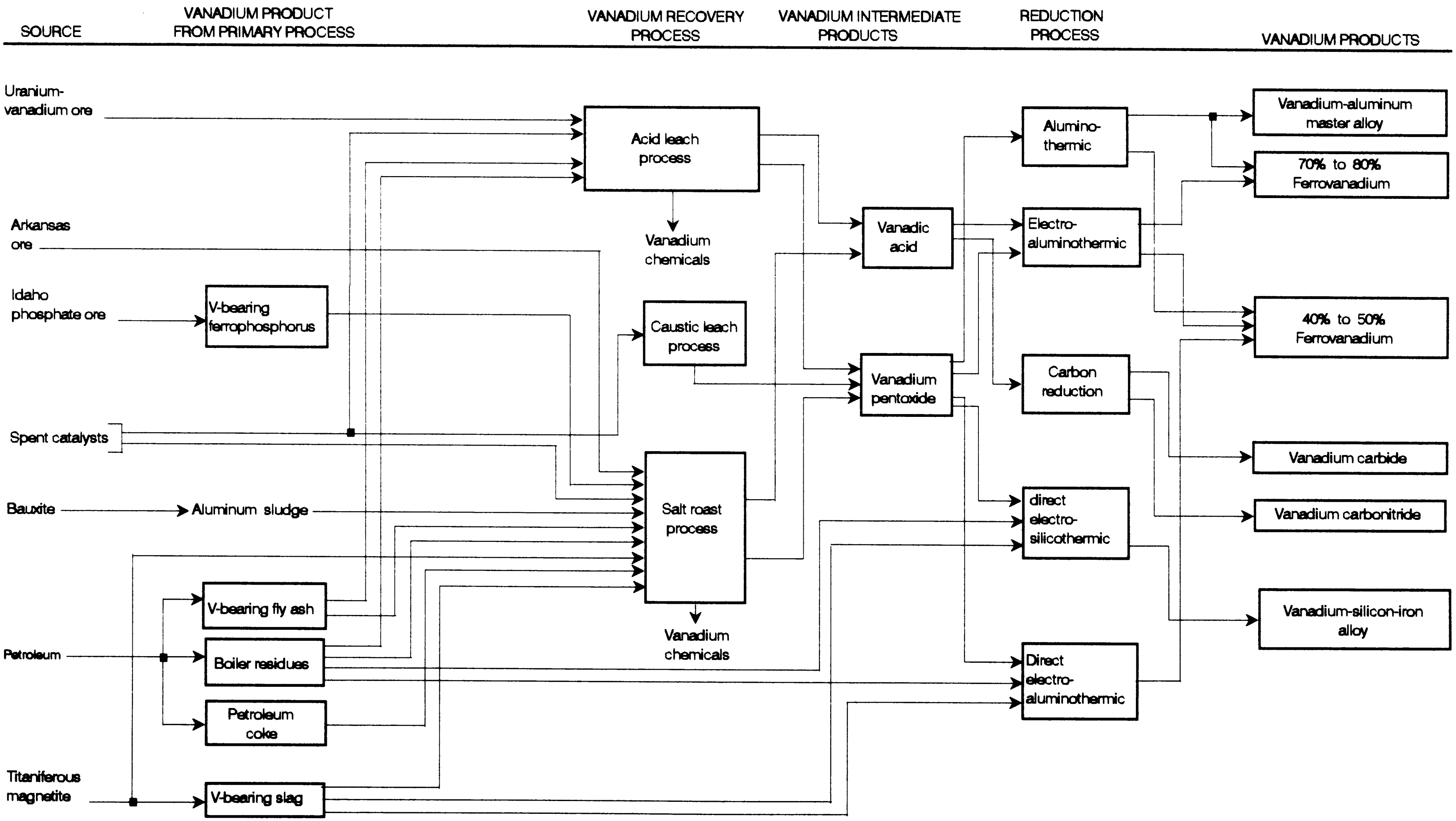


FIGURE 2
GENERALIZED FLOWSHEET FOR THE PROCESSING OF VANADIFEROUS RAW MATERIALS



ZINC

By Stephen M. Jasinski

Mr. Jasinski, a physical scientist with 7 years of U.S. Bureau of Mines experience, has been a commodity specialist in the Branch of Metals since 1988. Domestic survey data were prepared by Gloria A. Peebles, statistical assistant. International production tables were prepared in collaboration with country specialists in the Division of International Minerals.

Zinc was produced at 24 mines in the United States in 1993. For the third consecutive year, Alaska was the leading zinc-producing State, followed by Tennessee, New York, Missouri, Colorado, and Montana. U.S. mine production greatly exceeded smelter capacity, which resulted in a net export of 250,000 metric tons of zinc in concentrates. The value of zinc mine production was $520 million.

Four primary smelters produced slab zinc in 1993 from domestic and primary ore and scrap materials. Ten secondary smelters produced slab zinc using about 70% new scrap and 30% old scrap. A detailed discussion of the secondary zinc industry is contained in the Recycling—Nonferrous Metals Annual Report. Total slab zinc production was about 380,000 tons, a slight decrease from 1992, caused by the closure of one primary zinc smelter in September.

The domestic zinc industry continued to improve despite a reduction in mine and smelter production. Apparent consumption of zinc in all forms increased 11% and imports of slab zinc grew by 12% to meet the demand. Domestic apparent consumption of slab zinc grew 9% from that of 1992. The increase was greatest in the galvanizing and diecasting industries owing to strong growth by the U.S. automobile industry. Zinc use in brass and bronze products and other uses showed modest increases. The chemical, rubber, and paint industries used zinc in compound form and as zinc dust at about the same level as in 1992.

In 1993, 355,000 tons of zinc in waste and scrap, including 109,000 tons in old scrap, was recovered in the form of slab zinc, brass, zinc-base alloys, dust, oxide, and other chemicals.

U.S. producer prices, which are based on the London Metal Exchange (LME) price for zinc, declined to record-low levels. The price drop was attributed to an oversupply caused by LME stocks nearly doubling in 1993.

World mine production of zinc decreased 5%. Australia, Canada, China, Peru, and the United States were the top producers, accounting for nearly 60% of the world total.

Identified world resources of zinc total about 1.8 billion tons. The world reserve base was estimated at 330 million tons and reserves at 140 million tons. Canada has the largest reserves, 15% of the world total, and Australia has the largest reserve base, 20%. The U.S. share of reserves and reserve base was 11% and 15% percent, respectively.

DOMESTIC DATA COVERAGE

Domestic data for zinc were developed by the United States Bureau of Mines (USBM) from five separate, voluntary surveys of U.S. operations. Typical of these was the "Slab Zinc" consumption survey sent out monthly or annually, depending on consumption quantities; small consumers are canvassed annually. Consumption for nonrespondents was estimated using their prior-year consumption adjusted for industry trends.

Reported consumption for slab zinc, however, accounted for only 67% of apparent metal consumption, a reflection of the low current response rate for the voluntary industry surveys.

ANNUAL REVIEW

Strategic Considerations

Supply.—U.S. mine and smelter production capacity can supply only about one-half of domestic zinc requirements. The domestic ore reserve base is large, but could not be tapped adequately until after the first year of an emergency situation. Domestic smelter capacity is inadequate and would limit refined zinc output. It also would severely limit the country's ability to produce strategic and critical zinc byproduct elements such as cadmium and germanium.

Zinc mine production in Alaska accounted for nearly one-half of U.S. output; however all output from the State is exported. Even if Alaskan zinc concentrates were redirected to U.S. smelters, there is not enough domestic production capacity to process the material. U.S. mine output greatly exceeds smelter capacity and in 1993 resulted in the net export of 250,000 metric tons of zinc in concentrate. An additional strategic factor related to production in Alaska is that more than 80% of the State's output is inaccessible for 9 months of the year because of sea ice.

Although imports constitute a large part of the U.S. zinc supply, about 60% of the zinc metal, concentrates, and compounds comes from Canada and Mexico; therefore the risk of supply disruption is low.

Stockpile.—A stockpile for zinc for national defense purposes has been maintained for more than 50 years. In 1992, the President signed Public Law

102-484, which authorized the disposal of the entire inventory of zinc from the National Defense Stockpile (NDS). The Defense Logistics Agency (DLA), which maintains the NDS, was authorized to sell 68,000 tons in FY 1993 and 43,545 tons in FY 1994; it sold 19,000 tons during calendar year 1993.

Production

Mine Production.—U.S. zinc mine output decreased 8% in 1993, despite higher production at the Red Dog Mine in Alaska. This was a result of several mine closures. The 20 leading mines accounted for more than 98% of production, with 5 leading mines accounting for 75%. For the third consecutive year, Alaska was the leading zinc-producing State, followed by Tennessee, New York, Missouri, Colorado, and Montana. The leading domestic producers were ASARCO Incorporated, Cominco Alaska Inc., Union Zinc Co., and Zinc Corporation of America (ZCA).

The Red Dog Mine in northwestern Alaska and the Greens Creek Mine on Admiralty Island accounted for nearly all zinc production in Alaska in 1993. The Red Dog Mine, which began operations in late 1989, is owned by NANA Regional Corp. Inc. and leased to Cominco Alaska Inc., a subsidiary of Cominco, Ltd., which owns and operates the mining and processing facilities. NANA is paid a royalty that is scheduled to increase after the capital investment plus interest is recovered by Cominco.

In 1993, the grinding circuit was improved, resulting in increased production. By the end of the year, zinc concentrate production was at design capacity. An expansion of the grinding circuit was initiated late in the year and completed early in 1994, and improvements were made to the concentrator circuit. Zinc concentrate production was expected to be above design capacity in 1994. According to the Cominco annual report, zinc recovery was 81%, up 5% from 1992, and total ore milled was 1,700,600 tons, or 265,400 tons more than in 1993. The ore grade was 18.4% zinc, down 1.5% from last year. A total of 235,200 tons of zinc in zinc concentrate and bulk lead-zinc concentrate was produced in 1993, an increase of 17,000 tons from 1992. Ore reserves at yearend were 56.8 million tons averaging 18.4% zinc, 5.7% lead, and 93 grams per ton silver. An additional 14.1 million tons of lower-grade ore was classified as inferred reserves.

The Greens Creek Joint Venture is a consortium 53% owned by RTZ Ltd, through its Kennecott subsidiary, Greens Creek Mining Co.; and 47% owned by minority partners Hecla Mining Co., Exalas Resources Corp., and CSX Alaska Mining Inc. The mine was closed in April because of low metal prices. It produced 5,200 tons of zinc in concentrates, according to the RTZ annual report. Development and engineering activity continued at the mine.

In Tennessee, zinc was produced at seven underground mines, four owned by Asarco in the eastern part of the State and three owned by Jersey Miniere Zinc Co. (JMZ) in the western part. Asarco's production was 56,000 tons of zinc in concentrates, down 11,900 tons from 1992. Asarco's ore reserves at yearend were 4.8 million tons averaging 3.28% zinc. The drop in production was caused by the failure of a ball mill at Asarco's Young Mine in late July, which was not repaired until November. This also forced the temporary closure of three of the company's mines for the same period. JMZ reduced output from its Jefferson City Mine by 25% in July because of low metal prices and declining reserves.

In Missouri, zinc was produced as a coproduct of lead at nine underground lead mines along the Viburnum Trend by three companies, Asarco, The Doe Run Co., and Cominco American Inc., a subsidiary of Cominco Ltd. According to the Asarco annual report, production of zinc in concentrate at the West Fork and Sweetwater Mines was 15,900 tons, an increase of 2,000 tons. Ore reserves at yearend were 23.7 million tons, averaging 0.86% zinc. Zinc output at the Magmont Mine, a joint venture of Cominco American and Dresser Industries, continued to drop as the ore body was nearly depleted; the mine was scheduled to be closed in 1994. According to the Cominco annual report, the Magmont mill processed 630,000 tons of ore grading 1.2% zinc, yielding 6,200 tons of zinc in 10,200 tons of concentrate. At yearend, the ore reserves were 2.5 million tons, averaging 8.3% lead, 1.2% zinc, and 0.3% copper.

In Colorado, zinc was produced only as a coproduct of gold-silver operations at the Leadville Unit, managed by Asarco, but owned jointly with the Resurrection Mining Co. Production of zinc in concentrate was 13,900 tons. At yearend, ore reserves were 635,000 tons, averaging 8.1% zinc.

In Montana, the Montana Tunnels Mining Co., a subsidiary of Pegasus Gold Inc., milled 4.6 million tons of ore in 1993, containing 16,300 tons of zinc, 6,350 tons of lead, 2,137 kilograms of gold, and 43,545 kilograms of silver. Zinc recovery was 88%, with the mill feed averaging 0.52% zinc. At yearend, proven and probable reserves were 32.4 million tons, grading 0.60% zinc, 0.22% lead, 0.6 gram of gold per ton, and 10 grams of silver per ton. The reserves are lower than in 1992 because material containing less than 0.5 gram gold per ton is being stockpiled for processing when economic conditions are more favorable.

In January, Equinox Resources Ltd., placed its Van Stone Mine in Washington on a care and maintenance basis because of low metal prices. The mine had reopened in August 1992 after being closed for 9 months. The mine had an annual production capacity of 14,000 tons of zinc in concentrates.

In September, Exxon Coal & Minerals Co. formed a 50-50 joint venture with Rio Algom Ltd., of Canada, to develop the Crandon zinc-copper deposit in Northeastern Wisconsin. The companies began permitting procedures early in 1994 and anticipated beginning shipments of concentrates by the end of 1999. Development of this project was to require a capital expenditure of $300 million. The deposit has reserves of 27 million tons, grading 9.4% zinc and 0.4% copper, with lead, gold, and silver in byproduct quantities. In 1986, Exxon had proposed a mining program for the site and applied for permits, but shelved the project due to unfavorable economic conditions. The new mining program was to be similar to that of 1986, except that production will be reduced 25%, and the program will be modified to meet current environmental standards and improvements in technology.

Smelter and Refinery Production.—Refined metal production was down about 4% because of the closure of one plant at the end of September. ZCA, Jersey Miniere Zinc (JMZ), and Big River Zinc Co. operated four primary zinc refineries in 1993. ZCA closed its Bartlesville, OK, electrolytic refinery at the end of September because of low metal prices and for renovations that were expected to take one year to complete. The plant has a production capacity of 54,000 tons per year. Secondary slab zinc was produced at 10 plants from waste and scrap materials. The largest secondary producer was ZCA at its electrothermic primary smelter in Monaca, PA. A substantial part of the plant's feed material was crude zinc calcine recovered from steel mill electric arc furnace (EAF) dust by ZCA's sister company, Horsehead Resource Development Co. The largest producers of zinc metal at secondary plants were Huron Valley Steel Corp., Interamerican Zinc Co., and Gulf Metals Corp.

Zinc Oxide.—In 1993, seven companies produced French-process zinc oxide only and one company, Eagle Zinc Co., produced American-process zinc oxide. Some impure zinc oxide produced at secondary plants was sold directly for agricultural purposes. The principal producers in 1993 were Asarco, Eagle Zinc, North American Oxide Inc., and ZCA.

Consumption and Uses

Zinc is found in many manufactured products, but its role is not obvious to the public because it tends to lose its identity in the products. Zinc-containing products were used extensively in 1993 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 oil drilling rigs, submerged and buried steelwork, tanks, and pipes. Brass was used as shell casings in ammunition, and for tubes, valves, motors, pipes, 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 machinery, appliances, household hardware, and scientific and electronic equipment. Zinc dust was used in primers and paints; in alkaline dry cell batteries; in the sherardizing process to protectively coat nuts, bolts, and small parts; for the precipitation of noble metals from solution; and in the zinc industry for the removal of impurities, such as copper, cadmium, and lead, before electrolysis. The metal casings of dry cell zinc-carbon batteries were zinc. In 1993, 29,000 tons of Special High Grade (SHG) zinc was used by the U.S. mint to produce 12.1 billion pennies.

Zinc compounds were used in corrosion-inhibiting paint primers, chemical catalysts, welding and soldering fluxes, fungicides and pharmaceuticals, paints, rubber, phosphors for cathode ray tubes, ceramics, and additives for lubricating oils and greases. Zinc ferrites were used in electrical devices, such as transformers, coils, amplifiers, and motors.

Domestic consumption of slab zinc rose about 110,000 tons to 1.1 million tons in 1993. Galvanized zinc protective coatings, mainly on steel sheet and strip, continued to be the principal use of zinc metal, consuming an estimated 54%; followed by zinc-base die-cast alloys, 21%; brass alloys, 14%; and other uses 11%. SHG accounted for about 55% of the reported consumption, followed by Prime Western (PW), 25%; High-Grade (HG), 12%; and other grades, 8%. Overall, zinc metal accounted for more than 75% of the total zinc in final products in 1993, and zinc chemicals accounted for the balance.

Consumption of zinc in the production of copper-based alloy for brass mills, ingotmakers, and foundries increased nearly 40,000 tons in 1993, to 345,200 tons, according to the Copper Development Association Inc. (CDA). Consumption was evenly split between refined metal and zinc contained in brass and bronze scrap. According to the CDA, brass mills accounted for 87% of the total zinc consumed as metal and scrap in producing copper-based alloys.

Apparent domestic consumption of zinc oxide was about 160,000 tons. Domestic production was 102,000 tons, whereas net imports were 30,400 tons. USBM information on zinc oxide consumption reflects only shipments as reported by the domestic producers; because reporting is incomplete, the consumption data listed in table 11 account for only about 80% of the market. Of the reported amounts, the rubber and chemical industries continued to be the principal consumers.

Stocks

Metal stocks held by domestic producers, merchants, and consumers continued to decline in 1993 and were at the lowest levels since the early 1940's. This reflected the general trend toward lower inventories and just-in-time deliveries. Inventories of slab zinc at domestic primary smelters totaled 10,300 tons at yearend, compared with 12,300 tons at the end of 1992, according to the American Bureau of Metal Statistics (ABMS). Metal stocks in other countries (exclusive of Eastern Europe and China) continued to rise sharply in 1993. According to the International Lead and Zinc Study Group (ILZSG), stocks in Western countries were 1,580,000 tons at the end of 1993, up 450,000 tons from the end of 1992. Virtually all the additional stocks were placed into LME warehouses, as industrial stocks tended to remain at 1992 levels. ILZSG data indicated that 85% of the metal stock rise was attributable to increased exports from Eastern Europe and China.

Markets and Prices

Since 1991, U.S. zinc producers have used the LME as their price basis. For domestic metal, sellers generally charged either a premium of 2-to-5 cents per pound over the LME spot price or some average of LME prices to account for delivery and/or importing costs. The price reported in table 1 was published by Platt's Metals Week, which based its price on the daily LME spot price for SHG plus a premium that reflected market conditions.

The domestic zinc price began the year on an upward trend at 50.52 cents per pound and reached a high for the year in February, averaging 50.90 cents per pound for the month. LME stocks increased throughout the year, causing prices to drop. An all-time low price of 39.66 cents per pound was set on the LME in September. Speculation about smelter closures in Europe and a drop in the availability of concentrates led to a gradual increase in price from October until yearend, when it finished at 46.4 cents per pound. That was still 7% lower than in January. The average for the year was 46.16 cents per pound.

Foreign Trade

The value of U.S. exports of basic zinc materials, including waste and scrap, was about $197 million, down from $283 million in 1992, owing to lower zinc prices in 1993. Exports of zinc concentrates increased slightly; however, their value was almost $100 million lower than in 1992.

General imports of zinc concentrates relative to imports for consumption continued to be high because of shipments of Canadian concentrates through Skagway, AK, to world markets. Imports of slab zinc were up nearly 80,000 tons to meet increased domestic demand in 1993. Slab zinc accounted for about 71% of the total value of imports.

World Review

Western world mine production dropped 5% in 1993; however, smelter production increased slightly. Consumption in Western countries grew about 75,000 tons in 1993, according to ILZSG. In Eastern countries, mine and smelter output increased, whereas consumption deceased slightly. Net exports from Eastern Europe to Western countries continued to grow, further swelling world stocks to more than 1.5 million tons at yearend, up 450,000 tons from 1992. Virtually all excess metal went into LME stocks.

According to ILZSG, world annual zinc mine capacity was 7 million tons, but this figure was believed to be low because data were not available for every mine in the former republics of the U.S.S.R. World annual smelter capacity was 8 million tons.

OUTLOOK

U.S. demand for zinc is forecast to rise slowly, increasing from about 1.15 million tons in 1993 to 1.25 million tons by the year 2000. No major shifts in zinc use are foreseen, although some present uses may decline owing to substitution. Over the next 5 years, zinc-air and other zinc battery systems may become important for electric vehicle propulsion or for load-leveling and power backup systems.

Although the United States has an adequate resource base, imports are expected to account for more than one-half of the domestic supply during the next decade, especially if the Bartlesville, OK, smelter remains closed. No new primary smelters are likely to be built because of permitting delays and potential long-term liability threats posed by Superfund legislation. The improvements at the Red Dog Mine are expected to boost production and will likely keep the United States as a major exporter of zinc concentrates. Projected growth in demand also will maintain the United States as the world's largest importer of refined zinc metal.

Secondary zinc metal recovery from waste and scrap is anticipated to be a strong growth sector for the zinc industry. Domestic secondary zinc production could constitute at least 40% of total zinc metal and compounds used annually by the year 2000. The increasing trend in public policy to encourage recycling likely will impact more zinc-containing products, such as batteries. Large-scale use of zinc in electric vehicle batteries could boost secondary zinc consumption to more than 50% of the U.S. total by early in the next century.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Zinc. Ch. in Mineral Commodity Summaries, annual
Zinc. Reported monthly in Mineral industry Surveys.

Other Sources

ABMS Nonferrous Metal Data.
American Metal Market.
Canadian Mining Journal.
Engineering and Mining Journal.
Journal of Metals.
Lead and Zinc Statistics (monthly bulletin of ILZSG).
Metal Bulletin (London).
Metals Week.
Mining Journal (London).
World Metal Statistics (WBMS).

TABLE 1
SALIENT ZINC STATISTICS

(Metric tons unless otherwise specified)

	1989	1990	1991	1992	1993
United States:					
Production:					
Domestic ores, recoverable content	275,883	515,355	517,804	[r]523,430	488,283
Value thousands	$499,103	$847,485	$602,426	$673,686	$496,795
Slab zinc:					
From domestic ores	229,870	230,470	217,691	[r]227,116	214,246
From foreign ores	30,435	32,234	35,585	[r]44,751	26,036
From scrap	97,904	95,708	122,457	127,623	141,472
Total	358,209	358,412	375,733	[r]399,490	381,754
Secondary zinc[1]	249,122	245,692	W	W	W
Exports:					
Ores and concentrates (zinc content)	78,877	220,446	381,818	[r]307,118	311,278
Slab zinc	5,532	1,238	1,253	5,886	8,765
Imports for consumption:					
Ores and concentrates (zinc content)	40,974	46,684	45,419	44,523	33,093
Slab zinc	711,554	631,742	549,137	644,482	723,563
Stocks of slab zinc, Dec. 31:					
Industry (rounded)	60,100	60,400	57,300	57,900	52,400
Government stockpile	340,577	340,577	[r]343,613	[r]340,987	325,880
Consumption:					
Slab zinc:					
Reported	884,655	801,969	790,378	814,228	773,709
Apparent (rounded)[2]	1,060,000	992,000	933,000	1,035,000	1,148,000
All classes (rounded)[3]	1,311,000	1,240,000	1,165,000	1,276,000	1,367,000
Price: High Grade, cents per pound (delivered)	82.02	74.59	52.77	58.38	46.15
World:					
Production:					
Mine thousand metric tons	[r]6,825	[r]7,158	[r]7,258	[r]7,227	[e]6,895
Smelter do.	[r]7,245	[r]7,178	[r]7,311	[r]7,136	[e]7,177
Price: London, cents per pound	77.64	66.46	50.67	56.24	43.64

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

[1] Excludes secondary slab and remelt zinc.

[2] Domestic production plus net imports plus or minus stock changes.

[3] Based on apparent consumption of slab zinc plus zinc content of ores and concentrates and secondary materials.

TABLE 2
MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY STATE

(Metric tons)

State	1989	1990	1991	1992	1993
Kentucky	—	W	—	W	W
Missouri	50,790	48,864	42,506	44,031	40,171
Montana	W	W	W	20,588	W
Nevada	—	7,889	W	—	—
New Mexico	W	W	W	(1)	—
Oregon	—	—	751	—	—
Washington	—	—	W	W	W
Other[2]	225,093	458,602	474,547	458,811	448,112
Total	275,883	515,355	517,804	[r]523,430	488,283

[r] Revised. W Withheld to avoid disclosing company proprietary data; included in "Other."

[1] Revised to zero.

[2] Includes production from Alaska, Colorado, Idaho, Illinois, New York, Tennessee, and States indicated by symbol "W."

TABLE 3
LEADING ZINC PRODUCING MINES IN THE UNITED STATES IN 1993, IN ORDER OF OUTPUT

Rank	Mine	County and State	Operator	Source of zinc
1	Red Dog	Northwest Arctic, AK	Cominco Alaska Inc.	Zinc ore.
2	Balmat	St. Lawrence, NY	Zinc Corporation of America	Do.
3	Elmwood-Gordonsville	Smith, TN	Jersey Miniere Zinc Co.	Do.
4	Pierrepont	St. Lawrence, NY	Zinc Corporation of America	Do.
5	Montana Tunnels	Jefferson, MT	Montana Tunnels Mining Inc.	Do.
6	Young	Jefferson, TN	ASARCO Incorporated	Do.
7	New Market	do.	do.	Do.
8	Immel	Knox, TN	do.	Do.
9	Leadville Unit	Lake, CO	do.	Do.
10	Jefferson City	Jefferson, TN	Union Zinc Co.	Do.
11	West Fork	Reynolds, MO	ASARCO Incorporated	Lead-zinc ore.
12	Greens Creek	Southeastern Alaska, AK	Kennecott Greens Creek Mining Co.	Zinc ore.
13	Idol	Grainger, TN	Jersey Miniere Zinc Co.	Do.
14	Cumberland	Smith, TN	do.	Do.
15	Fletcher	Reynolds, MO	The Doe Run Co.	Lead ore.
16	Coy	Jefferson, TN	ASARCO Incorporated	Zinc ore.
17	Buick	Iron, MO	The Doe Run Co.	Lead-zinc ore.
18	Magmont	do.	Cominco American Inc.	Lead ore.
19	Rosiclare	Hardin and Pope, IL	Ozark-Mahoning Co.	Fluorspar.
20	Casteel[1]	Iron, MO	The Doe Run Co.	Lead ore.
21	Sweetwater	Reynolds, MO	ASARCO Incorporated	Do.
22	Viburnum No. 29	Washington, MO	The Doe Run Co.	Do.
23	Lucky Friday	Shoshone, ID	Hecla Mining Co.	Lead-zinc ore.
24	Van Stone	Stevens, WA	Equinox Resources	Zinc ore.

[1] Includes Brushy Creek Mill.

TABLE 4

PRIMARY AND SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES

(Metric tons)

	1989	1990	1991	1992	1993
Primary:					
From domestic ores	229,870	230,470	217,691	r227,116	214,246
From foreign ores	30,435	32,234	35,585	r44,751	26,036
Total	260,305	262,704	253,276	r271,867	240,282
Secondary:					
At primary smelters	W	W	W	W	W
At secondary smelters	W	W	W	W	W
Total	97,904	95,708	122,457	127,623	141,472
Grand total (excludes zinc recovered by remelting)	358,209	358,412	375,733	r399,490	381,754

rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 5

DISTILLED AND ELECTROLYTIC ZINC, PRIMARY AND SECONDARY, PRODUCED IN THE UNITED STATES, BY GRADE

(Metric tons)

Grade	1989	1990	1991	1992	1993
Special High	113,819	116,647	W	W	W
High	79,145	86,006	96,469	100,250	89,934
Continuous Galvanizing	48,252	50,577	41,358	50,503	65,385
Controlled Lead	W	W	W	W	W
Prime Western	116,993	105,182	237,906	r248,737	226,435
Total	358,209	358,412	375,733	r399,490	381,754

rRevised. W Withheld to avoid disclosing company proprietary data, included in "Prime Western."

TABLE 6

SLAB ZINC ANNUAL PRODUCTION CAPACITY OF PRIMARY ZINC PLANTS IN THE UNITED STATES, DECEMBER 31, BY TYPE OF PLANT AND COMPANY

(Metric tons)

Type of plant and company	Slab zinc capacity	
	1992	1993
Electrolytic:		
Big River Zinc Corp., Sauget, IL	82,000	82,000
Jersey Miniere Zinc Co., Clarksville, TN	98,000	98,000
Zinc Corp. of America, Bartlesville, OK[1]	54,000	54,000
Electrothermic:		
Zinc Corp. of America, Monaca, PA[2]	146,000	146,000
Total available capacity	380,000	380,000
Total operating capacity	380,000	326,000

[1] Temporarily closed in Sept. 1993.

[2] Includes secondary capacity.

TABLE 7

U.S. CONSUMPTION OF ZINC

(Metric tons)

	1989	1990	1991	1992	1993
Slab zinc, apparent (rounded)	1,060,000	992,000	933,000	1,035,000	1,148,000
Ores and concentrates (zinc content)	2,107	2,178	W	W	W
Secondary (zinc content)[1]	249,122	245,692	W	W	W
Total (rounded)	1,311,000	1,240,000	1,165,000	1,276,000	1,367,000

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

[1] Excludes secondary slab and remelt zinc.

TABLE 8

U.S. REPORTED CONSUMPTION OF SLAB ZINC IN 1993, BY INDUSTRY USE AND GRADE

(Metric tons)

Industry use	Special High Grade	High Grade	Prime Western	Remelt and other grades	Total[1]
Galvanizing	73,868	79,006	148,268	71,138	372,279
Zinc-base alloys	156,862	W	W	W	157,676
Brass and bronze	45,371	W	W	W	107,137
Zinc oxide	W	W	—	—	63,448
Other	W	W	W	—	73,169
Total	403,696	116,500	182,309	71,202	773,709

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

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

TABLE 9

ROLLED ZINC PRODUCED AND QUANTITY AVAILABLE FOR CONSUMPTION IN THE UNITED STATES

(Metric tons)

	1992	1993
Production[1]	48,160	W
Exports	5,423	6,600
Imports for consumption	171	135
Available for consumption	44,391	W

W Withheld to avoid disclosing company proprietary data.

[1] Includes other plate more than 0.375 inch thick and rod and wire.

TABLE 10

ZINC CONTENT OF PRODUCTION AND SHIPMENTS OF ZINC PIGMENTS AND COMPOUNDS[1] IN THE UNITED STATES

(Metric tons)

	1992		1993	
	Production	Shipments	Production	Shipments
Zinc chloride[2]	6,332	6,309	4,235	4,238
Zinc oxide	[r]103,939	103,037	102,157	101,912
Zinc sulfate	28,236	27,763	20,506	19,855

[r] Revised.

[1] Excludes leaded zinc oxide and lithopone.

[2] Includes zinc content of zinc ammonium chloride.

TABLE 11

REPORTED DISTRIBUTION OF ZINC CONTAINED IN ZINC OXIDE SHIPMENTS, BY INDUSTRY[1]

(Metric tons)

	1989	1990	1991	1992	1993
Agriculture	1,520	1,764	1,822	W	1,584
Ceramics	2,780	2,618	2,973	W	W
Chemicals	22,462	20,723	20,177	W	W
Paints	4,695	4,579	3,848	3,669	3,419
Photocopying	W	W	W	W	W
Rubber	57,781	56,622	55,254	W	65,280
Other	13,277	12,681	11,990	99,368	31,629
Total	102,515	98,987	96,064	103,037	101,912

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

[1] In addition, zinc oxide was imported as follows, in metric tons: 1989-59,557; 1990-49, 454; 1991-38,215; 1992-38,997; and 1993-35,874; distribution cannot be distinguished by industry.

TABLE 12

U.S. EXPORTS OF ZINC ORES AND CONCENTRATES, BY COUNTRY

(Zinc content)

	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Australia	114	[r]$1,020	—	—
Belgium	[r]51,848	[r]29,630	48,641	$22,011
Canada	[r]136,576	[r]90,910	110,209	35,916
Finland	—	—	14,807	3,993
Germany	[r]28,854	[r]20,197	33,293	13,852
Haiti	4	51	—	—
India	—	—	154	40
Italy	[r]3,486	[r]3,156	—	—
Japan	[r]58,494	[r]42,605	68,771	26,692
Korea, Republic of	[r]6,040	[r]4,198	6,163	2,564
Mexico	2,930	2,373	755	909
Netherlands	27	96	—	—
Panama	—	—	2	4
Russia	—	—	9,948	1,990
Spain	—	—	7,926	2,099
United Kingdom	[r]18,746	[r]17,967	10,608	7,067
Total[1]	[r]307,118	[r]212,203	311,278	117,137

[r] Revised.

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

Source: Bureau of the Census.

TABLE 13
U.S. EXPORTS OF ZINC COMPOUNDS

	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	40	$226	216	$436
Zinc chloride	2,532	1,395	1,135	947
Zinc compounds, n.s.p.f.	4,554	40,382	5,489	31,093
Zinc oxide	5,594	7,263	5,455	7,252
Zinc sulfate	3,259	9,664	4,756	8,832
Zinc sulfide	102	663	219	1,840

Source: Bureau of the Census.

TABLE 14
U.S. IMPORTS FOR CONSUMPTION OF ZINC PIGMENTS AND COMPOUNDS

	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Lithopone	1,267	$804	1,140	$696
Zinc chloride	3,096	2,611	3,575	3,302
Zinc compounds, n.s.p.f.	260	574	312	686
Zinc oxide	38,997	49,702	35,874	40,451
Zinc sulfate	3,828	2,313	5,617	3,108
Zinc sulfide	1,624	3,590	2,054	4,967

Source: Bureau of the Census.

TABLE 15

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Algeria	6,263	4,160	2,610	[e]4,000	4,000
Argentina	43,155	38,664	39,253	[e]41,000	40,000
Australia	803,000	[r]940,000	[r]1,024,000	[r]1,008,000	945,000
Austria	14,783	16,727	[r]14,827	[r]13,511	5,400
Bolivia	74,789	103,849	129,778	143,936	123,000
Bosnia and Herzegovina	—	—	—	[r][e]3,000	600
Brazil	178,439	158,025	130,000	[e]140,000	140,000
Bulgaria	39,700	34,700	29,100	[e]29,000	25,000
Burma	1,400	1,559	1,750	[r][e]1,880	1,900
Canada	1,216,139	1,203,161	1,156,582	[r]1,324,675	[2]1,007,257
Chile	18,370	[r]25,056	30,998	[r]29,730	28,500
China[e]	538,000	619,000	[r]750,000	[r]800,000	900,000
Colombia	394	356	266	[r]277	280
Czech Republic[3]	—	—	—	—	4,400
Czechoslovakia[e][4]	[r]8,400	[r]9,800	[r]11,600	[r]7,500	—
Ecuador[e]	100	100	100	100	100
Finland	58,430	[e]51,700	55,500	[r]30,785	20,000
France	26,706	23,851	27,109	[e]16,500	15,200
Georgia	—	—	—	[r][e]2,000	1,500
Germany: Western states	63,900	[r]58,200	[r]53,987	[r]14,288	—
Greece	[r]24,600	26,700	[r]30,000	[r]26,000	22,400
Greenland	71,500	47,850	—	—	—
Honduras	37,184	29,628	38,280	[e]32,000	31,500
India	65,384	73,970	[r]75,000	[r][e]75,000	104,000
Iran[e]	29,000	29,000	70,000	[r]90,000	95,000
Ireland	[r]168,000	166,500	187,500	[r]198,500	210,000
Italy	43,258	43,043	36,349	[r]35,032	3,100
Japan	131,794	127,273	133,004	134,510	118,800
Kazakhstan	—	—	—	[r][e]250,000	250,000
Korea, North[e]	230,000	230,000	200,000	200,000	210,000
Korea, Republic of	23,202	22,792	22,039	[r]21,883	15,000
Macedonia	—	—	—	[r][e]16,000	16,000
Mexico	[r][e]300,000	306,656	[r]317,101	[r]294,408	[2]369,697
Morocco	18,652	18,799	24,331	[r]22,604	22,000
Namibia	41,675	37,719	33,150	36,053	28,380
Norway	15,023	17,546	18,886	21,058	21,000
Peru	597,413	583,934	627,824	[r]602,614	602,600
Philippines	1,200	53	—	—	—
Poland	[r]203,700	177,800	[r]171,800	[r][e]170,000	170,000
Romania	54,467	[r]36,048	[r]26,871	[r]25,030	28,000
Russia	—	—	—	[e]150,000	170,000
Saudi Arabia	2,580	2,472	2,475	[e]2,475	2,500
Serbia and Montenegro	—	—	—	[r]17,000	17,000
Slovakia[3]	—	—	—	—	3,100
Slovenia	—	—	—	[r]1,550	—
South Africa, Republic of	77,334	74,792	64,425	[r]71,928	75,000
Spain	266,724	[r]257,500	[e]261,300	[r]201,800	160,000
Sweden	173,515	164,128	161,170	[r]163,500	[2]173,300

See footnotes at end of table.

TABLE 15—Continued

ZINC: WORLD MINE PRODUCTION (CONTENT OF CONCENTRATE AND DIRECT SHIPPING ORE UNLESS NOTED), BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Thailand	[r]62,831	61,534	87,000	[r]62,000	70,000
Tunisia	10,000	7,000	5,000	[r]4,090	4,000
Turkey[5]	39,412	[r]39,066	[r]32,546	[r][e]27,500	32,500
U.S.S.R.[e] [6]	550,000	550,000	475,000	—	—
United Kingdom	5,771	6,673	1,078	—	—
United States	288,303	543,200	546,610	551,600	[2]513,100
Uzebekistan	—	—	—	[r][e]60,000	60,000
Vietnam[e]	[r]10,000	[r]10,000	15,000	15,000	15,000
Yugoslavia[7]	94,739	83,788	[e]75,000	—	—
Zaire	72,800	61,800	42,400	22,300	6,500
Zambia[8]	22,853	32,074	19,825	[r][e]15,000	13,500
Total	[r]6,824,882	[r]7,158,246	[r]7,258,424	[r]7,226,617	6,895,114

[e] Estimated. [r] Revised.

[1] Table includes data available through July 28, 1994.

[2] Reported figure.

[3] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[4] Dissolved Dec. 31, 1992.

[5] Content in ore hoisted.

[6] Dissolved in Dec. 1991.

[7] Dissolved in Apr. 1992.

[8] Data are for years beginning Apr. 1 of that stated. Content of ore milled.

TABLE 16

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Algeria, primary	28.0	23.6	24.9	[r][e]31.0	31.0
Argentina:					
Primary	31.6	31.5	35.8	[r]34.5	35.0
Secondary[e]	2.7	2.7	2.8	[r]2.8	2.8
Total	34.3	34.2	38.6	[r]37.3	37.8
Australia:					
Primary[2]	[r]291.0	304.0	322.0	[r]329.0	310.0
Secondary	5.5	4.5	4.5	4.5	4.5
Total	[r]296.5	308.5	326.5	[r]333.5	314.5
Austria, primary and secondary	26.1	26.0	16.6	[r]5.0	6.0
Belgium, primary and secondary	[r]306.0	[r]356.5	[r]385.1	[r]310.6	300.8
Brazil:					
Primary	155.8	149.5	157.5	[e]160.0	160.0
Secondary	6.4	4.6	5.5	[e]6.0	6.0
Total[3]	162.3	154.1	163.0	[e]166.0	166.0
Bulgaria, primary and secondary	[r]95.0	[r]75.5	[r]58.7	[r]7.0	47.0
Canada, primary	669.7	591.8	660.6	[r]671.7	60.0
China, primary and secondary[e]	451.0	550.0	612.0	[r]719.0	838.0
Czechoslovakia, secondary[4] [5]	1.3	[r]1.0	[r]0.8	[r]1.1	—
Finland, primary	162.5	174.9	170.4	170.5	170.0
France, primary and secondary	265.8	[r]263.1	299.6	[r][e]305.0	336.0

See footnotes at end of table.

TABLE 16—Continued
ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Germany:					
Eastern states, primary and secondary	18.5	12.7	—	—	—
Western states:					
Primary	301.0	289.0	—	—	—
Secondary	52.5	48.6	—	—	—
Total	372.0	350.3	345.7	383.1	380.0
Hungary, secondary[e]	[4]1.4	1.3	1.3	1.0	1.0
India:					
Primary	71.6	79.1	85.8	[r][e]80.0	115.0
Secondary[e]	.2	.2	.2	.2	.2
Total[e]	71.8	79.3	86.0	[r]80.2	115.2
Italy, primary and secondary	259.5	264.4	263.8	253.0	270.0
Japan:					
Primary	591.2	605.7	640.6	645.0	573.0
Secondary	[r]123.5	[r]125.9	[r]138.1	[r]135.6	123.0
Total	[r]714.7	[r]731.6	[r]778.7	[r]780.6	696.0
Kazakhstan, primary	—	—	—	[r][e]250.0	250.0
Korea, North, primary[e]	210.0	200.0	175.0	175.0	200.0
Korea, Republic of, primary	240.2	248.2	254.1	253.0	272.0
Macedonia, primary and secondary	—	—	—	[e]32.0	32.0
Mexico, primary	193.3	199.3	189.1	151.6	[6]209.9
Netherlands, primary[7]	[r]202.9	208.5	211.1	[r]210.0	[6]206.7
Norway, primary	120.4	125.1	124.9	127.6	127.5
Peru, primary	126.7	120.6	154.6	[r]124.4	124.0
Poland, primary and secondary	[r]163.7	[r]132.2	126.0	[r]134.6	130.0
Portugal, primary[e]	[4]5.0	5.5	[r]2.1	[r]2.9	2.8
Romania, primary and secondary[e]	[r]29.8	[r]11.5	[r]8.7	[r]11.6	12.0
Russia:					
Primary	—	—	—	[e]140.0	140.0
Secondary	—	—	—	60.0	60.0
Total	—	—	—	[e]200.0	200.0
Serbia and Montengero, primary and secondary	—	—	—	14.2	14.0
Slovakia, secondary[4 e]	—	—	—	—	1.0
Slovenia, primary and secondary[e]	—	—	—	2.5	2.5
South Africa, Republic of, primary	85.0	[r]91.9	[r]91.7	[r]83.2	95.0
Spain, primary and secondary	[r]246.4	252.7	[r][e]262.2	[r]365.9	258.0
Thailand, primary	68.4	63.3	62.2	[e]62.0	62.0
Turkey, primary	24.2	20.1	17.4	22.5	22.5
Ukraine, secondary	—	—	—	[e]20.0	12.0
U.S.S.R.:[e 9]					
Primary	862.0	780.0	700.0	—	—
Secondary	115.0	110.0	100.0	—	—
Total	977.0	890.0	800.0	—	—
United Kingdom, primary and secondary	79.8	93.3	100.7	96.8	105.0
United States:					
Primary	260.3	262.7	253.3	[r]271.9	[6]240.3
Secondary	97.9	95.7	122.5	[r]127.6	[6]141.5
Total	358.2	358.4	375.8	399.5	[6]381.8

See footnotes at end of table.

TABLE 16—Continued

ZINC: WORLD SMELTER PRODUCTION, BY COUNTRY[1]

(Thousand metric tons)

Country	1989	1990	1991	1992	1993[e]
Uzbekistan, primary	—	—	—	[e]65.0	65.0
Vietnam, primary and secondary[e]	[r]10.0	[r]10 0	10.0	10.0	10.0
Yugoslavia, primary and secondary[10]	119.4	113.7	78.0	—	—
Zaire, primary	54.0	38.2	28.3	18.8	4.0
Zambia, primary	12.4	9.7	6.3	[r]7.3	6.5
Grand total[3]	[r]7,244.7	[r]7,178.3	[r]7,310.5	[r]7,136.0	7,177.3
Of which:					
Primary	[r]4,767.2	[r]4,622.2	[r]4,367.7	[r]4,086.9	4,004.0
Secondary	[r]406.4	[r]394.5	[r]375.7	[r]358.8	352.0
Undifferentiated	[r]2,071.0	[r]2,161.6	[r]2,567.1	[r]2,690.3	2,741.3

[e]Estimated. [r]Revised.

[1] Wherever possible, detailed information on raw material source of output (primary—directly from ores, and secondary—from scrap) has been provided. In cases where raw material source is unreported and insufficient data are available to estimate the distribution of the total, that total has been left undifferentiated (primary and secondary). To the extent possible, this table reflects metal production at the first measurable stage of metal output. Table includes data available through July 28, 1994.

[2] Excludes zinc dust.

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

[4] All production in Czechoslovakia from 1989-92 came from Slovakia.

[5] Dissolved Dec. 31, 1992.

[6] Reported figure.

[7] Sales.

[8] Formerly part of Czechoslovakia; data were not reported separately until 1993.

[9] Dissolved in Dec. 1991.

[10] Dissolved in Apr. 1992.

ZIRCONIUM AND HAFNIUM

By Joseph M. Gambogi

Mr. Gambogi is a physical scientist with the Branch of Industrial Minerals. Domestic survey data were prepared by Debra Nolan, Section of Nonferrous Metals Data. World production data are provided by country specialists in the Division of International Minerals.

Zirconium and hafnium are relatively abundant in the Earth's crust; however, zircon (zirconium silicate) is the only naturally occurring mineral of commercial significance. Zircon is a byproduct of the mining and processing of heavy-mineral sands for the titanium minerals rutile and ilmenite. The major end uses of zircon are refractories, foundry sands (including investment casting), and ceramic opacification. Zirconium and hafnium metal are both contained in zircon at a ratio of about 50:1. Zirconium-clad fuel rods and hafnium control rods make up the core of nuclear reactors. Commercial-grade zirconium, unlike nuclear grade, contains hafnium and is used in the chemical process industries because of its excellent corrosion resistance.

World zircon production was estimated to have increased by 10% in 1993. A 5% growth in demand for zircon was attributed primarily to increased consumption by China in the ceramic tile industry. Consumption was estimated to have increased by 5%, and stocks of zircon were reported to be near record low levels.

DOMESTIC DATA COVERAGE

Data for zirconium and hafnium materials are developed by the U.S. Bureau of Mines from one voluntary survey of domestic operations. Of the 32 operations surveyed, all responded, representing 100% of the domestic data in table 1. *(See table 1.)*

BACKGROUND

Definitions, 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, have only one oxidation state, +4, and have similar ionic radii. Owing to these similar properties, zirconium and hafnium are usually found together in nature.

Zircon purity is commonly measured by the combined zirconium dioxide (zirconia)-hafnium dioxide (hafnia) content. Hafnium occurs in zircon in a typical ratio of 1 part hafnium to 50 parts zirconium. Commercially available zircon typically grades 64.5% to 66% combined zirconia-hafnia. Zircon grades are similar on a worldwide basis, but no standard requirement exists.

Standard-grade zircon has a typical analysis of 65% minimum zirconium dioxide-hafnium dioxide, 0.25% maximum titanium dioxide, and 0.12% maximum iron oxide. Intermediate-grade zircon has a typical analysis of 65.5% zirconium dioxide-hafnium dioxide, 0.03% maximum titanium dioxide, and 0.1% maximum iron oxide. Premium-grade zircon has a typical analysis of 66% minimum zirconium dioxide-hafnium dioxide, 0.1% maximum titanium dioxide, and 0.05% maximum iron oxide. Zirconium metal for the chemical process industry is available in three American Society for Testing and Materials (ASTM)-approved grades: R60702 for unalloyed zirconium, R60704 for the tin-iron alloy, and R60705 for the niobium alloy. Zirconium alloys for the nuclear industry, the compositions of which are specified, are designated as Zircaloy-2, Zircaloy-4, or Zr-2.5 Cb.

Hafnium metal as produced by the Kroll process is called hafnium sponge or "Kroll-process" sponge or metal. After refining by the iodide process, the metal is called crystal bar.

Industry Structure

Zirconium ore minerals are sold by mine producers directly to processors, consumers, and commodity brokers. Primary ore concentrate of zircon and baddeleyite may be used in certain industrial uses with little or no processing, but most applications require additional processing. Processors grind the concentrates to specification for certain applications or convert zircon and baddeleyite to refined products such as zirconium metal, hafnium metal, alloys, high-purity zirconia, and other compounds. Extensive processing is required to produce ultra-purity powders and nuclear-grade metals. Processors producing oxide and metal are often partially integrated. Fabricated and semifabricated products are often sold directly to manufacturers.

Geology-Resources

Zircon is a common accessory mineral in igneous rocks. It is frequently found associated with silicic rocks, including granite, granodiorite, syenite, monzonite, and nepheline syenite. Zircon is also found in pegmatites, crystalline limestone, and the metamorphic rocks gneiss and schist. From an economic viewpoint, sedimentary placer deposits are the most significant.

Placer deposits originate when chemical and mechanical weathering liberates minerals from the source rock. This is followed by transport of the minerals to the sea by water, wind, and gravity. Upon reaching the sea, deposits of economic value form primarily by hydraulic sorting. Heavy minerals, including zircon, are concentrated by marine currents and wave action. Mechanical sorting by the sea and wind further sorts the grains to produce well-sorted beach deposits.

Technology

Economic concentrations of zircon are found in association with other heavy minerals such as ilmenite, monazite, and rutile. Heavy-mineral sand deposits usually are mined by floating cutterhead- or bucket wheel-dredges that handle up to 2,800 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, leucoxene, and rutile, and often smaller amounts of the rare-earth mineral monazite.

The mixed heavy-mineral concentrate is scrubbed, dried, and screened, and the individual heavy minerals are separated by electrostatic, electromagnetic, magnetic, and gravity processes. Zircon, in contrast to ilmenite, rutile, and many other heavy minerals, is nonconductive and can be separated, along with monazite, by electrostatic methods. Monazite, which is slightly magnetic and may be slightly higher in specific gravity, can be separated from zircon by electromagnet or by gravity concentration methods.

To obtain premium-grade zircon, the zircon concentrate from the electrostatic-electromagnetic circuit is subjected again to gravity concentration to reduce the content of aluminum- and titanium-bearing minerals. Certain zircon products are leached in an acidic solution to remove iron oxide and other grain coatings.

Zircon used in foundry and certain refractory applications is graded and sized, and in many cases, ground or milled to produce zircon flour. Foundry applications generally use zircon sand and flour mixtures, which may be treated with resin coatings and binders.

Zirconia is produced directly from zircon by either plasma fusion or electric arc techniques. The plasma method for zirconia production employs heating a finely divided zircon above its dissociation temperature to form small zirconia crystallites and glassy amorphous silica. The hot zirconia and silica particles are rapidly quenched and the silica removed by leaching with sodium hydroxide, leaving insoluble zirconia crystallites.

In electric arc production, zircon is heated to temperatures of approximately 2,500° C to produce a dissociation. The silicon component is vaporized and recovered as fumed silica, leaving a residual melt that is air quenched to form zirconia. A more complex electric arc method melts a mixture of limestone and zircon to form calcium zirconate and tricalcium silicate clinker. Cooling of the mixture disintegrates 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 to form 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, monazite, rutile, and the tin minerals cassiterite and stannite. Its classification as a byproduct or a coproduct depends on the fraction of zircon in relation to the other minerals. If zircon and the titanium minerals are expected to account for the majority of the revenue, it is considered a coproduct. If minerals other than zircon provide the carrying costs of the operation, then zircon is considered a byproduct. Small quantities of baddeleyite are recovered as a byproduct of copper, phosphate, and vermiculite mining in the Republic of South Africa.

ANNUAL REVIEW

Issues

Processing of some mineral sands by certain methods results in the concentration of radioactive elements in the waste or byproduct streams. Monazite and xenotime, both rare-earth, thorium phosphates, are the usual minerals of consequence because 100% separation of a heavy-minerals deposit is impossible to obtain within economic considerations. Monazite inclusions within the zircon grains and/or ionic substitution of uranium, thorium, radium, and/or actinium for the zirconium and/or hafnium within the mineral lattice result in some radioactive contamination. Monazite processing to obtain rare-earth elements results in a relatively large production of a byproduct, thorium nitrate. Because demand for thorium is greater than that for rare earths, excess thorium has been placed in low-level storage sites such as those in Barnwell, SC, and Hanford, WA. Processing of zircon and the titanium minerals are much less of a problem because of lower concentrations in the bulk product. However, some concentration does occur in the zirconium chemical and metal industries. These industries have been adhering to Federal code in the handling, storage, and disposal of the byproduct "source material." Generally, if the combined weight of uranium and thorium exceeds 0.05%, the materials are considered to be sources for these radioactive elements. Domestic requirements for licensing source material, definitions, exemptions, and other pertinent information is found in the Code of Federal Regulations, Energy, 10, Part 40 (10CFR40).

Japan enacted strict importation and industrial guidelines on June 6, 1991, as a result of the July 1990 finding of radiation levels originating from titanium dioxide pigment plant wastes dumped in the Okayama Prefecture. Basically, the policy addresses the following key areas: protection of residential areas near plants and dump sites, air quality, strict containment of ore and processing wastes, and limits on the allowable dose rates exhibited by ores.

Production

Domestic production and consumption of zircon concentrates were withheld to avoid disclosing company proprietary data. Milled zircon production increased 4% during 1993, while zirconium oxide production increased 5%. *(See table 1.)*

U.S. mine producers of zircon in 1993 were RGC (USA) Mineral Sands, Inc. and E. I. du Pont de Nemours & Co. (Du Pont). Both producers mined heavy-mineral sand deposits in Florida.

Countless other end products also were produced from zircon. High-volume production included refractory bricks and shapes, alumina-zirconia abrasives, foundry sands and investment castings, milled and micronized zircon, zirconium chemicals, and zirconia. Zirconium chemicals and zirconia are further used to produce many other products in a wide range of applications. Examples of high-value production are cubic zirconia, technical zirconia ceramics, superalloy castings, zirconia textile refractories, and specialty chemicals.

In 1993, Du Pont began dredging and mineral separation operations at its Maxville site in Florida. The new dredge was reported to have extended the mine life to the year 2010. The startup of dredging operations at Maxville coincided with a partial shutdown of the company's nearby Highland operations.[1]

Markets and Prices

Published prices for zircon- and zircon oxide-related products varied considerably by product type. The domestic list price for standard- and premium-grade zircon were unchanged, while the price for imported grades of zircon increased slightly. The published price for imported baddeleyite concentrate containing 99%+ ZrO_2 decreased 17%, and prices for zircon oxides were unchanged. Published prices for zirconium and hafnium metal products were unchanged compared to those of 1992. *(See table 2.)*

Foreign Trade

In 1993, the United States was a net importer of zirconium ores and concentrates with 99% of the imports originating in Australia and the Republic of South Africa. According to the Bureau of Census, imports of zirconium ores and concentrates increased 87% compared with those in 1992. Exports under the same classification increased 29%. *(See tables 3 and 4.)*

World Review

Australia.—Australia continued to lead the world in the production of zircon concentrates. In 1993, production of zircon by Australian producers was estimated to be 409,000 tons. Increased production corresponded to a similar increase in exports.

ISK Mineral Sands was reported to have exhausted its Waroona mineral sands deposit near Perth, Australia. Owing to poor market conditions in the titanium minerals market, ISK delayed the development of its Darndanup heavy-mineral deposit near Bunbury, Western Australia. The delay in developing Darndanup resulted in the closure of ISK's Picton mineral separation plant.[2]

Canada.—Tiomin Resources Inc. announced the completion of pilot plant gravity separation testing on heavy-mineral concentrate produced at Natashquan, Quebec. Tiomin has contracted Mineral Deposits Ltd. to establish a design for a production-scale plant and produce a capital cost estimate.[3]

South Africa, Republic of.—As part of a major corporate restructuring, the South African conglomerate Gencor increased its interest in Richards Bay Minerals (RBM) from 25% to 50%. The remaining 50% interest was held by RTZ Corp. RBM operates Tisand Ltd., a heavy-mineral producer of ilmenite, rutile, and zircon, and Richards Bay Iron and Titanium Co., the world's largest producer of titanium slag.[4] At yearend, RBM awaited a decision by the South African Government for the approval of the development of the Lake St. Lucia heavy-mineral deposit. Reserves at St. Lucia were estimated to be 276 million tons containing 9.74 million tons of ilmenite, 0.94 million tons of rutile, and 1.66 million tons of zircon.

According to industry reports, Anglo American Corp. planned to commission its Namakwa Sands project in 1994. At full production, the project will produce 195,000 tons of slag, 38,000 tons of rutile, and 140,000 tons of zircon annually.

Vietnam.—Westralian Sands Ltd. was reported to be investing in the modernization and possible expansion of a heavy-mineral operation in Ha Tinh, Vietnam. The investment represented a 60% interest in the Hah Tinh operation. The remaining interest was held by the Provincial government and the Vietnamese Ministry of Heavy Industry.[5] *(See table 5.)*

OUTLOOK

Zircon is a byproduct of heavy-mineral operations whose primary products are titanium-bearing ores and concentrates. Almost all titanium ores are consumed for producing titanium dioxide, the predominant white pigment used in most industries. Therefore, zircon supply is largely driven by demand for titanium dioxide pigments. Because global demand in the titanium pigment industry is expected to increase moderately over the next few years, the available supply of zircon is also expected to increase moderately.

The outlook for demand of zircon materials is determined by the major consuming industries, including the steel, glass, refractories, and ceramics markets. During the late 1980's, a temporary shortage of material caused prices for zircon products to soar. In reaction to rising prices and the material shortage, consuming industries developed substitute materials, which had eroded zircon demand for a period of several years. However, zircon demand is expected to increase moderately over the next few years.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Zirconium, Ch. in Mineral Commodity Summaries, annual.
Hafnium, Ch. in Mineral Commodity Summaries, annual.

Other Sources

American Metal Market, daily newspaper.
Chemical Engineering, biweekly.
Chemical Week, weekly.
Engineering and Mining Journal, monthly.
Industrial Minerals.
Industrial Minerals (London), monthly.
International Strategic Minerals Inventory. U.S. Geological Survey, Circular 930-L.
Metal Bulletin (London), semiweekly.
Metals Week, weekly.
Mining Engineering, monthly.
Mining Journal.
Mining Magazine and Mining Journal (London), monthly and weekly.
Roskill Information Services Ltd. (London). The Economics of Zirconium, 7th edition, 1992.

TABLE 1

SALIENT U.S. ZIRCONIUM STATISTICS

(Metric tons)

	1989	1990	1991	1992	1993
Zircon:					
Production:					
Concentrates	118,388	102,073	103,140	108,156	W
Milled zircon	54,699	43,886	44,403	45,074	46,711
Exports	48,071	30,195	31,333	27,853	35,932
Imports for consumption[1]	73,129	26,783	35,706	37,439	70,035
Consumption, apparent[1]	145,683	102,713	111,148	119,951	W
Stocks, Dec. 31: Dealers and consumers[2]	32,133	28,081	24,446	21,572	26,009
Zirconium oxide:					
Production[3]	10,030	7,483	9,747	8,691	9,147
Exports[4]	NA	NA	NA	NA	1,275
Imports for consumption[4]	NA	NA	NA	NA	1,993
Consumption, apparent	NA	NA	NA	NA	W
Stocks, Dec. 31: Producer[3]	502	737	872	719	W

NA Not available. W Withheld to avoid disclosing company proprietary data.
[1] Includes insignificant amounts of baddeleyite.
[2] Excludes foundries.
[3] Excludes intermediate oxides associated with metal production.
[4] Includes germanium oxides and zirconium dioxides.

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[1] Skillings Mining Review. Du Pont in Fla., Korean Co. Operating New Dredges. V. 82, No. 22, May 29, 1993, p. 5.

[2] Industrial Minerals. ISK Minsands Development Shelved. No. 305, Feb. 1993, p. 9.

[3] Tiomin Resources Inc. Press Release, Nov. 23, 1993.

[4] Metals Week. Gencor Wants to Unravel its Operations. V. 64, No. 20, May 17, 1993, p. 21.

[5] Mining Journal. Vietnamese Project for Westralian Sands. V. 320, No. 8207, Jan. 15, 1993, p. 45.

TABLE 2

PUBLISHED YEAREND PRICES OF ZIRCONIUM AND HAFNIUM MATERIALS

Specification of material	1992	1993
Zircon:		
Domestic, standard-grade, f.o.b. Starke, FL, bulk, per short ton[1]	$265.00	$265.00
Domestic, 75% minimum quantity zircon and aluminum silicates, Starke, FL, bulk, per short ton[1]	242.00	242.00
Domestic, premium-grade zircon, Starke, FL, bulk, per short ton[1]	294.00	294.00
Imported sand, ceramic application, f.o.b., bulk, per metric ton[2]	$190.00 - 210.00	$210.00 - 220.00
Imported sand, refractory application, f.o.b., bulk, per metric ton[2]	190.00 - 210.00	210.00 - 220.00
Imported sand, foundry sand application, f.o.b., bulk, per metric ton[2]	190.00 - 210.00	190.00 - 210.00
Baddeleyite, imported concentrate: [3]		
96% to 98% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	.50 - .75	XX
98% to 99% ZrO_2, minus 100-mesh, c.i.f. Atlantic ports, per pound	XX	.75 - .85
99% + ZrO_2, minus 325-mesh, c.i.f. Atlantic ports, per pound	1.16 - 1.40	1.00 - 1.13
Zirconium oxide:[4]		
Powder, commercial-grade, drums, 2,000-pound minimum, per pound	3.00 - 6.60	3.00 - 6.60
Electronic, same basis, per pound	3.50 - 8.00	3.50 - 8.00
Insulating, stabilized, 325° F, same basis, per pound	3.35 - 4.00	3.35 - 4.00
Insulating, unstabilized, 325° F, same basis, per pound	3.35 - 4.00	3.35 - 4.00
Dense, stabilized, 300° F, same basis, per pound	3.60	3.60
Zirconium oxychloride: Crystal, cartons, 5-ton lots, from works, per pound [4]	.91 - 1.04	.91 - 1.04
Zirconium acetate solution:[4]		
25% ZrO_2, drums, carlots, 15-ton minimum, from works, per pound	.97	NA
22% ZrO_2, same basis, per pound	.78	NA
Zirconium hydride: Electronic-grade, powder, drums, 100-pound lots, from works, per pound [4]	.31 - .75	NA
Zirconium:[5]		
Powder, per pound	75.00 - 150.00	75.00 - 150.00
Sponge, per pound	9.00 - 12.00	9.00 - 12.00
Sheets, strip, bars, per pound	20.00 - 50.00	20.00 - 50.00
Hafnium: Sponge, per pound[5]	75.00 - 95.00	75.00 - 95.00

NA Not available. XX Not applicable.

[1] E. I. du Pont de Nemours & Co. Inc. price list, July 1, 1992, and July 1, 1993, respectively.

[2] Industrial Minerals (London). No. 303, Dec. 1992, p. 67; and No. 316, Jan. 1994, p. 71.

[3] The Applegate Group and American Vermiculite Corp. baddeleyite price lists.

[4] Chemical Marketing Reporter. V. 242, No. 26, Dec. 28, 1992; v. 244, No. 26, Dec. 27, 1993.

[5] American Metal Market. V. 101, No. 1, Jan. 4, 1993, p. 6; and v. 101, No. 233, Dec. 3, 1993, p. 7.

TABLE 3
U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Ore and concentrates:				
Argentina	336	$258	567	$312
Australia	39	46	39	41
Belgium	113	64	32	17
Brazil	644	214	672	167
Canada	3,561	1,981	2,749	2,021
Chile	7	3	—	—
China	—	—	135	152
Colombia	2,000	1,591	1,707	1,229
Costa Rica	54	57	36	37
Dominican Republic	227	262	175	173
Ecuador	191	108	195	59
Egypt	188	124	76	14
France	427	286	462	228
Germany	10,325	4,342	15,274	3,394
Hong Kong	—	—	310	249
India	—	—	73	40
Indonesia	—	—	309	201
Ireland	16	12	43	31
Israel	—	—	15	10
Italy	20	10	—	—
Japan	291	459	232	129
Korea, Republic of	204	91	112	43
Malaysia	—	—	253	167
Mexico	6,206	1,963	8,460	2,108
Netherlands	—	—	176	83
New Zealand	—	—	14	7
Pakistan	285	414	199	123
Panama	—	—	20	24
Singapore	175	150	526	320
Taiwan	54	49	577	420
Thailand	—	—	16	8
United Kingdom	491	299	896	418
Uruguay	29	17	—	—
Venezuela	1,092	883	1,559	922
Other	880	639	21	32
Total[1]	27,853	14,323	35,932	13,177
Unwrought zirconium and waste and scrap:				
Belgium	43	444	31	557
France	109	3,077	8	97
Germany	24	724	10	133
Japan	124	6,450	123	3,566
Korea, Republic of	—	—	21	458
Netherlands	1	36	—	—
Sweden	—	—	9	215

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF ZIRCONIUM, BY CLASS AND COUNTRY

Class and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Unwrought zirconium and waste and scrap—Continued:				
Switzerland	41	$966	—	—
United Kingdom	28	844	21	$459
Other	18	529	25	660
Total[1]	389	13,070	248	6,145

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

Source: Bureau of the Census.

TABLE 4

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

Class and country	1992		1993	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Zirconium ore and concentrates:[1]				
Australia	24,482	$4,876	37,048	$5,217
Canada	40	9	200	200
Germany	—	—	439	45
Netherlands	101	120	—	—
South Africa, Republic of	12,708	1,707	32,172	3,578
United Kingdom	108	178	168	253
Other	(2)	16	8	29
Total[3]	37,439	6,906	70,035	9,323
Zirconium, unwrought and waste and scrap:				
Canada	61	281	—	—
France	18	55	33	233
Germany	13	259	16	338
Japan	17	147	64	447
Other	6	79	8	147
Total[3]	115	821	121	1,164
Hafnium, unwrought and waste and scrap:				
Canada	—	—	(2)	2
France	2	430	3	556
Germany	(2)	1	(2)	104
United Kingdom	—	—	(2)	7
Total	2	431	3	669

[1] Australia and the Republic of South Africa are believed to be point of origin; other countries are point of shipment.

[2] Less than 1/2 unit.

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

Source: Bureau of the Census.

TABLE 5
ZIRCONIUM MINERAL CONCENTRATES: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1989	1990	1991	1992	1993[e]
Australia	511,000	437,000	292,000	[r]283,000	409,000
Brazil[2]	32,970	16,907	18,590	[r] [e]20,000	20,000
China[e]	15,000	15,000	15,000	15,000	15,000
India[e]	17,200	[r]17,500	18,200	18,000	20,000
Indonesia[e]	2,500	2,500	2,500	2,500	2,500
Malaysia	18,704	4,279	5,579	2,608	[3]2,184
Russia[4]	—	—	—	[e]3,000	2,500
Sierra Leone	—	—	1,119	[r]1,329	—
South Africa, Republic of [e] [5]	150,000	[3]151,536	230,000	230,000	230,000
Sri Lanka	21,983	19,727	26,123	[r]13,368	[3]14,401
Thailand	1,496	490	2,573	[r]1,723	1,500
Ukraine	—	—	—	[e]75,000	70,000
U.S.S.R.[e] [6]	90,000	85,000	80,000	—	—
United States	118,388	102,073	103,140	108,156	W
Total	979,241	[r]852,012	794,824	[r]773,684	787,085

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

[1] Includes data available through July 15, 1994.

[2] Includes production of baddeleyite-caldasite.

[3] Reported figure.

[4] Includes production of baddeleyite.

[5] Includes production of zircon and baddeleyite.

[6] Dissolved in Dec. 1991.