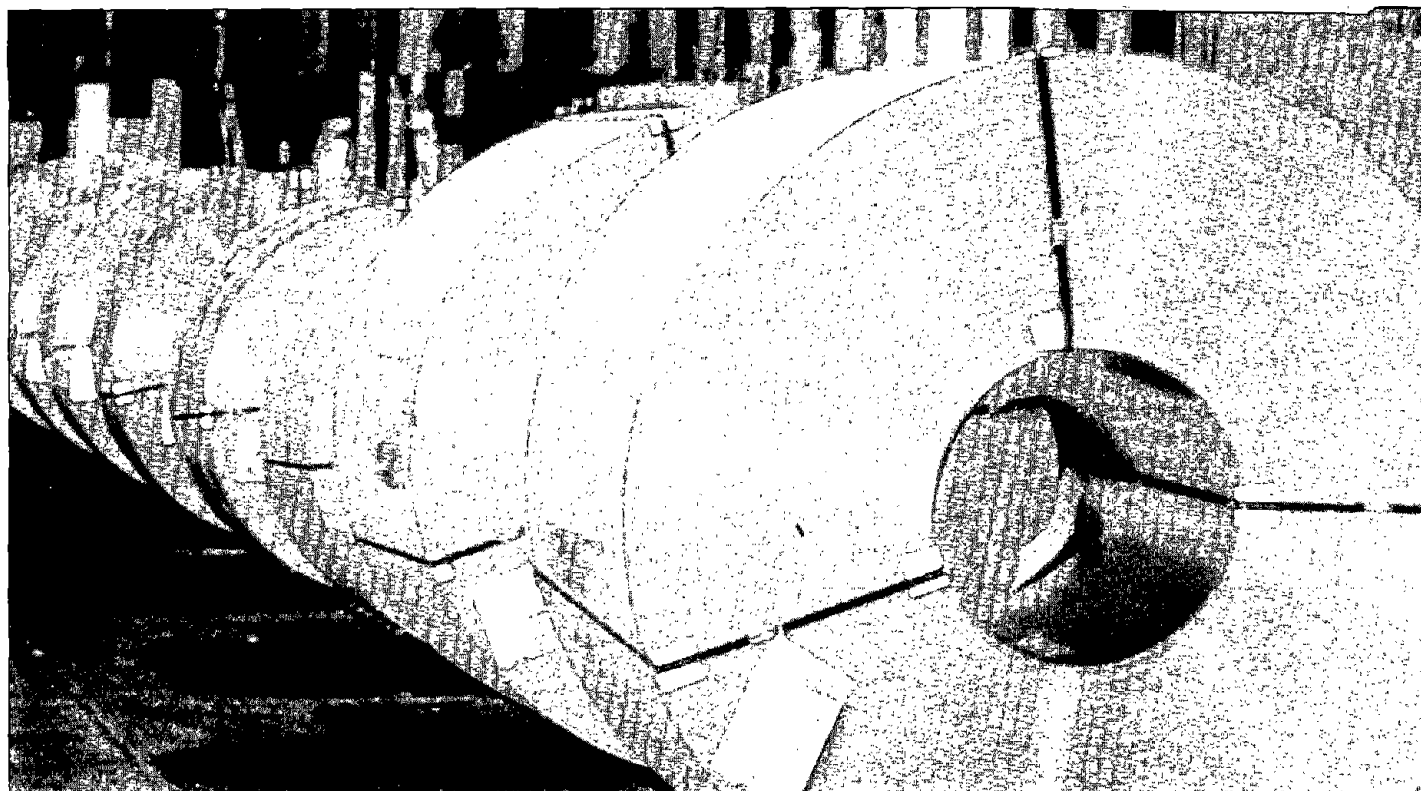




CHROMIUM

By John F. Papp

1993

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

REPRODUCED BY:
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161



CHROMIUM



U.S.
DEPARTMENT
OF THE
INTERIOR

Bruce Babbitt
Secretary



BUREAU
OF
MINES

October 1994

Contents

Domestic Data Coverage	1
Background	1
Definitions, Grades, and Specifications	2
Products for Trade and Industry	2
Industry Structure	2
Geology-Resources	3
Technology	3
Mining	3
Beneficiation	3
Smelting	3
Recycling	4
Byproducts and Coproducts	4
Economic Factors	4
Prices	4
Costs	4
Tariffs	6
Operating Factors	6
Environmental Issues	6
Health	6
Toxicity	6
Environmental Releases and Transfers	7
Energy Requirements	7
Transportation	7
Annual Review	7
Legislation and Government Programs	8
Strategic Considerations	8
Supply Security	8
Use	8
Stockpile	8
Issues	8
Production	9
Consumption and Uses	9
Stocks	9
Prices	9
Foreign Trade	10
World Review	10
Industry Structure	10
Capacity	10
Reserves	10
Production	10
Albania	10
National Developments	10
Chromite Ore	11
Ferrochromium	11
Australia	11
Brazil	11
National Developments	11

Chromite Ore and Ferrochromium	11
Bulgaria	11
Canada	12
National Developments	12
Ferrochromium	12
China	12
National Developments	12
Chromite Ore	12
Ferrochromium	12
Commonwealth of Independent States	12
Croatia	12
Egypt	12
Ethiopia	12
European Community	12
Finland	12
France	13
Greece	13
Greenland	13
India	13
National Developments	13
Chromite	13
Ferrochromium	14
Chemicals	14
Iran	14
Italy	14
Japan	14
Kazakhstan	15
National Developments	15
Chromite Ore	15
Ferrochromium	15
Korea, Republic of	15
Madagascar	15
Mexico	15
Oman	15
Philippines	16
National Developments	16
Chromite Ore	16
Ferrochromium	16
Romania	16
Russia	16
Ferrochromium	16
Chromium Metal	16
Slovakia	16
Slovenia	16
South Africa, Republic of	16
Chromite Ore	17
Ferrochromium	17
Stainless Steel	18
Taiwan	18
Thailand	18
Turkey	18
United Kingdom	18
Zimbabwe	18

Current Research	18
Mineral Processing and Industrial Applications	18
Environmental	19
Outlook	19
Stainless Steel	19
Chromium Chemicals	20

Tables

Table 1.—Principal World Chromite Producers, 1993	22
Table 2.—Principal World Ferrochromium Producers, 1993	24
Table 3.—Time-Value Relationships for Chromite Ore	26
Table 4.—Time-Value Relationships for Ferrochromium and Chromium Metal	27
Table 5.—Availability of Chromite and Chromium Ferroalloys From 10 Market Economy Countries	28
Table 6.—Salient Chromium Statistics	28
Table 7.—Historical and Projected Performance of the National Defense Stockpile Chromite Ore to Ferrochromium Conversion Program	29
Table 8.—Historical and Projected Performance of the National Defense Stockpile Low-Carbon Ferrochromium to Chromium Metal Conversion Program	29
Table 9.—U.S. Government Stockpile Yearend Inventories and Annual Disposals for Chromium in 1993	30
Table 10.—Principal U.S. Producers of Chromium Products in 1993, by Industry	30
Table 11.—Production, Shipments, and Stocks of Chromium Ferroalloys and Metal, and Other Chromium Materials in the United States	31
Table 12.—Consumption of Chromite and Tenor of Ore Used by Primary Consumer Groups in the United States	31
Table 13.—U.S. Consumption of Chromium Ferroalloys and Metal, by End Use	31

Table 14.—U.S. Consumer Stocks of Chromite, Chromium Ferroalloys, and Metal, December 31	33
Table 15.—Price Quotations for Chromium Materials at Beginning and End of 1993	33
Table 16.—U.S. Exports of Chromium Materials, by Type	34
Table 17.—U.S. Imports for Consumption of Chromite Ore, by Country	35
Table 18.—U.S. Imports for Consumption of Ferrochromium, by Country	35
Table 19.—U.S. Imports for Consumption of Chromium Materials, by Type	37
Table 20.—U.S. Import Duties for Chromium-Containing Materials in 1993	38
Table 21.—World Chromium Resources and Annual Production Capacity of Chromite Ore, Ferrochromium, Chromium Metal, Chromium Chemicals, and Stainless Steel in 1993	39
Table 22.—Chromite: World Production, by Country	41
Table 23.—Ferrochromium: World Production, by Country	42
Table 24.—Chromium Supply-Demand Relationships	43

Figures

Figure 1.—Chromium Material Flow	44
Figure 2.—General Recycling Chromium Material Flow Industry Structure	44
Figure 3.—Cost of Low-Carbon Ferrochromium Production at 0% and 15% Discounted Cash-Flow Rate of Return (DCFROR) for Selected Market Economy Producers	45
Figure 4.—Cost of High-Carbon Ferrochromium Production at 0% and 15% Discounted Cash-Flow Rate of Return (DCFROR) for Selected Market Economy Producers	45
Figure 5.—Imported High-Carbon Ferrochromium Weekly Price Range and Time-Averaged Annual Price in 1993	46

Figure 6.—Imported Low-Carbon Ferrochromium Weekly Price Range and Time-Averaged Price in 1993	46
Figure 7.—World Geographic Location and Size of Chromite Ore, Ferrochromium, and Stainless Steel Producers	47

COVER PHOTO:

Stainless steel is the major end use of chromium.

For comments or further information, please contact

The Branch of Metals

The Division of Mineral Commodities

U.S. Bureau of Mines

810 7th St., NW, MS 5208

Washington, DC 20241

Telephone: (202) 501-9438

Fax: (202) 501-9961

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 industry⁵ 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 Re-authorization 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 on-site; and the amount transferred to offsite locations. The collected data are called the TRI. EPA reported total releases and transfers of chromium in chromium and chromium compounds.

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% Cr₂O₃ (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 Aços 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 Dobromitsi 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% Cr₂O₃ to 51.9% Cr₂O₃.²⁰

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% Cr₂O₃. The mineralogy, mineral chemistry, and platinum-group element distribution were found to establish the podiform or layered affinity of these chromitites and, possibly, 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% Cr₂O₃ with a beneficiated concentrate analyzed at 43% Cr₂O₃.²⁶

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 Ferroleghé SpA. Ferroleghé 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 ferrochromium-silicon furnace, electing to use imported ferrochromium-silicon 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 Ilel 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 prereluction 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. (Ferroalloys 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. Cr₂O₃ 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 Enviropas 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 compounds³⁸ 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 Chemicals⁴³

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.

⁴³Stowe, C. W. (ed.). *Evolution of Chromium Ore Fields*. Van Nostrand Reinhold, 1987, 340 pp.

Petruscheck, W., S. Karamata, G. G. Kravchenko, Z. Johan, M. Economou, and T. Engin (eds.). *Chromites, Unesco's IGCP-197 Project Metallogeny of Ophiolites*

(Chromite Deposits and Occurrences). Theophrastus Publ. S.A., Athens, Greece, 1986, 339 pp.

²Papp, J. F. Chromium. Ch. in *Minerals Facts and Problems*, 1985 ed. BuMines 675, 1985, pp. 142-145.

³Because chromium ore price changes may lag those of ferrochromium by only a few months, the tables may show peak average annual values occurring in the same year.

⁴Boyle, E. H., D. J. Shields, and L. A. Wagner. Chromium Availability in Market Economy Countries and Network Flow Model Analysis of World Chromium Supply. BuMines IC 9337, 1993, 131 pp.

⁵Von Below, M. A. Planning for Future Ferroalloy Production in South Africa. Paper in *Ferroalloys*, ed. by H. W. Glen (V. 1 of Proc. 6th Int. Ferroalloys Congr. and 1st Int. Chromium Steel and Alloys Congr., Cape Town, South Africa, Mar. 8-11, 1992). The South African Institute of Mining and Metallurgy, Johannesburg, Symposium Series No. 11, 1992, pp. 261-268.

⁶National Research Council. *Recommended Dietary Allowances*. Natl. Acad. Sci., Washington, DC, 1989, pp. 241-243.

⁷Burrows, D. Chromium: Metabolism and Toxicity. CRC Press, 1983, 184 pp.

U.S. Environmental Protection Agency. *Health Effects Assessment for Trivalent Chromium*. Report EPA/540/1-86-035, Sept. 1984, 32 pp.

———. *Health Effects Assessment for Hexavalent Chromium*. Report EPA/540/1-86-019, Sept. 1984, 49 pp.

Ottoboni, M. A. *The Dose Makes the Poison*. Van Nostrand Reinhold, 2d ed., 1991, 244 pp.

Taylor, S. R., and S. M. McLennan. *The Continental Crust: Its Composition and Evolution*. Blackwell Scientific Publ., 1985, pp. 15-16, 67.

⁸Federal Register. Chromium (III) Compounds; Toxic Chemical Release Reporting; Community Right-To-Know. V. 56, No. 226, Nov. 22, 1991, pp. 58859-58862.

⁹American Congress of Government Industrial Hygienists. 1993-1994 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, p. 36, 1993.

¹⁰Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services. *Toxicological Profile for Chromium*. April 1993, 250 pp.

¹¹U.S. Environmental Protection Agency. 1991 Toxics Release Inventory—Public Data Release State Fact Sheets. EPA 745-F-93-002, May 1993, 110 pages.

———. 1991 Toxics Release Inventory—Public Data Release. EPA 745-R-93-003, May 1993, 364 pp.

———. *Toxic Chemical Release Inventory Reporting Form R and Instructions—Revised 1992 Version*. EPA 745-K-93-001, 1993, 100 pages.

¹²Commodities Research Unit. *The Cost of Producing Ferroalloys 1988-1990*. V. 3: High-Carbon Ferrochrome, 1991, 157 pp.

¹³Defense Logistics Agency (Dep. Defense). *Strategic and Critical Materials Report to Congress. Operations Under the Strategic and Critical Materials Stock Piling Act During the Period Oct. 1992-Sept. 1993*. 1994, pp. 15, 17.

¹⁴Associação Brasileira Dos Produtores De Ferroligas. *Anuario da Industria Brasileira de Ferroligas 1992*. 1994, 22 pp.

¹⁵Departamento Nacional da Produção Mineral, Ministério de Minas e Energia. *Sumário Mineral 1993* (preprint). 1993, pp. 25-26.

¹⁶Barbosa de Deus, P., L. Brigo, U. Costa, V. Diella, A. Ferrario, and G. Garuti. The Campo Formoso Ultramafic Complex, Bahia State, Brazil: An Example of an Archean PGE-Bearing Chromitites. *Terra Abstr.*, v. 3, No. 1, 1991, p. 110.

¹⁷Morin, Y., R. Hébert, and J. H. Bédard. Setting and Origin of the Hall Chromitite Ore Body in the Thetford Mines Ophiolite Complex, Quebec. Paper in 1992 Spring Meeting of the American Geophysical Union, Canadian

Geophysical Union, and Mineralogical Society of America, 1992, Montreal, Quebec Province, Canada, May 12-16. Am. Geophysical Union, 1992, p. 343.

¹²Zhou, M., and W. Bai. Chromite Deposits in China and Their Origin. *Mineralium Deposita*, v. 27, pp. 192-199, 1992.

¹³Genkin, A. D., and V. V. Disler. Main Types of Copper-Nickel, Chrome and Platinum Metals Deposits in Mafic and Ultramafic Rocks. *CSM Quarterly Rev.*, v. 92, No. 1, pp. 29-41, 1992.

¹⁴Atia, A. K. M., S. N. Boulis, S. I. Ismael, and M. E. Hilmy. Mineralogy and Geochemistry of Chromite Ores in Some Localities in Egypt. Source, Transport and Deposition of Metals, Pagel and Leroy (eds.), Balkema, Rotterdam, 1992, pp. 605-607.

¹⁵Bonavia, F. F., V. Diella, and A. Ferrario. Precambrian Podiform Chromitites From Kenticha Hill, Southern Ethiopia. *Econ. Geol.*, v. 88, 1993, pp. 198-202.

¹⁶Velev, V., A. Kuzniak, and S. T. Hall. Central and Eastern Europe: Changes in Minerals Sector. *Raw Materials Report*, v. 9, No. 2, 1993, pp. 14-18.

¹⁷Outokumpu News. V. 30, No. 1/93, pp. 23-25.

¹⁸Grivas, E., and A. Rassios. Drilling for "Blind" Podiform Chrome Orebodies at Voudolakkos in the Vourinos Ophiolite Complex, Greece. *Econ. Geol.*, v. 88, 1993, pp. 461-468.

¹⁹Indian Bureau of Mines, Nagpur, India. Chromite chapter in *Indian Minerals Yearbook 1992*, v. II. Apr. 1993, pp. 301-313.

²⁰Balakrishnan, S., M. H. Abbas, K. T. Vidyadharan, and K. R. Raghunandan. Chromite and Sulphide Mineralization in the Mafic-Ultramafic Complex of Usgaon, Bos. *Indian Miner.*, v. 46, Nos. 3 and 4, July-Dec. 1992, pp. 303-322.

²¹Indian Bureau of Mines, Nagpur, India. Ferro-alloys chapter in *Indian Minerals Yearbook 1992*, v. II. Apr. 1993, pp. 377-388.

²²Fetisov, V. Developments in the Donskoi Chrome Operation in Kazakhstan. In *Metal Bulletin's 9th International Ferro-Alloys Conference*, Orlando Florida, Nov. 16-18, 1993.

²³Grohmann, G. Chromium. In *South Africa's Minerals Industry 1992/93*. Minerals Bureau, Republic of South Africa, Aug. 1993, pp. 43-46.

²⁴Work cited in footnote 29.

²⁵Metal Bulletin. No. 7769, Apr. 1, 1993, p. 10.

²⁶The TEX Report, Ltd. V. 25, No. 5931, July 30-Aug. 2, 1993, p. 3, 4.

²⁷Samancor Annual Report 1993.

²⁸The TEX Report, Ltd. V. 25, No. 6011, Nov. 30, 1993, pp. 6-9.

———. V. 25, No. 5966, Sept. 22, 1993, p. 12.

²⁹Orberger, B. Chromite Mineralization in the Nantaratit Ultramafic-mafic Belt, Northern Thailand. *Terra Abstr.*, v. 3, No. 1, 1991, p. 110.

³⁰Mintek Bulletin. No. 62, June 1993, p. 1.

³¹Cortie, M. B. History and Development of Ferritic Stainless Steels. *J. South African Institute of Min. and Metall.*, v. 93, No. 7, July 1993, pp. 165-176.

³²U.S. Environmental Protection Agency. Evaluation of the Potential Carcinogenicity of Chromium and Hexavalent Chromium Compounds. EPA/600/8-91/093, 38 pp.

³³———. Atmospheric Releases of Hexavalent Chromium From Hard Chromium Plating Operations. EPA/600/14, 12 pp.

³⁴Papp, J. F. Chromium Life Cycle Study. U.S. Bureau of Mines report in progress.

³⁵Granville, A., and E. F. Statham. Profits From Processing. *Mintek*, Nov. 1989, pp. 10-11.

³⁶Bleiwas, D. I. Availability of Primary Nickel in Market Economy Countries. BuMines IC 9276, 1991, 52 pp.

³⁷Chemical Marketing Reporter. Oct. 14, 1991, p. 50. Page 7 of work cited above.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Chromium. Ch. in *Mineral Commodity Summaries*, annual.

Chromium. Ch. in *Minerals Yearbook*, annual.

Mineral Industry Surveys, monthly.

Other Sources

American Iron and Steel Institute.

American Metal Market.

Ceramic Bulletin.

Chemical Weekly.

Chromite. Ch. in *Industrial Rocks and Minerals*.

CRU Metal Monitor.

Defense Logistics Agency, *Stockpile Reports*.

Department of State, various communications.

European Chemical News.

The Economics of Chromium (Roskill Information Services, London).

Engineering and Mining Journal.

Federal Register.

Ferro-Alloy Directory and Databook (Metal Bulletin, London).

Ferro Alloys Manual (The TEX Report, Tokyo).

Ferrous Mineral Commodities Produced in the Republic of South Africa 1992 (South African Department of Mineral and Energy Affairs Directory D8/93).

Indian Minerals Yearbook 1992, Chromite and Ferro-alloys Chapters, (Indian Bureau of Mines).

Industrial Minerals (London).

International Chromium Development Association (Paris).

Metal Bulletin (London).

Metals Price Report (London).

Metals Week.

Mining Annual Review (London).

Mining Engineering.

Mining Journal (London).

Mining Magazine.

Stainless Steel Databook (Metal Bulletin Books, London).

The TEX Report (Tokyo).

TABLE 1
PRINCIPAL WORLD CHROMITE PRODUCERS, 1993

Country ¹	Company
Albania	Government owned.
Brazil	Bayer AG (Germany) Coitezeiro Mineração S.A. Cia. de Ferro-Ligas da Bahia S.A. Cia. de Mineração Serra de Jacobina S.A. Mineração Vale do Jacurici S.A. Industria e Comércio de Minérios S.A. Vila Nova Mine. Magnesita S.A.
Finland	Outokumpu Oy (Government owned).
India	Ferro Alloys Corp. Ltd. 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. Mooi-nooi 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 Madin Sirketi AS. Hayri Ogelman Madencilik AS.
Zimbabwe	Zimbabwe Alloys Ltd. Zimbabwe Mining and Smelting Co. (Pvt.) Ltd.

¹Other chromite-producing countries included Burma, China, Cuba, Egypt, Indonesia, Iran, Japan, Macedonia, Madagascar, Morocco, Oman, Pakistan, and Sudan.

²Includes 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. Ferroleghes 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. Yermakovskiy 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. Ferroalloys 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.

¹Other ferrochromium-producing countries include Albania, Chile, Poland, Mexico, Romania, Spain, and Taiwan.

TABLE 3
TIME-VALUE¹ RELATIONSHIPS FOR CHROMITE ORE

(Average annual value, dollars per metric ton of contained chromium)

Year	Not more than 40% chromic oxide		More than 40% but less than 46% chromic oxide		46% or more chromic oxide		Total, all grades	
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar
1963	86	315	40	146	63	232	54	197
1964	84	302	44	157	59	212	57	205
1965	88	309	48	169	59	208	59	209
1966	82	279	45	154	62	211	58	198
1967	87	289	48	159	66	218	62	205
1968	81	256	45	142	60	191	59	185
1969	75	226	51	153	66	198	64	192
1970	85	243	53	151	90	256	79	226
1971	98	265	58	157	98	264	87	235
1972	99	254	62	159	94	242	89	230
1973	104	252	55	132	93	225	82	199
1974	109	244	67	150	104	231	96	213
1975	178	362	101	206	209	425	175	355
1976	222	425	146	279	262	501	212	405
1977	235	421	166	296	254	454	206	368
1978	230	381	177	293	185	307	200	331
1979	240	367	187	285	232	354	215	329
1980	288	402	195	272	189	263	222	310
1981	266	337	192	244	184	234	219	277
1982	293	350	201	239	213	254	229	273
1983	359	412	172	198	166	190	194	223
1984	403	443	141	154	156	172	186	204
1985	261	277	160	170	160	169	184	195
1986	218	225	145	149	146	151	163	169
1987	185	185	160	160	155	155	168	168
1988	241	232	269	259	187	180	229	220
1989	292	269	290	267	247	228	271	250
1990	313	276	228	201	237	209	242	214
1991	562	477	209	178	263	223	232	197
1992	368	304	214	177	213	176	226	187
1993	506	^a 407	204	^a 164	190	^a 153	196	^a 158

^aPreliminary. ^bRevised.

¹Customs 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-VALUE¹ RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL

(Average annual value)

Year	Ferrochromium (dollars per metric ton of contained chromium)						Chromium metal (dollars per metric ton gross weight)	
	Low-carbon ²		High-carbon ³		Total, all grades		Actual	Constant dollar
	Actual	Constant dollar	Actual	Constant dollar	Actual	Constant dollar		
1963	397	1,461	290	1,067	376	1,383	1,677	6,165
1964	380	1,371	304	1,098	360	1,300	1,670	6,029
1965	408	1,437	268	942	395	1,390	1,661	5,849
1966	410	1,394	232	789	367	1,249	NA	NA
1967	417	1,375	264	870	394	1,301	NA	NA
1968	399	1,260	261	824	382	1,204	1,656	5,224
1969	426	1,279	236	710	370	1,112	1,800	5,405
1970	453	1,290	272	775	401	1,142	NA	NA
1971	585	1,582	342	925	464	1,254	2,003	5,414
1972	556	1,433	282	727	422	1,089	2,206	5,686
1973	617	1,493	289	700	392	948	2,491	6,031
1974	797	1,776	512	1,141	600	1,335	3,030	6,748
1975	1,534	3,119	942	1,914	1,061	2,157	4,486	9,118
1976	1,406	2,688	719	1,376	916	1,751	4,350	8,317
1977	1,385	2,478	702	1,255	826	1,477	4,938	8,834
1978	1,405	2,329	640	1,061	686	1,138	NA	NA
1979	1,737	2,652	853	1,303	945	1,443	NA	NA
1980	1,826	2,546	890	1,241	972	1,355	7,682	10,714
1981	1,609	2,040	870	1,102	952	1,206	7,662	9,711
1982	1,551	1,851	887	1,058	1,008	1,202	6,018	7,181
1983	1,437	1,648	683	783	737	845	4,491	5,150
1984	1,496	1,644	782	860	833	916	5,674	6,235
1985	1,571	1,664	847	897	914	968	5,468	5,792
1986	1,409	1,454	779	804	851	878	5,320	5,490
1987	1,543	1,543	783	783	893	893	6,097	6,097
1988	1,988	1,914	1,317	1,268	1,403	1,351	7,231	6,960
1989	1,909	1,759	1,524	1,404	1,609	1,483	6,598	6,081
1990	1,619	¹ 1,429	883	¹ 779	1,017	¹ 897	6,459	¹ 5,701
1991	1,991	¹ 1,692	874	742	997	¹ 847	7,584	¹ 6,444
1992	1,871	¹ 1,545	875	¹ 723	966	¹ 798	6,671	¹ 5,509
1993	1,307	¹ 1,052	679	¹ 547	790	¹ 636	6,136	¹ 4,940

¹Preliminary. ²Revised. NA Not available.

¹Customs value per ton of chromium contained in imported material.

²Carbon not more than 4%.

³More than 4% carbon.

NOTE.—Constant dollar value is actual value multiplied by gross domestic product (GDP) ratio. GDP ratio is 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		

¹Cost of production for zero percent discounted cash-flow rate of return in Jan. 1989 dollars per metric ton, gross weight, of product f.o.b. 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	² 14,006	² 12,959	² 13,320	² 10,993	² 10,001
CHROMIUM FERROALLOYS³					
United States:					
Net production ¹	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	³ 355	341
Stocks, December 31: Consumer	19	18	19	18	17
World production	³ 3,894	³ 3,619	³ 3,619	³ 3,425	³ 3,129

¹Estimated. ²Revised.

¹Less than 1/2 unit.

²High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.

³Includes 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*				
1994	99,026	16,574	NA	10.5

*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*			
October 1993 - September 1994	NA	NA	NA

*Estimated. NA Not available.

¹Nonspecification 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	—

¹Includes 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 ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O 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		Ferro-chromium-silicon	Other	Total ³
	Low-carbon ¹	High-carbon ²			
1991:					
Steel:					
Carbon	3,751	6,478	249	195	10,673
Stainless and heat-resisting	8,283	278,108	7,010	136	293,536
Full-alloy	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	—	(*)	319	479
Total ^{3 7}	22,151	318,604	15,125	*4,721	360,602
Chromium content	15,013	183,105	5,595	4,451	208,164
Stocks, December 31, 1991	2,455	15,355	367	*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	1895	15,160	15	19	16,088
Superalloys	2,753	W	—	3,005	5,758
Welding materials ⁴	W	W	W	276	276
Other alloys ⁵	W	W	—	120	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 ¹
	Low- carbon ¹	High- carbon ²			
1992—Continued:					
Miscellaneous and unspecified	(⁶)	⁴ 4,160	7,372	⁵ 511	⁷ 12,043
Total ⁷	² 21,670	³ 330,351	¹ 14,319	¹⁰ 4,060	³ 370,399
Chromium content ⁸	15,910	192,844	5,166	3,733	217,653
Stocks, December 31, 1992	<u>²2,520</u>	<u>14,218</u>	<u>276</u>	<u>¹¹614</u>	<u>¹17,628</u>
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 ^{1, 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

⁷Revised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹Low-carbon ferrochromium contains less than 3% carbon.

²High-carbon ferrochromium contains 3% or more carbon.

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

⁴Includes structural and hard-facing welding material.

⁵Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

⁶Withheld to avoid disclosing company proprietary data; included with "Other."

⁷Includes estimates.

⁸Includes 3,585 tons of chromium metal.

⁹Includes 433 tons of chromium metal.

¹⁰Includes 3,819 tons of chromium metal.

¹¹Includes 438 tons of chromium metal.

¹²Includes 4,120 tons of chromium metal.

¹³Includes 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	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	17,628	16,685

¹Revised.

¹Includes 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	⁵ 5,795	⁷ 8,820	⁸ 8,292	⁶ 10,071	7,804	Canada (69%); Mexico (28%).
Low-carbon ferrochromium ³	² 2,521	² 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	¹³ 800	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%).

¹Articles thereof and waste and scrap.

²More than 4% carbon.

³Contained 3,477 tons of chromium.

⁴Contained 4,617 tons of chromium.

⁵Contained 4,907 tons of chromium.

⁶Contained 5,992 tons of chromium.

⁷Not more than 4% carbon.

⁸Contained 1,517 tons of chromium.

⁹Contained 1,263 tons of chromium.

¹⁰Contained 1,085 tons of chromium.

¹¹Contained 2,673 tons of chromium.

¹²Contained 333 tons of chromium.

¹³Contained 261 tons of chromium.

¹⁴Contained 235 tons of chromium.

¹⁵Contained 280 tons of chromium.

¹⁶Contained 5,327 tons of chromium.

¹⁷Contained 6,141 tons of chromium.

¹⁸Contained 6,227 tons of chromium.

¹⁹Contained 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 ₂ O ₃			More than 40% but less than 46% Cr ₂ O ₃			46% or more Cr ₂ O ₃			Total ¹		
	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)
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

¹Data 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 (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)
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 (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)
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
Nether- lands	—	—	—	—	—	—	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

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

²Dissolved 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 (thou-sands)	
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	13,801	15,301	19,379	18,751	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%).

¹Contained 1,459 tons of chromium.

²Contained 2,046 tons of chromium.

³Contained 3,643 tons of chromium.

⁴Contained 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 ₂ O ₃	2610.00.0020	Free	Free	NA	NA.
More than 40% and less than 46% Cr ₂ O ₃	2610.00.0040	do.	do.	NA	NA.
Not less than 46% Cr ₂ O 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.

¹The following countries were non-MFN in 1993: Afghanistan, Albania, Cuba, Kampuchea, Laos, North Korea, Romania, and Vietnam.

²United States-Canada Free-Trade Agreement.

³A-Generalized System of Preferences, E-Caribbean Basin Economic Recovery Act, IL-United States-Israel Free Trade Area Implementation Act of 1985, I-Andean Trade Preference Act.

Source: U.S. International Trade Commission.

TABLE 21
WORLD CHROMIUM RESOURCES¹ 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	(*)	12	165
Burma	NA	NA	NA	(*)	—	—	—	—
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	(*)	5	45
Indonesia	200	200	200	20	—	—	—	—
Iran	700	700	17,700	34	—	—	2	—
Italy	—	—	—	—	64	—	—	107
Japan	(*)	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 RESOURCES¹ 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.

¹World resources derived in consultation with the U.S. Geological Survey.

²Data and total rounded to nearest 100,000 metric tons.

³The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).

⁴Less than 1/2 unit.

⁵Less than 50,000 metric tons.

TABLE 22
CHROMITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons, gross weight)

Country ²	1989	1990	1991	1992	1993*
Albania*	'900,000	'910,000	'500,000	150,000	90,000
Brazil ⁴	475,949	267,000	340,000	'460,044	430,000
Burma*	5,000	1,000	1,000	6,200	6,000
China*	25,000	25,000	25,000	25,000	25,000
Cuba*	'50,600	50,000	50,000	50,000	50,000
Egypt	2,448	399	649	'600	600
Finland*	'513,000	'504,000	'473,000	'499,000	500,000
Greece ³	'62,324	'35,400	'37,169	—	—
India	1,002,659	939,000	'1,087,000	'1,312,000	1,070,000
Indonesia	7,635	'8,000	1,950	'2,000	2,500
Iran ⁶	72,628	77,189	90,119	'130,265	150,000
Japan	11,674	8,075	'8,000	'8,000	7,000
Kazakhstan	—	—	—	3,600,000	2,900,000
Macedonia ⁷	—	—	—	'6,000	5,000
Madagascar ⁶	62,540	'73,000	'63,000	'69,123	69,000
Morocco	1,000	300	500	500	500
New Caledonia	60,281	6,223	—	'7	—
Oman	12,810	—	—	'1,764	10,000
Pakistan	27,105	18,191	31,474	'22,852	20,000
Philippines	216,562	185,595	'191,484	'101,690	'105,000
Russia	—	—	—	121,400	120,000
South Africa, Republic of ⁸	4,950,854	4,618,310	'5,100,299	'3,363,000	2,840,000
Sudan	25,000	12,500	'10,000	'10,000	10,000
Thailand	416	—	—	—	—
Turkey ⁹	'1,076,834	'835,704	'940,000	'531,112	490,000
U.S.S.R. ¹⁰	3,800,000	3,800,000	'3,800,000	—	—
Vietnam*	'4,000	—	—	—	—
Yugoslavia ^{7 11}	12,721	10,843	'6,000	—	—
Zimbabwe	627,424	'573,103	563,634	'522,013	400,000
Total	'14,006,464	'12,958,832	'13,320,278	'10,992,570	9,300,600

*Estimated. †Revised.

¹Table includes data through June 14, 1994.

²Figures for all countries represent marketable output unless otherwise noted.

³Reported figure.

⁴Average Cr₂O₃ content was as follows: 1989—39.5%; 1990—38.9%; 1991—42.0%; 1992—43.0% (revised); and 1993—43.0% (estimated).

⁵Direct-shipping ore plus concentrate.

⁶Concentrate.

⁷All production in Yugoslavia from 1989-91 came from Macedonia.

⁸Includes production by Bophuthatswana.

⁹Salable product: direct-shipping lump ore plus concentrate.

¹⁰Dissolved in Dec. 1991.

¹¹Dissolved in Apr. 1992.

TABLE 23
FERROCHROMIUM: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons)

Country	1989	1990	1991	1992	1993*
Albania	38,800	24,000	² 25,000	¹ 15,000	10,000
Brazil ²	113,267	¹ 83,753	¹ 82,225	¹ 91,829	³ 85,000
Chile	2,840	1,868	² 2,509	² 2,100	2,140
China ³	¹ 180,000	² 200,000	¹ 160,000	² 280,000	190,000
Croatia	—	—	—	56,456	² 27,336
Czechoslovakia ^{2,4}	29,844	31,866	³ 33,860	37,756	—
Finland	169,000	157,000	190,000	¹ 187,100	² 218,370
France ⁵	¹ 18,100	25,000	23,100	³ 6,694	—
Germany: ⁶					
Eastern states	22,000	21,000	—	—	—
Western states	³ 33,350	³ 37,500	—	—	—
Total	⁵ 55,350	⁵ 58,500	³ 33,650	² 26,520	³ 16,400
Greece	43,579	30,300	¹ 10,500	—	—
India ³	¹ 151,167	¹ 168,511	² 219,477	² 256,831	² 244,370
Italy	¹ 87,331	⁵ 53,000	⁴ 47,192	⁶ 60,315	⁵ 53,504
Japan ²	³ 333,978	³ 303,838	² 278,522	² 275,615	² 215,000
Kazakhstan ⁷	—	—	—	⁴ 400,000	400,000
Macedonia ⁸	—	—	—	¹ 3,958	³ 4,376
Mexico	2,569	275	72	⁷ 70	70
Norway	—	60,000	83,000	102,000	³ 80,000
Philippines ⁸	82,000	56,000	² 23,730	27,400	³ 12,000
Poland	² 28,222	¹ 13,679	¹ 1,928	³ 55,322	³ 38,449
Romania	26,849	20,633	20,380	6,977	³ 3,907
Russia	—	—	—	¹ 3400,000	400,000
Slovakia ^{2,4,6}	—	—	—	—	² 45,793
Slovenia	—	—	—	¹ 17,104	³ 9,000
South Africa, Republic of ^{7,8}	1,049,900	1,022,000	¹ 1,126,700	⁶ 664,856	650,000
Spain ⁸	29,000	15,000	6,000	—	² 2,390
Sweden	153,800	117,680	120,884	¹ 133,000	³ 127,543
Turkey	59,715	⁶ 62,360	³ 84,651	85,755	³ 90,030
U.S.S.R. ⁹	¹ 828,000	⁷ 700,000	⁷ 700,000	—	—
United States ¹⁰	146,844	108,932	68,327	60,945	² 63,018
Yugoslavia ¹¹	90,428	82,687	⁹ 91,000	—	—
Zimbabwe ²	¹ 173,000	² 222,102	¹ 186,774	¹ 190,994	140,000
Total	³ 3,893,583	³ 3,618,984	³ 3,619,481	³ 3,424,597	3,128,696

*Estimated. ²Revised.

³Table includes data available through June 14, 1994.

⁴Includes high- and low-carbon ferrochromium.

⁵Reported figure.

⁶Czechoslovakia was dissolved on Dec. 31, 1992. All production in Czechoslovakia from 1989-92 came from Slovakia.

⁷Includes ferrochrome and charge chrome.

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

⁹Includes high- and low-carbon ferrochromium and ferrochromium silicon.

¹⁰Includes production from Bophuthatswana.

¹¹Dissolved in Dec. 1991.

¹²Includes high- and low-carbon ferrochromium, ferrochromium silicon, chromium metal, and other chromium materials.

¹³Dissolved 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	4,219	3,901	4,010	3,309	3,011
Ferrochromium (smelter) ²	1,760	1,512	1,554	1,862	1,947	1,893	1,885	2,166	2,219	2,063	2,063	1,952	1,783
Stainless steel ³	1,084	1,345	1,563	1,764	1,761	1,876	2,053	2,324	2,260	2,248	2,259	2,169	2,240
U.S. SUPPLY													
Components of U.S. supply:													
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	65	61	75	79	85	84	95	119	100	104	99	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	1,080	1,110	1,079	1,057	1,097	1,099	1,166	1,197
Industry	219	232	181	164	114	106	102	119	137	139	125	118	118
Total U.S. supply ⁴	1,798	1,558	1,518	1,609	1,542	1,619	1,620	1,767	1,674	1,686	1,634	1,717	1,746
Distribution of U.S. supply:													
Exports:													
Chromite ore	18	2	3	15	27	25	(⁵)	1	12	2	3	2	3
Chromium ferroalloy	7	3	2	9	6	3	2	5	6	5	6	6	9
Chromium metal	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)	(⁶)
Chromium chemicals	6	5	5	7	4	7	6	8	6	7	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	125	118	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	1,239	1,315	1,331	1,252
Apparent industry demand	483	315	292	412	349	402	382	537	453	450	399	429	523

⁴Estimated. ⁵Revised. NA Not available.

¹Calculated assuming chromite ore to average 44 % Cr₂O₃ that is 68.42% chromium.

²Calculated assuming chromium content of ferrochromium to average 57%.

³Calculated from World Stainless Steel Statistics, 1992 ed. reported production, assuming chromium content of stainless steel to average 17%. Western world only in 1991.

⁴Variation in stockpile quantity does not contribute to apparent industry demand because variation resulted from upgrading programs.

⁵Government releases of chromium materials that contributed to apparent industry demand were as follows: 1992, 13; 1993, 97.

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

⁷Less than 1/2 unit.

⁸Included with "Chromium ferroalloy."

FIGURE 1
CHROMIUM MATERIAL FLOW

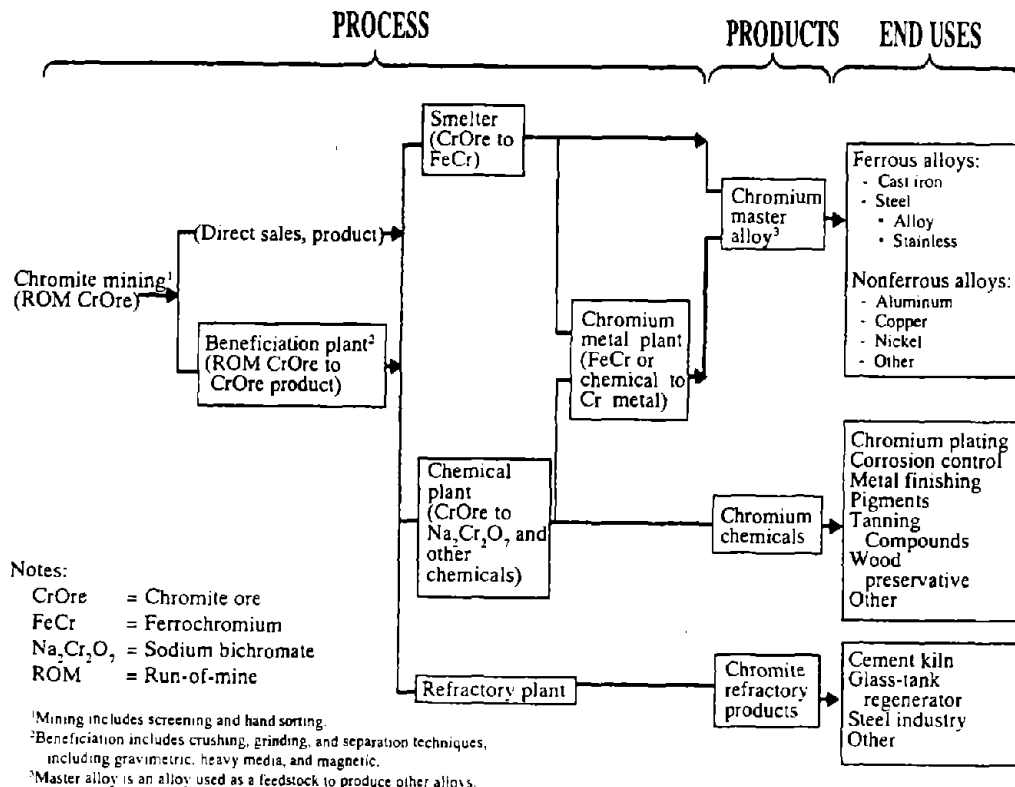


FIGURE 2
GENERAL RECYCLING CHROMIUM MATERIAL FLOW INDUSTRY STRUCTURE

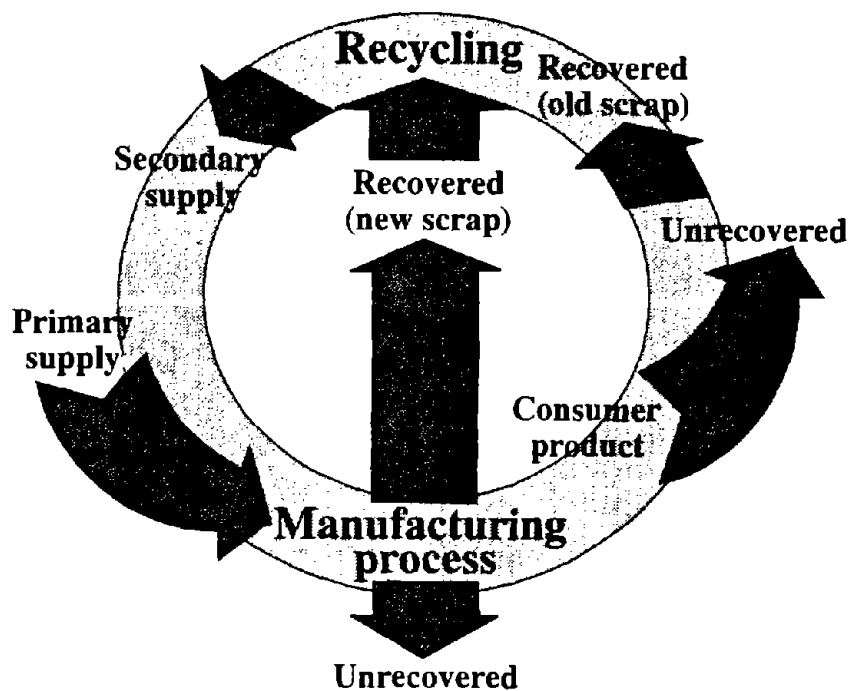


FIGURE 3
COST OF LOW-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFRR) FOR SELECTED MARKET ECONOMY PRODUCERS

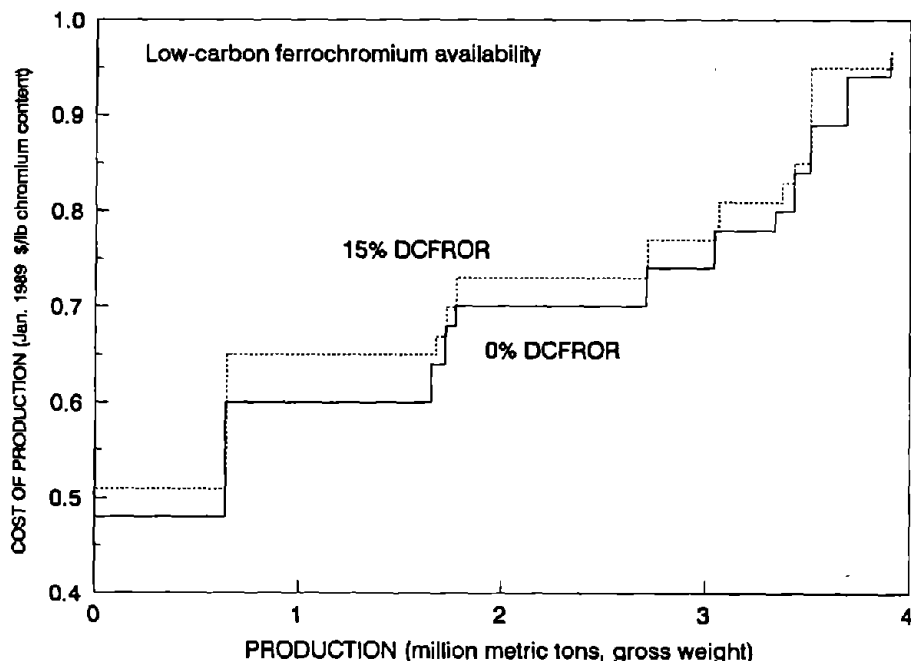
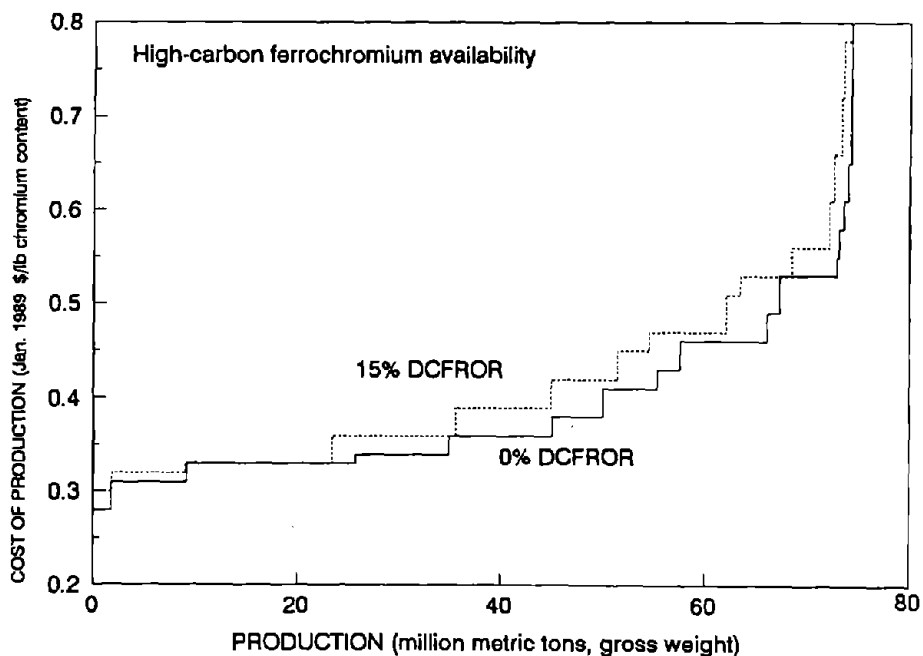


FIGURE 4
COST OF HIGH-CARBON FERROCHROMIUM PRODUCTION AT 0% AND 15% DISCOUNTED CASH-FLOW RATE OF RETURN (DCFRR) FOR SELECTED MARKET ECONOMY PRODUCERS



NOTE.—DCFRR 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

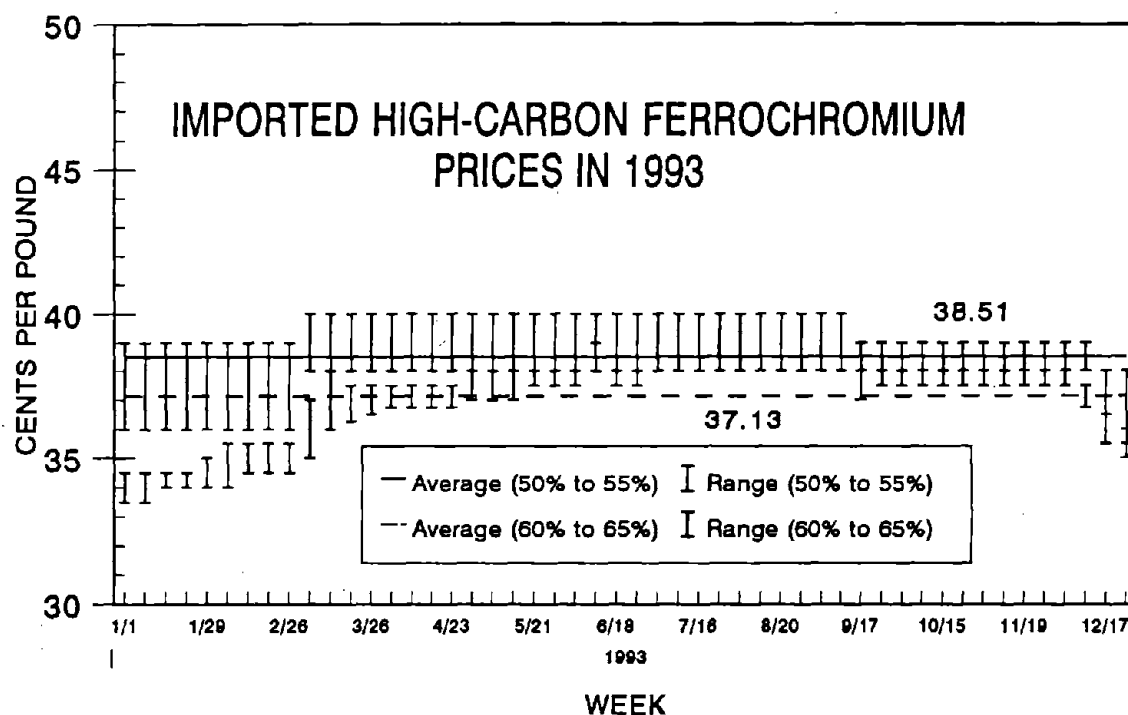
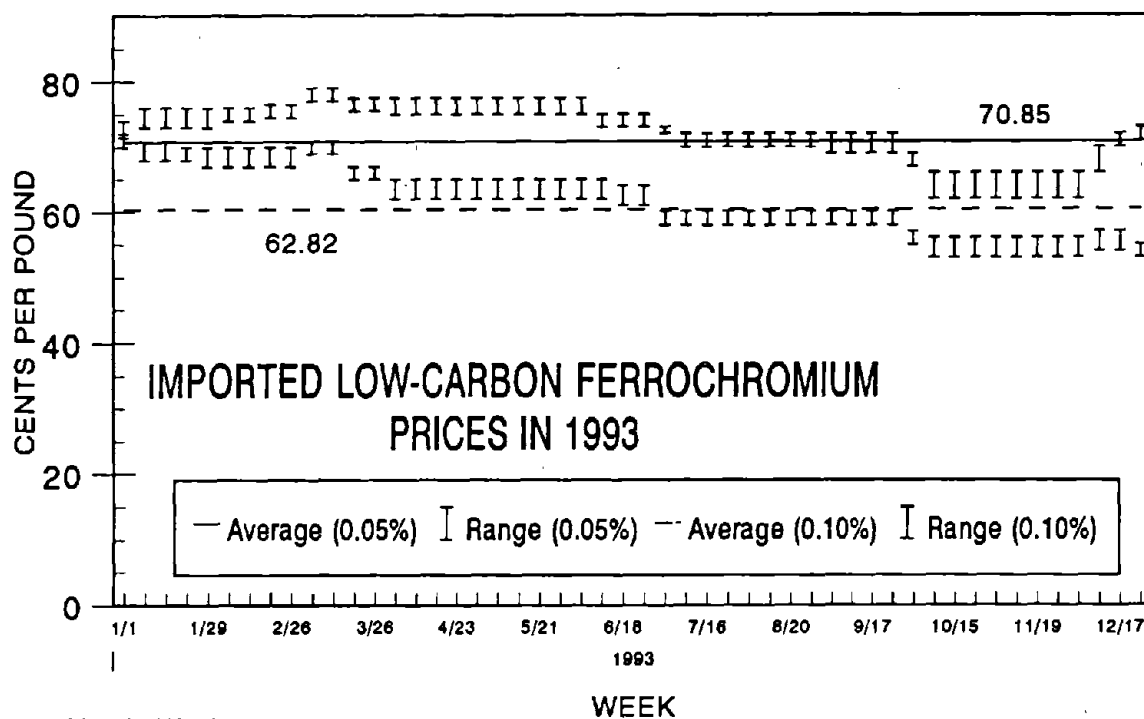


FIGURE 6
IMPORTED LOW-CARBON FERROCHROMIUM WEEKLY PRICE RANGE AND
TIME-AVERAGE PRICE IN 1993



Source: Metals Week.

FIGURE 7
WORLD GEOGRAPHIC LOCATION AND SIZE OF CHROMITE ORE, FERROCHROMIUM, AND STAINLESS STEEL PRODUCERS

