CHROMIUM

By John F. Papp

Domestic survey data and tables were prepared by Joseph M. Krisanda, statistical assistant, and the world production tables were prepared by Glenn J. Wallace, international data coordinator.

In 2003, the United States imported chromite ore to produce chromium chemicals and imported ferrochromium to produce stainless steel. Historical U.S. chromium use trend was reported by end use based on data from 1940 through 2001 (Papp, 2004).

More than one-half of U.S. ferrochromium imports and world production came from South Africa, where the value of the rand decreased to about R6.5 per $1.00 in December from about R8.6 per $1.00 in January, a drop of 24% (Antweiler, 2003§[1]). Since the cost of South African chromite ore and ferrochromium production in rands needs to be accounted for in the price of ferrochromium in U.S. dollars, much of the price increase resulted from the strengthening rand. Factors that contributed to increasing prices in 2003 included strengthening of the rand; increased metallurgical coke costs, transportation costs (in South Africa), and oil costs; and shortages of stainless steel scrap (Jones, 2003).

Domestic Data Coverage

Domestic data for chromium materials were developed by the U.S. Geological Survey (USGS) by means of the monthly "Chromite Ores and Chromium Products" and "Consolidated Consumers" consumer surveys. High-carbon ferrochromium is the most consumed chromium-containing material. Stainless and heat-resisting steel producers accounted for most of chromium-containing material consumed.

World Industry Structure

Industry Structure.—The chromium industry comprises the mining of chromite ore and the manufacturing of chromium chemicals and metal, ferrochromium, stainless steel, and chromite refractory products. Several trends are taking place simultaneously in the chromium industry. Domestically, chromium chemical production has been growing slowly, while the industry has eliminated excess capacity and concentrated production in the surviving plant. Chromite refractory use has been declining for technological and environmental reasons. No chromite refractory material production was reported in 2003.

Internationally, chromite ore production is moving from independent producers to vertically integrated producers. In other words, chromite ore mines tend to be owned and operated by ferrochromium or chromium chemical producers or by refractory product manufacturers. This trend is associated with the migration of ferrochromium production capacity from stainless-steel-producing countries to chromite-ore-producing countries, a change that is nearly complete. While ferrochromium production capacity was rationalized in historically producing countries, which usually have been stainless-steel-producing countries, new furnaces or plants were constructed in chromite-ore-producing areas.

The electrical power and production capacities of submerged-arc electric furnaces used to produce ferrochromium have been increasing. Production process improvements, such as agglomeration of chromite ore, preheating and prereduction of furnace feed, and closed-furnace technology, are being incorporated in newly constructed plants and have been retrofitted at many major producer plants. When ferrochromium plants started to be built, furnaces rated in the low-kilovoltampere range were common. Furnaces built recently have an electrical capacity in the tens of megavoltamperes (MVA). The introduction of postmelting refining processes in the steel industry after 1960 permitted a shift in production to high-carbon ferrochromium, displacing low-carbon ferrochromium as the predominant chromium ferroalloy.

After years of ferrochromium production, slag stockpiles have built up. Recently developed processes efficiently recover ferrochromium from that slag. These processes have been or are being installed at plant sites.

In South Africa, the leading chromite-ore- and ferrochromium-producing country, two trends are emerging—ferrochromium plants are being developed in the western belt of the Bushveld Complex, and ferrochromium production processes are being designed to accommodate chromite ore byproduct from platinum operations.

Production.—The International Chromium Development Association (ICDA) reported world chromite ore production in 2003 to have been 14.868 million metric tons (Mt), of which about 91.2% was produced for the metallurgical industry; 5.2%, chemical industry; 2.8%, foundry industry; and 0.8%, refractory industry (International Chromium Development Association, 2004, p. 1). The ICDA reported 2003 world production of 5.849 Mt of ferrochromium and 0.205 Mt of ferrochromium silicon. ICDA statistics showed production growth from 2002 to 2003 of 29% for ferrochromium silicon, 19% for high-carbon ferrochromium, 11% for low-carbon ferrochromium, and 6.2% for chromite ore. Chromite for nonmetallurgical applications is mined at the same mines that produce metallurgical-grade chromite, which typically dominates production. Historically, at least in South Africa, chromite not usable by the metallurgical industry because of its fine size was sold in nonmetallurgical markets; however, now that ferrochromium production processes have been modified to permit the use of fine ore, that marketing strategy is no longer as important. Since the metallurgical industry accounts for over 90% of chromite ore consumption, demand for metallurgical-grade chromite ore dominates that of other industries. As a result of the dominant

[1]References that include a section mark (§) are found in the Internet References Cited section.

role of metallurgical-grade chromite demand, changes in the metallurgical market affect supply in the nonmetallurgical markets. When metallurgical demand is high, producers can shift product mix to favor that market unless the price of nonmetallurgical grades increase sufficiently (Willis, 2003).

Stainless Steel.—The ICDA reported stainless steel production of 22.745 Mt in 2003, a growth of 11% compared with that of 2002. Valencia (2004) reported that world stainless steel ingot production had grown at a compound annual growth rate of 5.62% from 1950 through 2002, which was substantially greater than that of aluminum, copper, lead, steel (exclusive of stainless), and zinc. Amid this growth, the stainless steel industry consolidated. From 1990 to 2000, the number of flat product mills decreased to 18 from 31; the top 10 producers increased market share to 85% from 52%; and the top 5 producers increased their market share to 58% from 31%. Of those five companies in 2002, four were in Europe (Acerinox, Arcelor, ThyssenKrupp Steel, and Outokumpu Group) and one was in Asia [Pohang Iron and Steel Company (POSCO)]. Asia accounted for about one-half of demand growth in 2003 and China for one-half of Asia's share. Malm (2004) reported that the major stainless steel producers (Acerinox, Arcelor, AvestaPolarit, POSCO, and ThyssenKrupp Steel) planned to increase stainless steel production capacity to 12.363 million metric tons per year (Mt/yr) in 2005 from 9.150 Mt/yr in 2001. Major producers had production capacities in the range of 1.2 to 2.4 Mt/yr and collectively accounted for 60% of world stainless steel production in 2000. Malm reported that with increasing production, unit production cost was expected to drop to about $400 per metric ton in 2010 from the current about $600 per metric ton. Kaumanns (2004) reported crude stainless steel production of 22.790 Mt in 2003, an increase of about 11% from 20.595 Mt in 2002.

World Review

European Union.—Chirgwin (2004) reported that the European Union (EU) will put into effect a new chemical policy in 2007 when all metals and alloys and certain intermediates and recycled wastes will be subject to registration, evaluation and authorization of chemicals (REACH). The EU will establish a new agency based in Helsinki, Finland, to evaluate substances based on human and environmental risk and life-cycle assessment information supplied by producers and importers. Most chromium-containing compounds were expected to be required to be registered.

The EU identified global warming as a situation in need of technical remediation. Renewable energy technologies, such as wind and photovoltaic, are being developed to reduce fossil fuel based energy consumption. The United Kingdom set itself the goal of sourcing 10% of its energy needs from renewable sources by 2010 and 20% by 2020. Many renewable energy technologies depend on stainless steel, and therefore chromium, to work dependably and efficiently. Thus, implementation of such technologies is likely to increase demand for chromium (Bacon, 2003).

Australia.—Pilbara Chromite Pty. Ltd. (a division of Consolidated Minerals Limited) developed chromite ore reserves at its Coobina Chromite Project. Consolidated studied the feasibility of vertically integrating its business by constructing a ferrochromium smelter or investing in one to process its chromite ore.

Brazil.—Brazil produced chromite ore, ferrochromium, and stainless steel. Brazil reported 2002 chromite ore production of 284,000 metric tons (t) [39.8% chromic oxide (Cr_2O_3)], exported 27,900 t of chromite ore (11,186 t Cr_2O_3 content), and imported 8,500 t of chromite ore (3,402 t Cr_2O_3 content). Brazil produced from a chromite ore reserve containing about 4.9 Mt of chromium. In 2002, Brazil produced 164,140 t of chromium ferroalloys, of which 149,000 t was high-carbon ferrochromium, 9,850 t was low-carbon ferrochromium, and the remainder was ferrochromium-silicon. Brazil imported 8,922 t of ferrochromium and exported 462 t of ferrochromium (Gonçalves, 2002§). Based on production of chromite ore and trade of chromite ore and chromium ferroalloys, Brazilian chromium apparent consumption in 2002 was 81,000 t. Expansion of Brazilian stainless steel production capacity was expected to increase domestic demand for domestically produced ferrochromium.

Canada.—Allican Resources planned to construct a low-carbon ferrochromium smelter in the Gaspe region of Quebec. The plant was planned to have a production capacity of 20,000 metric tons per year (t/yr) and power rating of 30 megawatts and to cost $4.8 million.

China.—China produced chromite ore, chromium chemicals and metal, ferrochromium, and stainless steel. China's chromite ore production did not meet its domestic demand, so China imported chromite ore. Owing to its large population, low intensity of chromium use, and strong growth, China became the center of the chromium industry's attention in 2003. China's policy was to encourage raw material processing for export and to produce domestically to meet its domestic demand (TEX Report, 2003b). Hydroelectric power was in short supply in some parts of China causing reduced ferrochromium production in those areas. The power shortage resulted from a drought. Rainfall in those areas was at a 20-year low. The shortage resulted in thermoelectric power production capacity expansion of 1.2 million kilowatts, with 3,000 kilowatts planned for 2004. The expansions caused international shortages of supply for some grades of steel used in thermoelectric powerplants.

Coke is an important raw material for steel and ferrochromium production. Closure of coke plants outside of China resulted in worldwide dependence on Chinese coke production.

Increased demand for ferrochromium resulting from increased stainless steel production, largely in China, contributed to increased ferrochromium price. The cost of ferrochromium production in China exceeded that of South Africa and Kazakhstan. When ferrochromium prices are lower than China's production cost, China does not export ferrochromium; however, when ferrochromium price is higher than China's production cost, China exports ferrochromium, mainly to Japan and the Republic of Korea. China's ferrochromium exports in 2003 increased compared with those of 2002. Other factors that affected ferrochromium exports from China included high domestic ferrochromium price and rail transportation limitations that started when the severe acute respiratory syndrome (SARS) discouraged truck transportation early in the year.

Intensity of stainless steel use suggests a large potential demand. China's per capita stainless steel demand was about 1.4 kilograms (kg) compared with 10 kg in the West (Ryan's Notes, 2003). With such a large population under one economic and legal system, China has the potential to dominate world markets. Stainless steel production capacity was about 900,000 t/yr; however, an additional 500,000 t/yr of capacity was under construction and scheduled for completion in 2004, followed by an additional 700,000 t/yr in 2005 and 1,000,000 t/yr in 2007 (Ko, 2003). Completion of this capacity would make China potentially the third leading stainless steel producing country in 2005 and the second leading in 2007. China has secured ferrochromium supply by making joint venture production agreements with South Africa's ferrochromium producers ASA Metals (Pty.) and South African Chrome and Alloys Ltd. It is possible, if not likely, that this new capacity will compete for the world market share when demand growth lags capacity expansion. The result could be the further migration of stainless steel production capacity from the Western Hemisphere to the Eastern Hemisphere.

A free market economy with legal restraints that discourage deleterious economic behavior is thought to respond best to the needs of investors, producers, and consumers. China, however, is not a market economy country and does not have the same restraints as other countries on capital and on currency conversion. The potential for internal conflict between commercial, individual, and political interests exists and could influence economic development. There is also potential for international conflict based on current shortage of raw material supply and in the future an excess of product supply.

Finland.—Finland produced chromite ore, ferrochromium, and stainless steel. AvestaPolarit Chrome produced chromite ore and ferrochromium, and AvestaPolarit produced stainless steel as part of a vertically integrated company structure within Outokumpu Oyj and an integrated mine-smelter-steel works in Kemi and Tornio. Outokumpu increased stainless steel melting capacity to 900,000 t/yr in 2003 with the goal of reaching 1.65 Mt/yr. Outokumpu expected Kemi Mine reserves accessible by surface mining would be exhausted by 2008, so they began underground mine production in 2003. Kemi Mine has been producing 210,000 t/yr of lumpy ore and 382,000 t/yr of concentrate from 1.2 Mt/yr of run-of-mine chromite ore. Underground production capacity will be 2.7 Mt/yr of run-of-mine chromite ore.

Outokumpu produced 549,000 t of chromite and 250,000 t of ferrochromium in 2003 compared with 566,000 t of chromite and 248,000 t of ferrochromium in 2002. Outokumpu reported chromite ore reserves, in accordance with the September 1999 Australian code for reporting mineral resources and reserves, to be 52 Mt of proved ore reserves graded at 25% Cr_2O_3. The company also reported 74 Mt of inferred mineral resources graded at 29% Cr_2O_3, 13 Mt of indicated mineral resources graded at 29% Cr_2O_3, and 3.8 Mt of measured mineral resources graded at 28% Cr_2O_3. Outokumpu reported that electricity accounted for more than one-fourth of variable production cost of ferrochromium (Outokumpu, 2004§).

Outokumpu has been studying ways to improve the reliability, availability, and profitability of processing chromite ore from the Kemi Mine since its development started in 1960 (Daavittila and Honkaniemi, 2003). Kemi ore had a chromium-to-iron ratio that was too low to produce high-carbon ferrochromium containing 60% chromium, the standard grade at that time; electrical energy and labor costs were high in Finland as were environmental and industrial hygiene requirements. Overcoming these factors motivated Outokumpu's process research and development. A variety of processes for agglomeration, preheating, and reduction have been tried by Outokumpu since 1960. Outokumpu found that sintered pellets, preheating, and submerged-arc furnace smelting to be the best route for producing ferrochromium from Kemi chromite ore.

India.—India produced chromite ore, chromium chemicals, ferrochromium, and stainless steel. Electrical power availability limited ferrochromium production. The cost of ferrochromium production in India exceeded that of South Africa and Kazakhstan. As a result, India has been exporting chromite, mostly to China. When ferrochromium prices are lower than Indian production cost, India does not export ferrochromium; however, when ferrochromium price is higher than Indian production cost, India exports ferrochromium, mainly to Japan and the Republic of Korea. As ferrochromium prices rose, Indian ferrochromium producers brought idle capacity back into production.

Jindal Strips Ltd. (a stainless steel and ferrochromium producer) planned to expand its annual stainless steel and ferrochromium production capacity. Jindal held 2.4 Mt chromite ore reserves in the State of Orissa. Jindal planned to build a 150,000-t/yr ferrochromium plant in Orissa using two Demag furnaces at a cost of about $35 million. Jindal also planned to build a 1-Mt/yr stainless steel plant in the Jaipur District, Orissa, and a captive powerplant.

Tata Iron and Steel Co. produced chromite ore, chromite concentrates, and ferrochromium. Tata increased production capacity at its concentrator to 700,000 t/yr of concentrate from 108,000 t/yr of concentrate. The Government of India sets export quotas for lump chromite ore; however, there is no limitation on concentrates. Tata planned to build a 120,000-t/yr ferrochromium plant near Richards Bay, South Africa.

Visa Industries planned to build a ferrochromium plant and a captive powerplant in Orissa to support planned steel plant development in Orissa.

IMFA Group, comprising Indian Charge Chrome Ltd. (ICCL) (an export-oriented producer) and Indian Metals and Ferroalloys (IMFA) (a domestic-oriented producer), is integrated from chromite ore mining through ferrochromium production, including thermoelectric power generation. IMFA Group planned to restructure the company in order to convert dollar debt to rupee debt. ICCL's dollar debt resulted in unexpected cost when the rupee-to-dollar exchange rate changed. IMFA reported chromite ore production in fiscal year 2003 (April 1, 2002, through March 31, 2003) from its Nuashi and Sukinda Mines. Nuashi Mine produced 60,000 t of lumpy chromite ore graded at 45% to 50% Cr_2O_3 from a proven reserve of 1.2 Mt. Nuashi planned to increase its production capacity to 90,000 t/yr by 2005. Sukinda Mine produced 150,000 t of chromite ore from a proven reserve of 12 Mt. IMFA Group produced 100,300 t of ferrochromium, about 65,000 t from ICCL and 35,000 t from IMFA.

Orissa Mining Corp. (OMC) (wholly owned by the government of Orissa) reported mining chromite ore from a reserve of 28.2 Mt over 11 properties covering 5,800 hectares in the Jajpur District, Orissa. OMC operated the Bangur, Kaliapani, Kalrnagi, Katpal, and Sukrangi Mines, of which Kaliapani was the largest. OMC also operated a benficiation plant at Kaliapani with an output capacity of 84,000 t/yr of chromite concentrate (Orissa Mining Corp., undated§).

Iran.—Iran produced chromite ore and ferrochromium. Faryab Mining Company has mined chromite ore at the Aseminoon Mining Complex since 1963. Iran exported its chromite ore to China and Japan until 1995, when the Faryab ferroalloy plant was commissioned, and has since exported chromite ore and ferrochromium. The Faryab ferroalloy plant operated two 12.5-MVA furnaces, which were used to produce ferrochromium and manganese ferroalloys.

Japan.—Japan produced chromium chemicals, ferrochromium, and stainless steel. Japan has the world's largest stainless steel production capacity. Shunan Denko, the ferrochromium producer that supplied liquid ferrochromium to Nisshin Steel Corp., stopped producing. The furnaces were to be scrapped; however, the sinter plant and pelletizer were sold to KazChrome (Kazakhstan). Shunan Denko's production facilities were located at Nisshin Steel's Shunan Works. Shunan Denko had a production capacity of 70,000 t/yr.

Kazakhstan.—Kazakhstan produced chromite ore, chromium chemicals, chromium metal, and ferrochromium. KazChrome produced ferrochromium at Aktyubinsk and Donskoi.

Kongorm-Khrom explored and exploited the Tsentralnoye chromite deposit in the Yamalo-Nenets Autonomous District. It produced chromite ore from two surface mines and a beneficiation plant about 30 kilometers (km) from Kharp. Kongorm-Khrom had a production capacity of 100,000 t/yr; however, it planned to increase to 300,000 t/yr in 2004 and then to 500,000 t/yr, if warranted by increased demand. Kongorm-Khrom reported 6 Mt of commercial reserves and 14 Mt of resources (Interfax Mining & Metals Report, 2003a-c). KazChrome was developing surface and underground mines. KazChrome developed the Poiskovy Mine, a surface mine with 5.5 Mt of reserves that would become depleted by 2007, and an underground mine to replace it in 2007.

Donskoi reported reserves of 300 Mt and resources of 700 to 800 Mt. KazChrome is currently mining underground at the Imeni 10-letiya nezavisimos Kazakhstana (formerly Tsentralnaya) Mine and developing underground workings at the Molodyozhnaya Mine, which were to start production in 2004 (Smirnov and others, 2004). Molodyozhnaya has been operating as a surface mine since 1982 and has 41 Mt of underground accessible chromite reserves graded at 50% to 55% Cr_2O_3.

KazChrome reported its production to be about 600,000 t of ferrochromium in 2002. Production increased to about 700,000 t of ferrochromium in 2003 owing mainly to increased demand from China. Process improvements were being implemented to increase ferrochromium production capacity to 1.2 Mt by 2005. KazChrome planned to install beneficiation and pelletizing equipment purchased from Shunan Denko (Japan) and contracted Outokumpu (Finland) to build a pelletizing plant with output capacity of 700,000 t/yr of sintered pellets.

Kazakhstan reported production in 2002 of 835,800 t of ferrochrome and 102,200 t of ferrosilicon chrome (Interfax Information Services, 2004§).

Madagascar.—Madagascar produced 80,000 to 85,000 t of lumpy-grade chromite and 50,000 to 55,000 t of chromite concentrate from 200,000 to 250,000 t of run-of-mine chromite ore.

Russia.—Russia produced chromite ore, chromium chemicals and metal, and ferrochromium. Ferrochromium was produced at Serov Ferroalloy Plant and Chelyabinsk Ferroalloy Plant mostly from chromite ore imported from India, Kazakhstan, and Turkey. Serov reported production in 2002 of 40,300 t of low-carbon ferrochromium, 17,950 t of high-carbon ferrochromium, 14,060 t of medium-carbon ferrochromium, and 2,480 t of ferrosilicon chromium, most of which was consumed to make low-carbon ferrochromium. Serov reported production in 2001 of 48,700 t of low-carbon ferrochromium and 20,400 t of medium-carbon ferrochromium. Serov planned to improve its production processes to meet consumer needs and to recover metal from slag.

The Polymetal Inter-Regional Research and Production Association planned to develop the Agonozerskoye chromite ore deposit in the Republic of Karelia. Polymetal planned to mine the deposit and smelt the chromite ore at Tikhvin.

Serov Ferroalloy Works, Chelyabinsk Electrometallurgy Plant, and Klyuchevskoi Ferroalloy Plant produced ferrochromium for domestic use and export using chromite ore mostly from Donskoi Mining Facility (Kazakhstan) but also from the Saranovskoye deposit (Perm region) (Smirnov and others, 2004). Russia's ferrochromium production was 450,000 t in 1990, 168,000 t in 1998, and 250,000 t in 2000. The production decline from 1990 to 1998 resulted from shortages of ore supply. As a result of ore supply shortages, Russia started surveying its chromite resources. Reserves were found at three deposits—5.3 Mt graded at 25% Cr_2O_3 at the Sopcheozerskoye in Murmansk; 212 Mt graded at 22% to 23% Cr_2O_3 at the Aganozerskoye in Karelia; and 237 Mt graded at less than 50% Cr_2O_3 at the Rai-Iz in Yamalo-Nenetsky Autonomous Region. The Rai-Iz deposit was being investigated for mine development.

South Africa.—South Africa produced chromite ore, chromium chemicals, ferrochromium, and stainless steel. South Africa's chromium supply depends on transportation from mine to smelter to port, then ocean transportation to consumers. It also depends on material inputs, such as electrical energy and coke supply. Ferrochromium production requires about 3.77 megawatthours per metric ton (MWh/t) produced (1.81 MWh/t with preheated furnace feed). Eskom (South Africa's electrical energy supplier) developed energy supply contracts that adjusted electrical energy price based on ferrochromium price to assure use of excess electrical energy production capacity built during the 1970-80 time period. Ferrochromium demand for electrical energy grew to 10,000 gigawatthours (GWh) in 1998 from 7,000 GWh in 1994. Eskom's risk from commodity price change threatened to increase its capital cost (Smit, 2003). Since Eskom introduced higher electric power rates during the winter months, South Africa's ferrochromium producers have increased production during the summer months and reduced production during the winter months.

The South African Minerals Bureau reported that, from a reserve base of 5,500 Mt of chromite ore in 2002, South Africa produced 6.436 Mt of chromite ore, from which it produced 2.351 Mt of chromium ferroalloys. South Africa exported 651,000 t of chromite ore and 2.190 Mt of ferrochromium in

2002 (Kweyama, 2003, p. 100-103). Based on chromite ore production and chromite ore and ferrochromium trade, South Africa's apparent consumption of chromium in 2002 was 537,000 t of contained chromium. The South African Minerals Bureau reported chromite ore production in 2003 to be 7.417329 Mt and sales of 6.863888 Mt; domestic sales accounted for 92.5% of production (South African Minerals Bureau, 2004).

South Africa was in the process of modifying its mining law to encourage mineral recovery. The Government worked to pass the Minerals and Petroleum Resources Development Act that was to replace the Minerals Act of 1991.

Demand for ferrochromium was strong by the end of 2003. As a result, all the ferrochromium producers planned capacity expansions. The economic outlook for plant construction and expansions was positive because the price of ferrochromium was high. High export rates showed inefficiencies in export loading facilities at Richards Bay that led to increased transportation costs. The loading rate was reported to have fallen to 40 metric tons per hour (t/h) from 120 t/h.

Tata planned to build a ferrochromium plant at Richards Bay, a port city removed from the South Africa's chromite mines. Tata is a major chromite ore and ferrochromium producer in India. Owing to the high cost of electricity in India, ferrochromium production in India exceeded that in South Africa. In order to take advantage of its chromite ore resources in India and its vertically integrated chromium business, Tata studied the possibility of producing ferrochromium at Richards Bay using chromite ore from India. The South African Centre of Scientific & Industrial Research was preparing an environmental impact assessment for the proposed plant. Tata planned to build a plant with production capacity of 120,000 t/yr with the potential to double production capacity. The project was approved by the Department of Trade and Industry for Strategic Investment Projects and was projected to provide 115 new jobs.

Transvaal Ferrochrome Company planned construction of a chromite mine and a ferrochromium plant. The Buffelsfontein chromite deposit had 24 Mt of chromite ore reserves that could support the production of 250,000 t/yr of ferrochromium. Transvaal completed an environmental impact assessment and an environmental management program report. The company planned to use closed furnace technology to produce 230,000 t/yr of ferrochromium. Transvaal and Jiuquan Iron & Steel (China) made a joint-venture agreement in which Jiuquan took a 26% share and committed to take 120,000 t/yr of ferrochromium. Transvaal planned to start construction in 2004 and production in 2005.

ASA produced chromite ore and ferrochromium at Burgersfort, North West Province. ASA constructed a second 36-MVA furnace that would add 70,000 t/yr of ferrochromium production capacity to the current capacity of 55,000 t/yr. The additional furnace was expected to cost about $21 million and require an additional 100 workers, bringing the number of employees to 240. ASA was owned 60% by East Asia Metal Investment (China) and Limpopo Development and Enterprises (De Wit, 2003). ASA started operating its second furnace in December.

Assmang Ltd. reported ferrochromium production by financial year (July 1 through June 30) as 244,000 t in 2003, 190,000 t in 2002, 125,000 t in 2001, 114,000 t in 2000, and 112,000 t in 1999. In addition to that consumed for internal use, Assmang's chromite ore production was 20,000 t in 2003 and 39,000 t in 2002. Feralloys Limited (owned by Assmang Ltd.) produced chromite ore at Dwarsrivier and ferrochromium at Machadodorp. The Dwarsrivier Mine had a production capacity of 600,000 t/yr, with plans to increase to 1 Mt/yr (Assmang Ltd., 2003§).

Hernic (Pty.) Ltd. (Hernic) produced chromite ore and ferrochromium at Brits, North West Province. Hernic continued to produce chromite ore from the Maroela Bult Mine while it developed shafts from which it could access underground reserves of about 100 Mt evenly divided between the MG-1 and MG-2 seams. These seams are about 500 meters underground. Underground mining was planned to begin in 2006. Hernic also sought to secure mineral rights to nearby properties.

SA Chrome produced chromite ore and ferrochromium at Boshoek near Brits. The ferrochromium plant started production in 2002 using Outokumpu technology, which comprised two 54-MVA closed, electric-arc furnaces, a pelletizing and sintering plant capable of processing 520,000 t/yr of chromite, and preheating process equipment. The plant was designed to produce about 235,000 t/yr of marketable ferrochromium. The closed furnace design reportedly prevents the escape of hexavalent chromium compounds during smelting, increases chromium recovery by 15%, and reduces energy consumption by 25% compared with open or semiclosed furnaces. The plant was built on a 13.6-Mt chromite ore reserve held by SA Chrome and adjacent to reserves held by the Bafokeng Nation (a coowner of SA Chrome). The Horizon Mine, which is 40 km from the plant, provides chromite ore from the LG6 seam. The smelter used a blend of 40% LG6 and 60% UG2 ore. Chromite byproduct from platinum mining of the UG2 seam is 8 km from the plant (Engineering News, 2003). SA Chrome reported production of 90,000 t of ferrochromium in financial year 2003 (April 1, 2002, through March 31, 2003) of which it sold 75,564 t. Startup problems caused SA Chrome to produce below designed optimum production rate resulting in higher than expected unit production cost. In addition, the rand strengthened against the U.S. dollar. The net effect was that SA Chrome had a pretax loss of about $20 million for which it had to raise additional funds by issuing stock. The acquisition of additional chromite reserves and the doubling of plant capacity were delayed.

Mogale Alloys leased Samancor's three idle electric furnaces at Palmiet. Mogale planned to use the 63-MVA direct-current (DC) arc furnace to produce a master alloy containing 15% chromium and 3% to 6% nickel from stainless steel dust generated by Columbus Stainless Steel. The master alloy was to be used in stainless steel production.

Xstrata S.A. (Pty.) Ltd. produced 3.331 Mt of chromite ore in 2003 compared with 2.503 Mt in 2002. In 2003, Xstrata's Kroondal Mine produced 1.926 Mt of chromite ore; the Waterval Mine produced 453,000 t of chromite ore; and the Thorncliffe Mine produced 1.146 Mt of chromite ore. Xstrata produced 1.105 Mt of ferrochromium in 2003 compared with 0.985 Mt in 2002. In 2003, Xstrata's Wonderkop plant produced 398,000 t of ferrochromium; the Rustenburg plant produced 322,000 t of ferrochromium; and the Lydenburg plant produced 402,000 t of ferrochromium. Xstrata planned to build a ferrochromium plant and negotiated a joint venture with SA Chrome. Xstrata commissioned first-phase work, design of a 1-Mt/yr plant to be constructed in three phases of 330,000 t/yr each. Design work was to be completed in 2004 at an estimated cost of $170 million. Xstrata planned to locate the new smelter at its Vantech facility in Mapumalanga Province, where resources were available owing to a recent decision to reduce vanadium production at that site. The new smelter was planned to use Xstrata-developed technology that reportedly was more cost efficient than currently used technologies (Xstrata S.A. (Pty.) Ltd., 2004§).

Samancor was owned 60% by BHP Billiton plc and 40% by Anglo American Corp. of South Africa. BHP reported chromite ore production of 2.826 Mt in financial year 2003 (July 1, 2002, through June 30, 2003), 2.451 Mt in 2002, and 3.158 Mt in 2001. BHP reported ferrochromium production of 990,000 t in financial year 2003, 837,000 t in 2002, and 908,000 t in 2001. BHP reported 10 Mt of chromite ore proved reserves graded at 36.7% Cr_2O_3 and 9 Mt graded at 37.9% Cr_2O_3, and probable reserves of 15 Mt graded at 36.7% Cr_2O_3 and 28 Mt graded at 37.9% Cr_2O_3. Samancor closed its Elandsdrift Mine (BHP Billiton plc, 2003§).

Columbus Stainless (Pty.) Ltd. produced stainless steel in Middelburg, Mpumalanga. Columbus planned to increase stainless steel production capacity by 350,000 t/yr to about 750,000 t/yr.

Turkey.—Turkey produced chromite ore and ferrochromium. The Government of Turkey planned to privatize Turkey's two ferrochromium plants—Eti Krom at Elazig, a high-carbon ferrochromium producer, and Eti Elektometalurji at Anatalya, a low-carbon ferrochromium producer. Eti Krom reported high-carbon ferrochromium production of 24,510 t in 2003, 3,148 t in 2002, 41,480 t in 2001, and 86,500 t in 2000.

Zimbabwe.—Anglo American reported chromite resources of 0.6 Mt graded at 39.1% Cr_2O_3 measured and 104.2 Mt graded at 41.2% Cr_2O_3 indicated in 2003 and 0.6 Mt graded at 40.4% Cr_2O_3 measured and 103.4 Mt graded at 40.3% Cr_2O_3 indicated in 2002. Ferrochromium production at Anglo American's subsidiary Zimbabwe Alloys Ltd. (Zimalloys), was 39,179 t in 2003 and 44,064 t in 2002 (Anglo American Corp., 2004§). Zimbabwe Mining and Smelting Company Consolidated Enterprises Ltd. (Zimasco) reported ferrochromium production of 230,000 t in 2003. Ferrochromium producers in Zimbabwe experienced problems with currency exchange rate, energy supply, and transportation. The capacity of the Zimbabwe National Railways dropped to 9 Mt/yr in 2002 from 18.5 Mt/yr in 1990. Road transportation was not an option owing to road disrepair and fuel shortages.

Current Research and Technology

Mineral Processing and Industrial Applications.—Industry conducts research to develop new, more efficient processes and to improve the efficiency of currently used processes. The Council for Mineral Technology (Mintek) of South Africa conducts Government-sponsored, industry-sponsored, and cosponsored research and development on chromite ore and ferrochromium.

Researchers at Mintek studied platinum-group metal recovery from chromite tailings, electric-arc furnace processing of stainless steel dust, and ferrochromium production. Mintek demonstrated a flotation procedure at the laboratory scale that separates platinum-group metals from chromite tailings. Mintek planned to pursue the technology at a larger scale. Mintek reported developing DC arc furnace technology to recover platinum-group metals. The ConRoast process is based on removal of sulfur by roasting followed by smelting. The process offers considerable environmental benefits—flexible ore feed requirements, not limited sulfur feed, and tolerance of high chromite concentration. Mintek planned to demonstrate the process on UG2 concentrates that have high Cr_2O_3 concentration. Mintek processed stainless steel dust using a DC electric arc furnace in support of Mogale Alloys. Mintek studied DC arc furnace ferrochromium production using chromite ore fines preheated to 1,000° C in a fluidized bed reactor that burns carbon dioxide supplied by the furnace. Preheating the chromite feed materials resulted in a 20% energy savings (South Africa Council for Mineral Technology, 2003§).

Research.—Hiltunen and Härkki (2004) studied the reduction of chromite from the Akanvaara intrusion in Savukoski, Finland, compared with that of the Kemi deposit. Akanvaara chromite has lower aluminum oxide and higher magnesium oxide content than the Kemi chromite. Based on thermodynamic considerations, these unique qualities should facilitate reduction of the Akanvaara chromite compared with the Kemi chromite, which Hiltunen and Härkki found to be the case.

Cramer, Basson, and Nelson (2004) studied the impact of platinum production from UG2 ore on ferrochromium production in South Africa. South Africa's platinum producers have historically exploited the Merensky Reef, a chromite-free platinum deposit; however, as Merensky Reef platinum reserves diminish, platinum producers are turning to the chromite-containing UG2 reef and producing chromite byproduct. The UG2 reef is 10% to 25% Cr_2O_3 with a ratio of chromium to iron of 1.35; however, chromite from platinum operation tailings can be upgraded to 40% to 42% Cr_2O_3. DC arc furnace smelting or pelletizing followed by sintering and electric arc furnace smelting are currently used processes that accommodate UG2 chromite byproduct of platinum production. Platinum production is growing, and based on cost of ferrochromium production, chromite byproduct is an attractive alternative to primary chromite, especially when ferrochromium prices are low.

Denton, Bennie, and de Jong (2004) reported an improved DC arc process for chromite smelting. The authors compared several possible DC arc processes with the currently popular Outokumpu process and found that the best DC arc processes, ones that used furnace offgas to preheat the chromite feed, offered small operating cost and significant capital advantages.

Niemelä, Krogerus, and Oikarinen (2004) studied the formation, characteristics, and utilization of carbon monoxide (CO) gas formed in ferrochromium smelting. CO gas is a product of carbon reduction of chromite in the ferrochromium production process. In closed and semiclosed furnaces, CO gas burns as it leaves the furnace burden; however, it is captured and used in Outokumpu's closed furnaces process. By recovering, cleaning, and utilizing CO offgas to offset smelting energy demand, the authors found that the Outokumpu process saved about 1 t of oil for every 5.2 t of ferrochromium produced.

Derin, Erçayhan, and Yücel (2004) studied the effects of charge components on reduction of chromite concentrates by an aluminothermic process. The authors reacted various mixtures of chromite, CrO_3, and sodium chlorate with aluminum to produce ferrochromium in an open crucible, thereby avoiding the electrical energy production cost of 3,930 kilowatthours per ton (kWh/t) for high-carbon ferrochromium and 9,700 kWh/t for low-carbon ferrochromium.

Eksteen, Frand, and Reuter (2004) studied the distributed compositional and temperature nature of melts in submerged and open arc furnaces in high-carbon ferrochromium production. The authors showed how distribution information could be incorporated in mass balance calculation and in dynamic process control, fundamental thermodynamics, and inventory models to predict tap chemistry.

Farjadi and Azari (2004) reported on measured smelting performance with respect to the ratio of MgO to Al_2O_3 in the chromite ore. The authors found optimum chromite ore characteristics to be 43% to 46% Cr_2O_3 and an MgO-to-Al_2O_3 ratio between 2.2 and 2.5, where energy consumption was minimum and chromium recovery maximum at 95%.

Shoko and Chirasha (2004) reported that Zimalloys improved production efficiency, lowered production cost, created a cleaner working environment, and improved product quality consistency by enhancing process control, changing their ladle refractory linings, changing their alloy casting methodology, and granulating their slag. Zimalloys has produced low-carbon ferrochromium by the Perrin process since 1953. Process control was enhanced by converting from ladle duplexing to argon blowing.

Shoko and Malila (2004) reported that, of the three agglomeration methods available to ferrochromium producers (briquetting, pelletizing, and sintering), briquetting has the lower capital and operating cost. The authors reported that augmenting lumpy ore feed with briquetted feed for high-carbon ferrochromium production in the range of 28% to 83% of feed by weight, chromium recovery improved as greater amounts of briquetted feed were used. The authors also found that chromite ore, electrode consumption, and power were lower when briquetted feed fraction was higher.

Roschin and others (2004) studied solid-phase reduction of chromite. The authors found that solid-phase reduction is preceded by order-disorder transformation of the oxide lattice; reduction starts at a temperature where there is a transition from surface diffusion to volume diffusion; and reduction (metal lattice replaces oxide lattice) takes place as oxygen anion is removed from the oxide.

Daavittila, Honkaniemi, and Jokinen (2004) reviewed the changes in ferrochromium smelting since 1980 when Outokumpu last made major changes in their production process as part of its capacity expansion. Technological changes that have been tried since 1980 include smelting fine ore in open or semiclosed furnaces, rotary kiln preheating and prereduction of furnace feed, plasma and DC arc furnaces, preheating shaft kiln, and advanced automation. Of the technological changes, the authors found that the greatest cost-to-saving benefit, based on European cost structure, accrued most to preheating, then to agglomeration. Potential new technologies include fluidized bed preheating, closed furnace technology, and high automation. The authors found that increased automation of process control could improve environmental performance and working conditions and permit processing lower quality ores more efficiently.

Hayes (2004) reviewed the chemical reactions when chromite ore is processed in a submerged arc electric furnace. Hayes characterized the smelting process by describing what happens as the chromite, flux, and reductants move from the top of the furnace to the bottom with the goal of applying that information to optimize production rate and energy efficiency.

Yang, Xiao, and Reuter (2004) analyzed the transport phenomena in a submerged arc furnace during the smelting of ferrochromium. The authors reported that smelting of chromite ore with reductants (anthracite, char, or coke) requires electrical energy in the range of 2 to 4 MWh/t of product where the lower end of the range represents preheating of furnace charge. The authors presented a three-dimensional computational fluid dynamic model of a South African electric arc furnace with the intent of using such models to improve furnace design and control.

Corrosion of metals results in a significant economic cost to society. Kaesche reported that iron and unalloyed or low-alloy steels are the predominant metallic structural materials, far outweighing all other structural metals. For this reason, the protection of iron and steel from corrosion has outstanding economic importance. Chromium provides an adherent passivation (corrosion resistant) layer to chromium-iron alloys (called stainless steel when the amount of chromium alloyed exceeds a certain minimum amount) that is enhanced by the addition of nickel and molybdenum. Stainless steel is susceptible to pitting and crevice corrosion. The structure of the chromium-containing passivation layer and the corrosion mechanisms are the subject of current research (Kaesche, 2003, p. 193, ch. 10.4, 10.5, 12.5, 12.6, 15.2.3).

Technology.—Gonzalez-Quijano (2004) reported that 80% to 90% of tanned leather is tanned with chromium chemicals. In Europe, those chemicals account for 12% to 20% of leather tanning cost. The European leather tanning industry planned to participate in the REACH program (more information can be found in the "European Union" portion of the "World Review" section).

Outlook

The outlook for chromium consumption in the United States and the rest of the world is about the same as that for stainless steel, which is the major end use for chromium worldwide. Thus, stainless steel industry performance largely determines chromium industry demand worldwide.

The trend to supply chromium in the form of ferrochromium by countries that mine chromite ore is expected to continue. With new efficient ferrochromium production facilities and excess capacity in chromite-ore-producing countries, ferrochromium capacity and production are expected to diminish in countries that produce ferrochromium but not chromite ore and in countries with small, less efficient producers. Further vertical integration of the chromium industry is expected as chromite-ore-producing countries expand ferrochromium or stainless steel production capacity.

Chromite Ore.—Chromite ore production capacity is in balance with average consumption. Consumption capacity by ferrochromium plants, however, exceeds production capacity, which can lead to short supply when demand surges, thus preventing ferrochromium producers from meeting surge demand. To improve chromite ore availability and to stabilize feed material price, ferrochromium producers are investing in chromite mines. Indeed, most chromite is produced under vertically integrated mine-smelter or mine-plant ownership.

Chromium Chemicals.—Major producing countries where large plants (capacity in excess of 100,000 t/yr of sodium dichromate) operate included Kazakhstan, Russia, the United Kingdom, and the United States. Moderate-sized production facilities were in China, Japan, Romania, South Africa, and Turkey. Small-scale local producers operated in China and India.

The chemical industry accounted for about 8% of annual chromium consumption, and hexavalent chromium compounds accounted for only 3% of chromium chemical production (Tomkinson, 2003).

Despite 100 years of hard chromium plating, a chemical process that first carried out in 1848 and first commercially applied in 1924, challenges for chromium process improvements remain (Gabe, 2001).

Chromium Metal.—Major chromium metal producers include Russia and the United States by the electrolytic process and China, France, Russia, and the United Kingdom by the aluminothermic process. Chromium metal demand was estimated to be 19,500 t in 2002, down from about 21,000 t in 2001. Demand in 2003 was expected to decline. The decline in demand was anticipated to last as long as was necessary for chromium metal consumers that service the aerospace and electrical power generation industries to use stocks that were generated in anticipation of electrical power industry expansions in 2002. The sharp rise in electrical energy cost suggested that new powerplants would be required; however, the price change was found to have resulted from market manipulation. Chromium metal produced by aluminothermic reduction was estimated to have accounted for about 90% of production in 2002. Aluminothermically produced chromium metal accounted for 60% to 65% of production during the 1990s. The decline in chromium metal production in the United States appeared to have been offset by increased production in China and Russia (Lofthouse, 2003).

During the past 20 years, the aluminothermic production process accounted for 70% of world chromium metal production, while the electrolytic process accounted for 30%. In 2001, aluminothermic accounted for 85%; electrolytic, 15%. The major industry events from 1989 through 1995 were the closure of five plants (Continental Alloys of Luxemburg, Metal Alloys Ltd. of the United Kingdom, Murex Ltd. of the United Kingdom, Shieldalloy of the United States, and Tosoh of Japan) and the integration of producers in China and Russia into the world market, leaving eight aluminothermic chromium metal producers and four electrolytic chromium metal producers. Demand was distributed among the United States (50%), Western Europe (25%), Asia (20%), and other areas (5%). Chromium metal use by market sector was estimated to have been superalloys, 52%; aluminum alloys, 12%; and welding and hard facing, 12%; with the remainder going to other uses. Declining military and increasing civilian use was anticipated (Defrance, 2001).

Ferrochromium.—Ferrochromium production is electrical-energy intensive. Charge-grade ferrochromium requires 2,900 to 4,100 kWh/t of product, with efficiency varying by ore grade, operating conditions, and production process. Thus, the location of a ferrochromium plant reflects a cost balance between raw materials and electrical energy supply.

Stainless Steel.—Stainless steel demand is expected to grow in the long term. Short-term demand fluctuations can exceed long-term demand growth. A portion of stainless steel contains nickel; the price of stainless steel, therefore, is sensitive to the price of nickel.

Stainless steel demand, production capacity, and production grew in China. Patterns in the intensity of stainless steel use in the West suggest that China and India have the capacity to increase their use of stainless steel. The rising price of nickel acted against stainless steel market growth by causing the price of stainless steel to rise often in the form of raw materials cost surcharges imposed by stainless steel manufacturers, so Asian producers looked to 200-series stainless steel. 200-series stainless steel, like 300-series, is a stainless steel, with a microstructure referred to as austenitic, but with lower nickel content (maximum 7%) (ASM International, 1998, p. 364). 200-series stainless steel was developed in the United States during World War II to conserve nickel use. 300-series stainless steel attains its austenitic microstructure and therefore properties through the use of nickel whereas 200-series stainless steel attains them with manganese and nitrogen (Tverberg, 2000§). 300-series stainless steel is the stainless most used in the West. As a result of its lower nickel use, 200-series stainless steel is now an attractive alternative to 300-series in stainless steel-producing countries that do not have nickel resources or for producers that seeking to lower raw materials cost.

References Cited

ASM International, 1998, Stainless steels, *in* Metals handbook (2d ed.): Metals Park, OH, ASM International, p. 362-375.

Bacon, Phil, 2003, Sun, sea and stainless: Metal Bulletin Monthly, September, p. 29, 31.

Chirgwin, Alan, 2004, International Chromium Development Association HSE Committee report: International Chromium Development Association Members' Forum, Andalucia, Spain, February 26, 2004, Presentation, unpaginated.

Cramer, L.A., Basson, J., and Nelson, L.R., 2004, The impact of platinum production from UG2 ore on ferrochromium production in South Africa, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 47-59.

Daavittila, Jorma, and Honkaniemi, Matti, 2003, History of Outokumpu's ferroalloy technology development: Metal Bulletin International Ferro-Alloys Conference, Monte Carlo, Monaco, November 3-5, 2003, Presentation, unpaginated.

Daavittila, Jorma, Honkaniemi, Matti, and Jokinen, P., 2004, The transformation of the ferrochromium smelting technologies during the last decades, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 83-93.

De Wit, Renay, 2003, Limpopo ferrochrome furnace is 50% complete: Engineering News, August 15-21, p. 36, 52.

Defrance, Alian, 2001, The chromium metal industry: Bulletin du Cercle d'Etudes des Metaux [Bulletin of the Circle for the Study of Metals], v. XVII, no. 4, September, p. XXVIII-1-XXVIII-20.

Denton, G.M., Bennie, J.P.W., and de Jong, A., 2004, An improved DC-arc process for chromite smelting, *in* International Ferroalloys Congress, 10th,

Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 60-67.
Derin, B., Erçayhan, S., and Yücel, O., 2004, Effects of charge components on reduction of chromite concentrates by aluminothermic process, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 78-82.
Eksteen, J.J., Frand, S.J., and Reuter, M.A., 2004, Distributed compositional and temperature nature of melts in submerged and open arc furnaces in high carbon ferrochrome production, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 83-93.
Engineering News, 2003, Chrome-miner commissions its new smelter: Engineering News, August 15-21, p. 40.
Farjadi, M.H., Azari, J., 2004, Effect of chrome ore quality on ferrochrome production efficiency, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 94-102.
Gabe, D.R., 2001, Past, present, and future of hard chromium electrodeposition: Bulletin du Cercle d'Etudes des Metaux [Bulletin of the Circle for the Study of Metals], v. XVII, no. 4, September, p. IV-1-IV-12.
Gonzalez-Quijano, Gustavo, 2004, Chromium & leather the perfect partnership: International Chromium Development Association Members' Forum, Andalucia, Spain, February 26, 2004, Presentation, [unpaginated].
Hayes, P.C., 2004, Aspects of SAF smelting of ferrochrome, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 1-14.
Hiltunen, R., and Härkki, J., 2004, Reduction behavior of the Akanvaara chromites of northern Finland, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 36-46.
Interfax Mining & Metals Report, 2003a, Kazchrom plans to deep mine only by 2007: Interfax Mining & Metals Report, v. XI, issue 39, September 26, p. 32.
Interfax Mining & Metals Report, 2003b, Kazchrom to spend $38.5 mln to process slime, low-grade ore: Interfax Mining & Metals Report, v. XI, issue 39, September 26, p. 31-32.
Interfax Mining & Metals Report, 2003c, Phase-1 of Yamalo-Nenets chromite mine to be built in 2005: Interfax Mining & Metals Report, v. XI, issue 39, September 26, p. 30-31.
International Chromium Development Association, 2004, Statistical bulletin 2004 edition: Paris, France, International Chromium Development Association, July, 45 p.
Jones, Andrew, 2003, Chrome market spotlight: Resource-Net, [various issues], [variously paginated].
Kaesche, Helmut, 2003, Corrosion of metals: Berlin, Germany, Springer, 594 p.
Kaumanns, Stefan, 2004, Statistical efforts by ISSF and fields of co-operation: International Chromium Development Association Members' Forum, Andalucia, Spain, February 26, 2004, Presentation, [unpaginated].
Ko, Terrance, 2003, Too many guests at China's party?: Metal Bulletin Monthly, no. 393, September, p. 20-21.
Kweyama, N., 2003, Chromium in South Africa's minerals industry 2002/2003 (20th ed.): Pretoria, South Africa, Department of Minerals and Energy [South Africa], December, 202 p.
Lofthouse, Howard, 2003, Chromium metal—A global overview: International Chromium Development Association Meeting Chromium 2003, March 31-April 3, 2003, Johannesburg, South Africa, Presentation, [unpaginated].
Malm, Stefan, 2004, A vision for market growth and active co-operation: International Chromium Development Association Members' Forum, Andalucia, Spain, February 26, 2004, Presentation, [unpaginated].
Niemelä, P., Krogerus, H., and Oikarinen, P., 2004, Formation, characteristics and utilization of CO-gas formed in ferrochromium smelting, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 68-77.
Papp, J.F., 2004, Chromium use by market in the United States, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 770-778.
Roschin, A.V., Karnoukhov, V.N., Roschin, V.E., and Malkov, N.V., 2004, New findings in research of solid phase reactions in chromite ore reduction processes, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 333-342.
Ryan's Notes, 2003, FeCr producers betting the house on China: Ryan's Notes, v. 10, no. 16, April 21, p. 2.
Shoko, N.R., Chirasha, J., 2004, Technological change yields beneficial process improvements for low carbon ferrochrome at Zimbabwe Alloys, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 94-102.
Shoko, N.R., Malila, N.N., 2004, Briquetted chromite ore fines utilization in ferrochrome production at Zimbabwe Alloys, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 291-299.
Smirnov, L.A., Zhuchkov, V.I., Arzamastsev, E.I., and Babenko, A.A., 2004, An overview of current manganese and chromium ferroalloy production in Russia, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 766-769.
Smit, Johann, 2003, Eskom's role in developing the ferroalloy industry in South Africa: International Chromium Development Association Meeting Chromium 2003, March 31-April 3, 2003, Johannesburg, South Africa, Presentation, [unpaginated].
South African Minerals Bureau, 2004, South African Minerals Bureau Report, ME-P-014: South African Minerals Bureau, March 18, [unpaginated].
TEX Report, 2003, Strengthened contents for practice of processing trade system in China: TEX Report, v. 35, no. 8273, May 7, p. 12.
Tomkinson, Paul, 2003, Chromium chemicals—A global perspective: International Chromium Development Association Meeting Chromium 2003, March 31-April 3, 2003, Johannesburg, South Africa, Presentation, [unpaginated].
Valencia, J.C., 2004, Perspective of ACERINOX on the global stainless steel industry: International Chromium Development Association Meeting Chromium 2003, March 31-April 3, 2003, Johannesburg, South Africa, Presentation, [unpaginated].
Willis, Mark, 2003, Caught short: Industrial Minerals, no. 429, June, p. 23-31.
Yang, Y., Xiao, Y., and Reuter, M.A., 2004, Analysis of transport phenomena in submerged arc furnace for ferrochrome production, *in* International Ferroalloys Congress, 10th, Cape Town, South Africa, February 1-4, 2004, Proceedings: Marshalltown, South Africa, The South African Institute of Mining and Metallurgy, p. 15-25.

Internet References Cited

Antweiler, Werner, 2004, Database retrieval system, accessed June 12, 2004, via URL http://pacific.commerce.ubc.ca/xr/data.html.
Anglo American Corp., 2004, Anglo American a world of difference, Annual report 2003, accessed June 21, 2004, via URL http://www.angloamerican.co.uk.
Assmang, 2003, Dwarsrivier, accessed October 21, 2003, via URL http://www.assmang.co.za.
BHP Billiton plc, 2003, 2003 annual report, accessed June 3, 2003, via URL http://www.bhpbilliton.com.
Gonçalves, Maria de Melo, Cromo [Chromium], Sumario Mineral [Mineral Summary] 2003, accessed June 6, 2004, via URL http://www.dnpm.gov.br.
Interfax Information Services, [undated], Kazakhstan raises steel production 3.8%, accessed June 13, 2004, at URL http://www.interfax.com/com?item=search&pg=10&id=5616600&req=chrom.
Orissa Mining Corp., [undated], Profile, accessed March 28, 2003, via URL http://www.orissamining.com.
Outokumpu Oyj, 2004, Annual report 2003, accessed June 3, 2004, via URL http://www.outokumpu.com.
South Africa Council for Minerals Technology, 2003, Annual report 2003, accessed via URL http://www.mintek.ac.za.
Tverberg, John, 2003, A stainless steel primer—Part I: The types of stainless steel, accessed September 22, 2004, at URL http://www.flowcontrolnetwork.com/PastIssues/aug2000/3.asp.
Xstrata S.A. (Pty.) Ltd., 2004, Annual report 2003, accessed June 2004, via URL http://www.xstrata.com.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Chromium. Ch. in Mineral Commodity Summaries, annual.
Chromium. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
Chromium. International Strategic Minerals Inventory Summary Report, Circular 930-B, 1984.
Chromium. Mineral Industry Surveys, monthly.

Other

American Iron and Steel Institute.
American Metal Market.
Annual Stainless Steel Statistics.
Chrome Market Spotlight.
Chromite. Ch. in Industrial Minerals and Rocks, 6th ed., Society for Mining, Metallurgy, and Exploration, Inc., Donald Carr, ed., 1994.
Chromium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
CRU Metal Monitor.
Economics of Chromium, The. Roskill Information Services.
Ferro-Alloy Directory and Databook. Metal Bulletin.
Ferro Alloys Manual. The TEX Report.
Ferrous Mineral Commodities Produced in the Republic of South Africa. South African Department of Mineral and Energy Affairs Directory D8.
International Chromium Development Association.
Mining Annual Review.
Nickel Outlook.
South Africa's Minerals Industry. South Africa Minerals Bureau.
Stainless Steel Databook. Metal Bulletin Books.
Strategic and Critical Materials Report to the Congress. U.S. Department of Defense.
Welt-Bergbau Daten.
World Metal Statistics Yearbook.
World Mineral Statistics.
World Stainless Steel Statistics.

TABLE 1
SALIENT CHROMIUM STATISTICS[1]

(Metric tons, contained chromium, unless otherwise specified)

		1999	2000	2001	2002	2003
World production:						
Chromite ore (mine)[2]		4,290,000 r	4,440,000 r	3,650,000 r	4,290,000 r	4,650,000 e
Ferrochromium (smelter)[3]		2,850,000	3,260,000	2,650,000 r	2,830,000 r	3,140,000 e
Stainless steel[4]		2,970,000	3,260,000	3,150,000 r	3,370,000 r	3,700,000 e
U.S. supply:						
Components of U.S. supply:						
Domestic mines		--	--	--	--	--
Secondary		118,000	139,000	122,000	137,000 r	129,000
Imports:						
Chromite ore		85,000	86,200	62,000	35,300	55,300
Chromium chemicals		10,400	12,500	12,800	17,400	10,300
Chromium ferroalloys		371,000	344,000	156,000	203,000	243,000
Chromium metal		9,030	9,930	8,190	7,430	8,570
Stocks, January 1:						
Government		928,000	909,000	825,000 e, 5	706,000 r	604,000
Industry[6]		59,700	14,600 r	15,600	16,700	8,430
Total		1,580,000	1,520,000	1,200,000	1,120,000	1,060,000
Distribution of U.S. supply:						
Exports:						
Chromite ore		37,200	44,600	20,000	7,680 r	32,800
Chromium chemicals		17,300	16,400	13,200	10,500	9,710
Chromium ferroalloys and metal		5,790	25,400	9,840	10,800	3,770
Stocks, December 31:						
Government		909,000	825,000	816,000 e, 5	604,000	534,000
Industry[6]		54,600 r	15,600	16,700	8,430 r	9,970
Total		1,020,000	927,000	875,000	642,000 r	591,000
Production, reported:[7]						
Chromium ferroalloy and metal net production:						
Gross weight		W	W	W	W	W
Chromium content		W	W	W	W	W
Net shipments		W	W	W	W	W
Consumption:						
Apparent		558,000	589,000	326,000	481,000 r	468,000
Reported:						
Chromite ore and concentrates, gross weight		W	W	W	W	W
Chromite ore, average Cr_2O_3	percentage	45.0	44.8	45.0	45.4	45.0
Chromium ferroalloys, gross weight[8]		398,000	385,000 r	329,000	400,000 r	415,000
Chromium ferroalloys, contained chromium[8]		220,000	215,000	190,000 r	232,000 r	242,000
Chromium metal, gross weight		4,690	4,990 r	5,890 r	5,080 r	5,140
Stocks, December 31, gross weight:						
Government:						
Chromite ore		820,000	636,000	636,000 e, 5	204,000	154,000
Chromium ferroalloys		973,000	919,000	906,000 e, 5	763,000	683,000
Chromium metal		7,720	7,550	7,430 e, 5	7,220	6,660
Industry, producer[9]		W	W	W	W	W
Industry, consumer:						
Chromite ore[10]		130,000	W	W	W	W
Chromium ferroalloys[11]		25,000 r	26,500 r	W	13,900 r	16,500
Chromium metal		245	191	210	230 r	242
Prices, average annual:						
Chromite ore, gross weight[12]	dollars per metric ton	$63	NA	NA	NA	NA
Ferrochromium, chromium content[13]	dollars per pound	$0.366	$0.414	$0.324	$0.317	$0.433
Standard chromium metal, gross weight[14]	do.	$4.43	$4.43	$4.24	NA	NA
Vacuum chromium metal, gross weight[14]	do.	$5.38	$5.42	$5.43	NA	NA
Electrolytic chromium metal, gross weight[15]	do.	$4.50	$4.50	$4.50	$4.50	$4.50

See footnotes at end of table.

TABLE 1--Continued
SALIENT CHROMIUM STATISTICS[1]

(Metric tons, contained chromium, unless otherwise specified)

		1999	2000	2001	2002	2003
U.S. supply--Continued:						
Consumption--Continued:						
Prices, average annual--Continued:						
Domestic aluminothermic chromium metal, gross weight[16]	do.	$3.00	$2.75	$2.09	$2.09	$1.86
Imported aluminothermic chromium metal, gross weight[17]	do.	$2.50	$2.35	$2.08	$2.08	$1.84
Value of trade:[18]						
Exports	thousands	92,500	110,000	89,400	67,600	58,400
Imports	do.	420,000	427,000	239,000	256,000	322,000
Net exports[19]	do.	-327,000	-317,000	-149,000	-188,000	-264,000
Stainless steel, gross weight:						
Production[20]		2,190,000	2,190,000	1,820,000	2,190,000	2,210,000
Shipments[21]		1,890,000	1,930,000	1,670,000	1,720,000	1,950,000
Exports		216,000	264,000	249,000	273,000	327,000
Imports		941,000	989,000	761,000	752,000	639,000
Scrap:						
Receipts		694,000	817,000	720,000	808,000 r	757,000
Consumption		1,140,000	1,220,000	1,080,000	1,180,000 r	1,070,000
Exports		260,000	468,000	438,000	342,000	505,000
Imports		66,100	56,200	42,300	81,000	89,200
Value of trade:						
Exports	thousands	$628,000	$782,000	$752,000	$742,000	$895,000
Imports	do.	$1,560,000	$2,010,000	$1,430,000	$1,350,000	$1,320,000
Scrap exports	do.	$151,000	$310,000	$270,000	$252,000	$382,000
Scrap imports	do.	$27,700	$35,500	$24,100	$49,400	$70,200
Net exports[19, 22]	do.	-$811,000	-$955,000	-$433,000	-$405,000	-$115,000

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

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Calculated assuming chromite ore to average 44% Cr_2O_3, which is 68.42% chromium.

[3]Calculated assuming chromium content of ferrochromium to average 57%.

[4]Calculated assuming chromium content of stainless steel to average 17%.

[5]2001 stocks were estimated based on the previous accounting system and reported sales. Stocks before and after 2001 are those reported by the National Defense Stockpile.

[6]Includes consumer stocks of chromium ferroalloys and metal and other chromium-containing materials. Also includes chromium chemical and refractory producer stocks of chromite ore before 2000.

[7]Includes chromium ferroalloys and metal and other chromium materials in the United States.

[8]Chromium ferroalloy and other chromium-containing materials excluding chromium metal.

[9]Chromium ferroalloy and metal producer stocks of chromium ferroalloys and metal.

[10]Chemical, chromium ferroalloy and metal, and refractory producer stocks of chromite ore.

[11]Consumer stocks of chromium ferroalloys and metal and other chromium-containing materials.

[12]Time-weighted average price of South African chromite ore, as reported in Platts Metals Week.

[13]Time-weighted average price of imported high-carbon chromium that contains 50% to 55% chromium, as reported in Platts Metals Week.

[14]Time-weighted average price of electrolytic chromium metal, as reported in American Metal Market, before 2002.

[15]Time-weighted average price of domestically produced electrolytic chromium metal as reported by Ryan's Notes.

[16]Time-weighted average price of domestically produced aluminothermic chromium metal as reported by American Metal Market.

[17]Time-weighted average price of imported aluminothermic chromium metal as reported by Ryan's Notes.

[18]Includes chromite ore and chromium ferroalloys, metal, and chemicals.

[19]Data indicate that imports are greater than exports.

[20]Data on stainless steel production from American Iron and Steel Institute Annual Reports and quarterly production of stainless and heat-resisting raw steel.

[21]Data on stainless steel shipments from American Iron and Steel Institute Annual Reports and quarterly shipments of stainless and heat-resisting raw steel by market classification.

[22]Includes stainless steel and stainless steel scrap.

TABLE 2
U.S. REPORTED CONSUMPTION AND STOCKS OF CHROMIUM PRODUCTS[1]

(Metric tons)

	2002		2003	
	Gross weight	Chromium content	Gross weight	Chromium content
Consumption by end use:				
Alloy uses:				
Iron alloys, steel:				
Carbon steel	9,540 r	5,550 r	6,010	3,550
High-strength low-alloy steel	6,560 r	3,920 r	7,280	4,040
Stainless and heat-resisting steel	334,000 r	193,000 r	350,000	205,000
Full alloy steel	17,300 r	10,400 r	17,300	10,300
Electrical steel	W	W	W	W
Tool steel	5,030 r	3,000 r	5,840	3,480
Superalloys	8,220 r	6,640 r	7,940	6,550
Other alloys[2]	22,100 r	12,700 r	22,300	12,700
Other uses not reported above	W	W	W	W
Total	405,000 r	237,000 r	420,000	247,000
Consumption by material:				
Low-carbon ferrochromium	36,400 r	24,400 r	36,800	24,700
High-carbon ferrochromium	314,000 r	188,000 r	335,000	201,000
Ferrochromium silicon	46,900 r	18,200 r	39,000	15,200
Chromium metal	5,080 r	5,050 r	5,140	5,130
Chromite ore	1,530	474	2,660	834
Chromium-aluminum alloy	557 r	386 r	632	355
Other chromium materials	472	213	494	235
Total	405,000 r	237,000 r	420,000	247,000
Consumer stocks:				
Low-carbon ferrochromium	1,990	1,340	1,880	1,260
High-carbon ferrochromium	10,700	6,380	13,100	7,880
Ferrochromium silicon	971 r	377 r	1,250	484
Chromium metal	230 r	230 r	242	242
Chromite ore	72	22	80	25
Chromium-aluminum alloy	67 r	46 r	84	47
Other chromium materials	103	46	73	34
Total	14,100 r	8,430 r	16,700	9,970

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes cast irons, welding and alloy hard-facing rods and materials, wear- and corrosion-resistant alloys, and aluminum, copper, magnetic, nickel, and other alloys.

TABLE 3
U.S. GOVERNMENT STOCKPILE YEAREND INVENTORIES AND CHANGE FOR CHROMIUM-CONTAINING MATERIALS[1]

(Metric tons, gross weight)

	2003		Change	
Material	January 1	December 31	Quantity	Percentage[2]
Chromite ore:[3]				
Chemical	78,300	71,500	6,800	-9
Refractory	126,000	82,600	43,400	-34
Chromium ferroalloys:[4]				
High-carbon ferrochromium	531,000	466,000	64,500	-12
Low-carbon ferrochromium	232,000	217,000	15,400	-7
Chromium metal	7,220	6,660	563	-8

See footnotes at end of table.

TABLE 3--Continued

U.S. GOVERNMENT STOCKPILE YEAREND INVENTORIES AND CHANGE FOR CHROMIUM-CONTAINING MATERIALS[1]

[1]Data are rounded to no more than three significant digits.
[2]Quantity change as a percentage of stocks on January 1, 2003.
[3]Metallurgical grade chromite ore was used up in 2002.
[4]Ferrochromium silicon was used up in 2002.

Source: Defense Logistics Agency, Defense National Stockpile Center.

TABLE 4

TIME-VALUE RELATIONS FOR IMPORTS OF CHROMITE ORE, FERROCHROMIUM, AND CHROMIUM METAL[1, 2]

(Annual average value in dollars per metric ton)

Material	2002		2003	
	Contained chromium	Gross weight	Contained chromium	Gross weight
Chromite ore:				
Not more than 40% chromic oxide	833	195	1,830	390
More than 40%, but less than 46% chromic oxide	232	67	300	87
46% or more chromic oxide	182	58	162	52
Average[3]	191	60	168	54
Ferrochromium:				
Not more than 3% carbon:				
Not more than 0.5% carbon	1,550	1,030	1,810	1,230
More than 0.5%, but not more than 3% carbon	950	586	936	600
Average[3]	1,410	921	1,630	1,100
More than 4% carbon	546	326	771	443
Grand average[3]	646	390	835	485
Chromium metal	XX	5,770	XX	5,270

XX Not applicable.
[1]Based on customs value of chromium contained in imported material.
[2]Data are rounded to no more than three significant digits; may not add to totals shown.
[3]Mass-weighted average.

Source: U.S. Census Bureau.

TABLE 5

PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 2003

Material	January	December	Year average[1]
Cents per pound of chromium:			
High-carbon ferrochromium (imported):[2]			
50% to 55% chromium	34.00-36.00	54.00-57.00	43.27
60% to 65% chromium	33.50-36.00	54.00-57.00	43.63
Low-carbon ferrochromium (imported):[2]			
0.05% carbon	71-76	80-83	73
0.10% carbon	62-65	70-75	62
0.15% carbon	59-62	65-70	60
Cents per pound of product:			
Chromium metal (domestic):			
Electrolytic[3]	450	450	450
Aluminothermic[4]	200-210	180-190	186
Chromium metal (imported), aluminothermic	190-205	NA	184 [5]

NA Not available.
[1]Time-weighted average.
[2]The source for ferrochromium prices is Platts Metals Week.
[3]The source for domestic electrolytic and imported aluminothermic chromium metal is Ryan's Notes.
[4]The source for domestic standard aluminothermic chromium metal is American Metal Market.
[5]Time-weighted average over 51 weeks.

TABLE 6
U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE[1]

HTS[2]	Type	2002 Quantity (kilograms)	2002 Value (thousands)	2003 Quantity (kilograms)	2003 Value (thousands)	Principal destinations, 2003
2610.00.0000	Chromite ore and concentrate, gross weight	24,300,000	$4,070	103,000,000	$7,410	China (53%); Sweden (37%); Canada (9%); Mexico (1%).
	Metal and alloys:					
8112.21.0000	Unwrought chromium powders, gross weight	247,000	2,510	293,000	2,700	Belgium (27%); Canada (23%); Japan (19%); Germany (11%); Netherlands Antilles (6%); Mexico (3%); United Kingdom (3%); Republic of Korea (3%); Singapore (2%); Austria (1%); China (1%).
8112.22.0000	Chromium metal waste and scrap, gross weight	30,200	449	153,000	3,350	Japan (66%); Germany (13%); Canada (12%); Australia (3%); Austria (3%); Singapore (2%).
8112.29.0000	Chromium metal other than unwrought powders and waste and scrap, gross weight	467,000	4,490	496,000	5,860	Japan (61%); Belgium (15%); Mexico (7%); Germany (6%); Singapore (3%); Austria (2%); Netherlands (2%).
	Total chromium metal, gross weight	745,000	7,450	941,000	11,900	
	Chromium ferroalloys:					
7202.41.0000	High-carbon ferrochromium, gross weight[3]	13,500,000	7,140	3,180,000	2,720	Canada (58%); Mexico (34%); Brazil (5%).
7202.41.0000	High-carbon ferrochromium, contained weight[3]	8,710,000	XX	1,930,000	XX	
7202.49.0000	Low-carbon ferrochromium, gross weight[4]	2,070,000	2,640	1,230,000	2,000	Canada (49%); China (10%); Mexico (10%); United Kingdom (8%); Belgium (6%); Sweden (4%); Brazil (3%); Venezuela (3%); Hong Kong (2%); Peru (2%); Finland (1%); Taiwan (1%).
7202.49.0000	Low-carbon ferrochromium, contained weight[4]	1,250,000	XX	733,000	XX	
7202.50.0000	Ferrochromium-silicon, gross weight	281,000	290	481,000	511	Mexico (78%); Canada (22%).
7202.50.0000	Ferrochromium-silicon, contained weight	97,000	XX	168,000	XX	
	Total ferroalloys, gross weight	15,900,000	10,100	4,890,000	5,240	
	Total ferroalloys, contained weight	10,100,000	XX	2,830,000	XX	
	Chemicals, gross weight:					
	Chromium oxides:					
2819.10.0000	Chromium trioxide	8,380,000	15,700	7,840,000	12,600	Canada (25%); Republic of Korea (12%); China (10%); France (9%); Brazil (8%); India (6%); Taiwan (6%); Japan (5%); Mexico (4%); Switzerland (3%); Hong Kong (2%); Thailand (2%); Colombia (1%); Malaysia (1%); Pakistan (1%).
2819.90.0000	Other	2,410,000	7,660	2,250,000	8,010	Canada (59%); United Kingdom (7%); Taiwan (4%); Japan (3%); Philippines (3%); Spain (3%); Brazil (2%); China (2%); Germany (2%); Mexico (2%); Republic of Korea (2%); Australia (1%); Indonesia (1%); Malaysia (1%).
2833.23.0000	Chromium sulfates	93,400	365	5,440	62	Italy (55%); Australia (24%); Hong Kong (12%); Singapore (7%); Japan (2%).
	Salts of oxometallic or peroxometallic acids:					
2841.20.0000	Zinc and lead chromate	125,000	389	104,000	340	Canada (88%); Mexico (7%); Germany (4%).
2841.30.0000	Sodium dichromate	12,600,000	12,400	11,600,000	6,900	Canada (32%); Thailand (24%); Japan (14%); Mexico (6%); Peru (6%); Republic of Korea (3%); China (2%); Colombia (2%); Philippines (2%); Switzerland (2%); Taiwan (2%); Ecuador (1%); Hong Kong (1%); Venezuela (1%).
2841.50.0000	Other chromates and dichromates; peroxochromates:					
2841.50.1000	Potassium dichromate	25,800	46	42,400	63	Italy (60%); Mexico (21%); Canada (18%).
2841.50.9000	Other	516,000	1,750	412,000	1,290	Republic of Korea (44%); Mexico (15%); Brazil (13%); Malaysia (12%); Canada (7%); Argentina (2%); Saudi Arabia (2%).

See footnotes at end of table.

TABLE 6--Continued

U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE[1]

HTS[2]	Type	2002 Quantity (kilograms)	2002 Value (thousands)	2003 Quantity (kilograms)	2003 Value (thousands)	Principal destinations, 2003
3206.20.0000	Pigments and preparations, gross weight	824,000	7,650	867,000	4,610	Canada (37%); Mexico (32%); Brazil (8%); Guatemala (3%); Taiwan (3%); Sweden (2%); Thailand (2%); Hong Kong (1%); Italy (1%); Republic of Korea (1%).

XX Not applicable.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States code.

[3]More than 4% carbon.

[4]Not more than 4% carbon.

Source: U.S. Census Bureau.

TABLE 7

U.S. IMPORTS FOR CONSUMPTION OF CHROMITE ORE, BY COUNTRY[1]

Country	Not more than 40% Cr_2O_3 (HTS[2] 2610.00.0020)			More than 40%, but less than 46% Cr_2O_3 (HTS[2] 2610.00.0040)			46% or more Cr_2O_3 (HTS[2] 2610.00.0060)			Total		
	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value[3] (thousands)	Gross weight (metric tons)	Cr_2O_3 content (metric tons)	Value[3] (thousands)
2002:												
Canada	38	13	$15	--	--	--	--	--	--	38	13	$15
Philippines	981	335	180	--	--	--	--	--	--	981	335	180
South Africa	63	22	16	10,600	4,470	$710	100,000	46,700	$5,800	111,000	51,200	6,530
Total	1,080	370	211	10,600	4,470	710	100,000	46,700	5,800	112,000	51,600	6,720 r
2003, South Africa	77	24	30	7,940	3,370	692	165,000	77,400	8,570	173,000	80,800	9,290

r Revised. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States code.

[3]Customs import value generally represents a value in the foreign country and therefore excludes U.S. import duties, freight, insurance, and other charges incurred in bringing the merchandise into the United States.

Source: U.S. Census Bureau.

TABLE 8

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

	Not more than 0.5% carbon (HTS[2] 7202.49.5090)			More than 0.5% carbon, but not more than 3% carbon (HTS[2] 7202.49.5010)			More than 4% carbon (HTS[2] 7202.41.0000)			Total (all grades)		
Country	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thousands)
2002:												
China	98	65	$138	--	--	--	82	54	$94	180	119	$232
France	4	3	5	--	--	--	--	--	--	4	3	5
Germany	4,180	2,920	7,710	--	--	--	6,120	4,260	2,850	10,300	7,180	10,600
India	--	--	--	--	--	--	89	57	46	89	57	46
Japan	1,040	726	2,160	--	--	--	--	--	--	1,040	726	2,160
Kazakhstan	2,600	1,820	1,950	1,960	1,360	$1,370	109,000	75,500	39,900	114,000	78,700	43,200
Russia	12,300	8,420	11,600	991	695	884	2,710	1,870	2,450	16,100	11,000	14,900
South Africa	5,040	2,820	2,410	5,090	2,900	2,450	132,000	68,100	36,600	143,000	73,800	41,400
Turkey	261	189	289	--	--	--	6,000	3,570	1,840	6,260	3,760	2,130
Venezuela	--	--	--	--	--	--	20	14	12	20	14	12
Zimbabwe	--	--	--	--	--	--	25,800	15,500	8,540	25,800	15,500	8,540
Total	25,600	17,000	26,200	8,040	4,960	4,710	283,000	169,000	92,300	316,000	191,000	123,000
2003:												
China	95	63	117	--	--	--	20	14	25	115	76	142
Germany	3,990	2,800	7,370	--	--	--	340	216	185	4,330	3,020	7,550
Japan	1,790	1,240	3,750	--	--	--	--	--	--	1,790	1,240	3,750
Kazakhstan	1,530	1,060	1,340	1,100	758	934	126,000	86,900	75,000	129,000	88,800	77,300
Russia	11,900	8,030	11,200	321	220	345	3,610	2,390	2,380	15,800	10,600	13,900
South Africa	88	59	128	3,920	2,440	1,920	207,000	103,000	72,600	211,000	106,000	74,600
Sweden	--	--	--	--	--	--	12	7	7	12	7	7
Turkey	160	107	241	--	--	--	--	--	--	160	107	241
Zimbabwe	--	--	--	--	--	--	29,000	17,500	11,800	29,000	17,500	11,800
Total	19,500	13,400	24,100	5,340	3,420	3,200	366,000	210,000	162,000	391,000	227,000	189,000

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Harmonized Tariff Schedule of the United States code.

Source: U.S. Census Bureau.

TABLE 9
U.S. IMPORTS FOR CONSUMPTION OF CHROMIUM MATERIALS, BY TYPE[1]

		2002		2003		
HTS[2]	Type	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)	Principal sources, 2003
	Metals and alloys:					
	Chromium metal:					
8112.21.0000	Unwrought Chromium powders, gross weight	783,000 r	$4,850 r	1,810,000	$11,600	Russia (37%); United Kingdom (35%); China (11%); Japan (11%); Kazakhstan (4%); Germany (2%).
8112.22.0000	Waste and scrap, gross weight	75,300 r	1,240 r	284,000	1,520	Russia (72%); Japan (13%); Germany (4%); Sweden (3%); United Kingdom (3%); Republic of Korea (2%); Taiwan (2%).
8112.29.0000	Other than waste and scrap, gross weight	6,570,000	36,800	6,480,000	32,100	United Kingdom (26%); China (25%); Russia (23%); France (21%); Kazakhstan (4%); Germany (1%).
	Total	7,430,000	42,900 r	8,570,000	45,200	
7202.50.0000	Ferrochromium-silicon, gross weight	28,900,000	11,800	38,700,000	24,900	Kazakhstan (87%); Russia (13%).
7202.50.0000	Ferrochromium-silicon, contained weight	12,000,000	XX	16,200,000	XX	
	Chemicals, gross weight:					
	Chromium oxides and hydroxides:					
2819.10.0000	Chromium trioxide	16,500,000	24,500	14,100,000	18,900	Turkey (45%); Kazakhstan (38%); United Kingdom (8%); South Africa (4%); China (2%); Japan (1%); Russia (1%).
2819.90.0000	Other	2,860,000	9,640	2,510,000	7,600	China (40%); Japan (26%); Germany (16%); Spain (6%); Russia (4%); United Kingdom (3%); Belgium (1%); Colombia (1%); Poland (1%).
2833.23.0000	Sulfates of chromium	75,900	90	162,000	194	United Kingdom (77%); Argentina (23%).
	Salts of oxometallic or peroxometallic acids:					
2841.20.0000	Chromates of lead and zinc	135,000	395	153,000	307	Norway (35%); China (24%); Colombia (16%); Japan (14%); Germany (11%).
2841.30.0000	Sodium dichromate	18,800,000	9,470	3,020,000	1,440	United Kingdom (87%); China (6%); South Africa (6%); Turkey (1%).
2841.50.0000	Other chromates and dichromates; peroxochromates:					
2841.50.1000	Potassium dichromate	189,000	322	102,000	142	Russia (59%); Kazakhstan (37%); Germany (2%); Japan (1%).
2841.50.9000	Other	241,000	555	377,000	862	Austria (35%); Republic of Korea (34%); China (21%); Germany (10%).
2849.90.2000	Chromium carbide	261,000	2,760	203,000	2,340	Russia (39%); Japan (24%); United Kingdom (15%); Germany (12%); Canada (10%).
	Pigments and preparations based on chromium, gross weight:					
3206.20.0010	Chrome yellow	6,610,000	14,900	5,560,000	13,000	Canada (52%); Republic of Korea (20%): Mexico (12%); Hungary (10%) Colombia (4%); Germany (1%); Venezuela (1%).
3206.20.0020	Molybdenum orange	1,300,000	5,330	987,000	4,310	Canada (88%); Colombia (5%); Mexico (2%); United Kingdom (2%); Japan (1%); Venezuela (1%).
3206.20.0030	Zinc yellow	--	--	657	5	Italy (100%).
3206.20.0050	Other	1,220,000	3,420	1,740,000	4,390	France (56%); China (20%); Italy (12%); Germany (6%); Belgium (3%); Hungary (1%); Israel (1%); South Africa (1%).

[r]Revised. XX Not applicable. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Harmonized Tariff Schedule of the United States code.

Source: U.S. Census Bureau.

TABLE 10

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

(Metric tons, gross weight)

Country[3]	1999	2000	2001	2002	2003
Afghanistan[4]	4,318	5,345	5,682	--	-- e
Albania[5]	71,434	120,400 r	86,000 r	91,000 r	90,000
Australia	70,000	90,000	11,800	132,665	138,826
Brazil[6]	457,579 r	550,000 r	418,402 r	284,000 r	390,640
Burma[e]	2,500	1,000	1,000	--	--
China[e]	220,000	208,000	182,000	180,000	200,000
Cuba	52,000	56,300	50,000	46,000	50,000 e
Finland	597,438	628,414	575,126	566,090	549,040
Greece[4]	2,273	--	--	--	-- e
India	1,472,766	1,946,910	1,677,924	2,698,577 r	2,210,000
Indonesia	6,355	--	--	--	-- e
Iran	254,685	153,000	104,905	80,000	120,000
Kazakhstan	2,405,600	2,606,600	2,045,700	2,369,400	2,927,500
Macedonia[e]	5,000 6	5,000	5,000	5,000	5,000
Madagascar	--	131,293 r	23,637 r	11,000 r	45,040
Oman	26,004	15,110	30,100	27,444	13,000
Pakistan	58,000	119,490	64,000	62,005	98,235
Philippines	19,566	26,361	26,932	23,703	24,000 e
Russia	115,100	92,000	69,926	74,300 r	116,455
South Africa	6,817,050	6,622,000	5,502,010	6,435,746	7,405,391
Sudan	48,000 e	54,500 r	-- r	15,000 r	47,000
Turkey	770,352	545,725	389,759	313,637	229,294
United Arab Emirates[e]	60,000	30,000	10,000	-- r	--
Vietnam	58,500	76,300	80,000 e	80,000 r, e	80,000 e
Zimbabwe	653,479	668,043	780,150	749,339	725,822
Total	14,200,000 r	14,800,000 r	12,100,000 r	14,200,000 r	15,500,000

[e]Estimated. [r]Revised. -- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through June 25, 2004.

[3]Figures for all countries represent marketable output unless otherwise noted.

[4]Gross weight estimated assuming an average grade of 44% chromic oxide (Cr_2O_3).

[5]Direct shipping plus concentrate production.

[6]Average chromic oxide (Cr_2O_3) content was as follows: 1999--45.2% (revised); 2000--46.0% (revised); 2001--42.5% (revised); 2002--40.1% (revised); and 2003--40% (estimated).

TABLE 11
FERROCHROMIUM: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons, gross weight)

Country	1999	2000	2001	2002	2003
Albania	28,120	12,500	11,900	22,100 [r]	37,800
Brazil[3]	90,784	172,443 [r]	110,468 [r]	164,140 [r]	196,032
China[e]	400,000	450,000	310,000	330,000 [r]	500,000
Croatia	--	15,753	361	--	--
Finland	256,290	260,605	236,710	248,181	250,040
Germany	16,960	21,600	19,308	20,018	18,318
India[4]	312,140	376,693	267,395	311,927	468,677
Iran	13,680	11,505	8,430	15,000	17,000
Japan[3]	119,777	130,074	111,167	91,937	26,000 [e]
Kazakhstan	731,563	799,762	761,900	835,800	993,000 [e]
Norway	159,714	153,500	82,600	61,100	--
Russia	249,000	274,000	210,600	210,000	357,000
Slovakia	6,986	17,702	5,968	5,695	1,924
Slovenia	560	--	--	--	--
South Africa[5]	2,155,202	2,574,000	2,141,000	2,351,122 [r]	2,470,000 [e]
Spain	935	905	-- [e]	-- [e]	-- [e]
Sweden	113,140	135,841	109,198	118,823	110,529
Turkey	99,105	97,640	50,735	11,200	35,393
United States[6]	W	W	W	W	W
Zimbabwe	244,379	246,324	243,584	258,164	245,200
Total	5,000,000	5,750,000 [r]	4,680,000	5,060,000 [r]	5,730,000

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.
[1]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

TABLE 12
WORLD CHROMIUM ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, CHROMIUM CHEMICALS, STAINLESS STEEL, AND APPARENT CONSUMPTION IN 2003[1]

(Thousand metric tons, contained chromium)

Country	Ore	Ferrochromium	Metal	Chemicals	Stainless steel	Apparent consumption[2]
Afghanistan	2	--	--	--	--	--
Albania	48	22	--	--	--	-5
Argentina	--	--	--	13	--	13
Australia	72	--	--	--	--	-30
Austria	--	--	--	--	8	69
Belgium	--	--	--	--	153	100
Brazil	157	109	--	--	82	125
Canada	--	--	--	--	26	27
China	66	272	6	70	289	613
Cuba	17	--	--	--	--	8
Egypt	--	--	--	--	3	(3)
Finland	189	139	--	--	187	159
France	--	--	7	--	204	138
Germany	--	17	1	--	272	283
Greece	4	--	--	--	--	(3)
India	812	244	(3)	4	215	215
Indonesia	2	--	--	--	--	(3)
Iran	77	12	--	2	--	-2
Italy	--	--	--	--	247	198
Japan	--	97	1	17	697	533
Kazakhstan	903	512	2	37	--	328
Korea, Republic of	--	--	--	--	323	254
Macedonia	2	--	--	--	--	(3)
Madagascar	40	--	--	--	--	12
Norway	--	--	--	--	--	(3)
Oman	9	--	--	--	--	2
Pakistan	36	--	--	3	--	-4
Philippines	8	--	--	--	--	-12
Poland	--	--	--	--	--	3
Russia	46	170	16	31	26	242
Slovakia	--	10	--	--	--	(3)
Slovenia	--	--	--	--	12	(3)
South Africa	2,230	1,470	--	23	109	656
Spain	--	--	--	--	204	112
Sudan	14	--	--	--	--	11
Sweden	--	86	--	--	138	72
Taiwan	--	--	--	--	255	241
Turkey	232	62	--	17	--	-14
Ukraine	--	--	--	--	88	(3)
United Arab Emirates	18	--	--	--	--	(3)
United Kingdom	--	--	7	44	92	65
United States	--	20	3	38	374	254
Vietnam	16	--	--	--	--	-43
Yugoslavia	--	--	--	--	51	--
Zimbabwe	214	221	--	--	--	72
Total	5,210	3,460	43	299	4,060	XX

XX Not applicable. -- Zero.

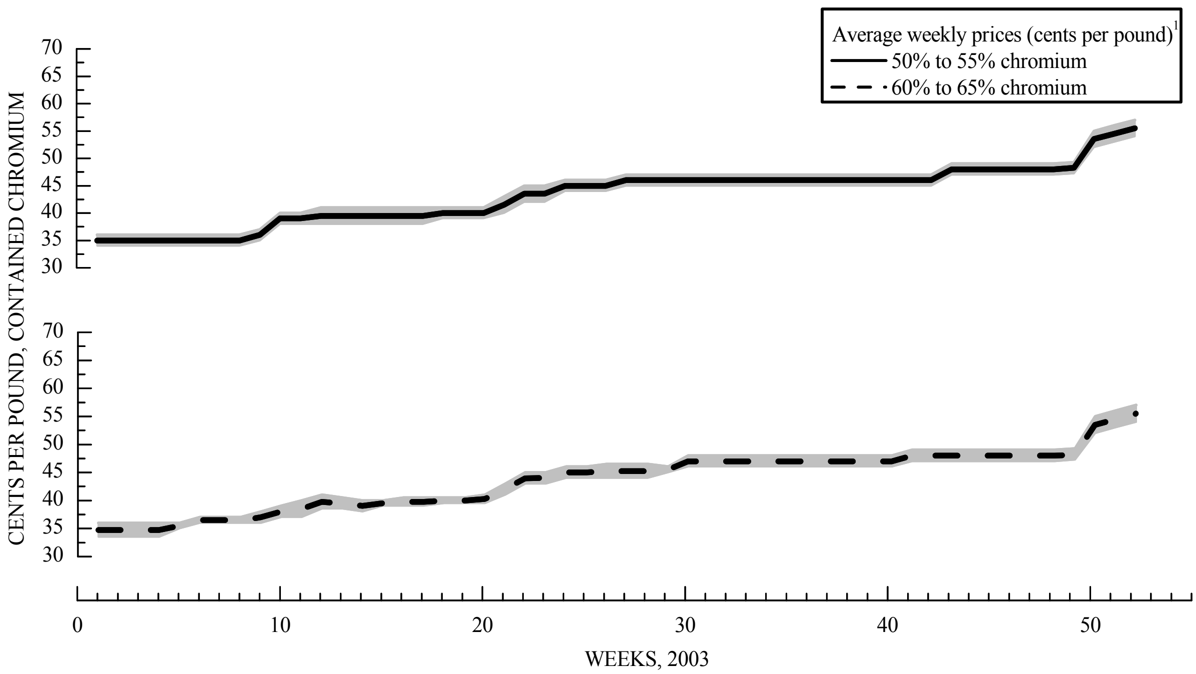
[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Apparent consumption is chromite ore production plus chromite ore, ferrochromium, and chromium metal net imports. Net imports are imports minus exports. Based on data reported by the International Chromium Development Association.

[3]Less than 1/2 unit.

FIGURE 1

U.S. IMPORTED HIGH-CARBON FERROCHROMIUM IN 2003

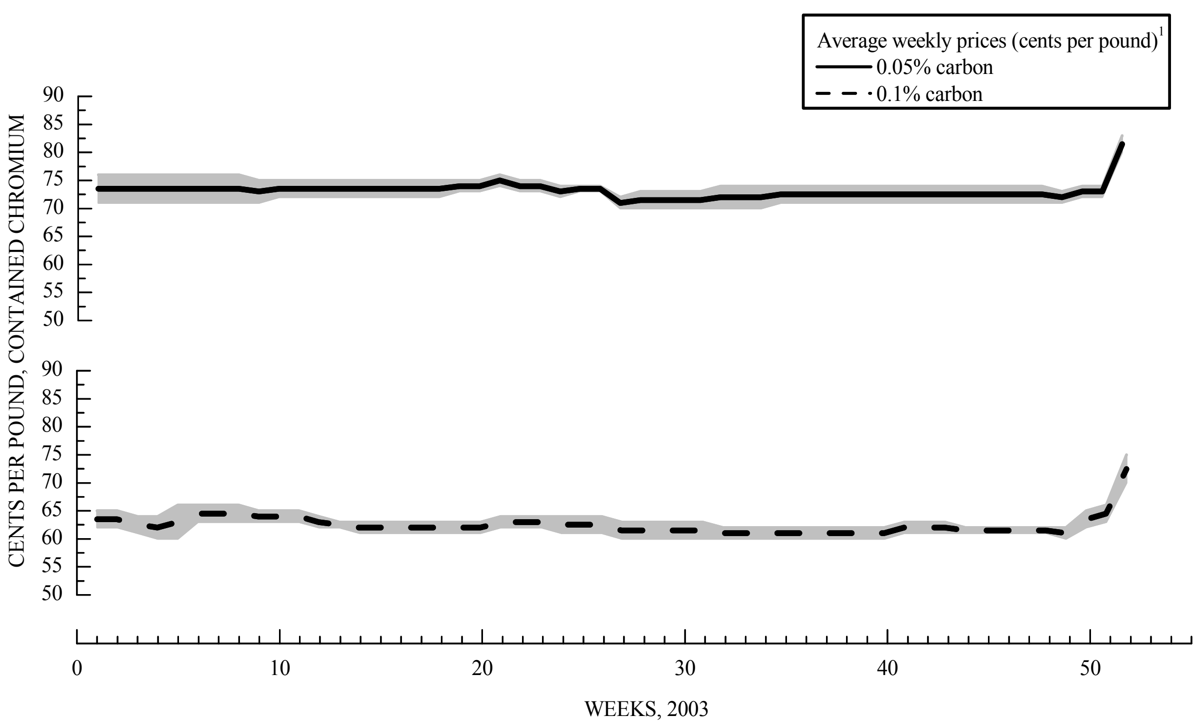


[1]Average weekly price shown against price range background.

Source: Platts Metals Week

FIGURE 2

U.S. IMPORTED LOW-CARBON FERROCHROMIUM IN 2003



[1]Average weekly price shown against price range background.

Source: Platts Metals Week