TITANIUM

By Joseph Gambogi

Titanium occurs primarily in the minerals anatase, brookite, ilmenite, leucoxene, perovskite, rutile, and sphene. Of these minerals, only ilmenite, leucoxene, and rutile have significant economic importance. As a metal, titanium is well known for corrosion resistance and for its high strength-to-weight ratio. However, approximately 95% of titanium is consumed in the form of titanium dioxide (TiO₂), a white pigment in paints, paper, and plastics. Titanium dioxide pigment is characterized by its purity, refractive index, particle size, and surface properties. The particle size is critical and is controlled within the range of about 0.2 to 0.4 micrometer to develop optimum pigment properties. The superiority of TiO₂ as a white pigment is mainly due to its high refractive index and resulting light-scattering ability, which impart excellent hiding power and brightness.

Following a flat year of demand growth, global demand for TiO_2 pigment increased about 5% in 1997. On a gross weight basis, apparent consumption of TiO_2 in the United States also increased about 5% compared with that of 1996. (See table 1.)

Legislation and Government Programs

In accordance with the excess stockpile requirements of the Strategic and Critical Materials Stockpiling Act, 31,600 metric tons of titanium sponge held in the National Defense Stockpile (NDS) were authorized for disposal. Near yearend, the Defense National Stockpile Center (DNSC) began soliciting offers for the sale of 3,630 tons (4,000 short tons) during the 1998 fiscal year. Also, 227 tons (250 short tons) of titanium sponge from the NDS were transferred by DNSC to the U.S. Army. The transfer was made in accordance with the National Defense Authorization Act for fiscal year 1996, Public Law 104-106, Section 3305 and was designated for use in the weight reduction program of the main battle tank upgrade program. At yearend, the NDS held 33,106 metric tons of titanium sponge.

The International Trade Administration (ITA) reaffirmed its 1996 preliminary review of antidumping duties on titanium sponge from Russia. The review covered imports from sponge producer AVISMA Titanium-Magnesium Works and three trading companies, Interlink Metals & Chemicals, S.A., TMC Trading International, Ltd. (TMC), and Cometals, Inc. during the period August 1, 1995, through July 31, 1996. The ITA concluded that AVISMA would continue to be subject to the Russia-wide 83.96% ad valorem antidumping margin, while the margin for the trading companies, Interlink, Cometals, and TMC, were determined to be 0%, 28.31%, and 0%, respectively (U.S. Department of Commerce, 1997).

In a separate action, TMC requested a review of the antidumping determination that is applied to imports of titanium sponge from Russia. According to the company, the justification for this review is a change of circumstance. In response to this request, the International Trade Commission requested comments from the public as to whether changed circumstances exist sufficient to warrant the institution of a review. The purpose of the proposed review was to determine whether revocation of all existing antidumping orders on imports of titanium sponge is likely to lead to continuation or recurrence of material injury to the domestic industry. At yearend, this investigation was ongoing (U.S. International Trade Commission, 1997).

Production

Ores and Concentrates.—Commercial forms of titanium ores and concentrates include ilmenite, leucoxene, rutile, titanium slag, and synthetic rutile. Australia, Canada, Norway, and South Africa are the major producing countries of titanium ores and concentrates. U.S. producers include E.I. du Pont de Nemours & Co. Inc. (DuPont), Kerr-McGee Chemical Corp., RGC (USA) Mineral Sands, Inc. (RGC), and P.W. Gillibrand Co. DuPont's Trail Ridge mining operations in Starke, FL, produce a mixed product containing rutile, leucoxene, and ilmenite, which is used as a feedstock in DuPont's titanium pigment operations. RGC's mining operations in Green Cove Springs, FL, and Stony Creek, VA, produce both rutile and ilmenite concentrates. P.W. Gillibrand produces ilmenite concentrate as a byproduct of its sand and gravel operation in Simi Valley, CA. Kerr McGee's operation in Mobile, AL, produces synthetic rutile from purchased ilmenite concentrate. Titanium slag is not produced in the United States.

At yearend, RGC was in the process of commissioning its mining operation at the Old Hickory deposit near Stony Creek, VA. At full production, the company plans to produce up to 100,000 tons per year of ilmenite (59% to 60% TiO₂), 3,500 tons per year of a high-grade titanium feedstock (85% TiO₂), and 30,000 tons per year of zircon. At RGC's mining operation at Green Cove Springs, FL, traditional dredging methods were being supplemented by dry mining pods of high-grade ore then relocating the ore into the dredge path (RGC Ltd., 1998).

Plans for the development of two domestic deposits were postponed. DuPont indefinitely delayed the development of a deposit in Georgia near the eastern edge of the Okefenokee National Wildlife Refuge. During 1997, DuPont held discussions with interested parties regarding the environmental impact of developing the deposit. 3R Minerals' development of the Escalante, UT, deposit was suspended pending the resolution of mining claims within the Grand Staircase-Escalante National Monument.

Teck Corp. continued to study the development of the large Powderhorn perovskite deposit near Gunnison, CO. However, the successful development of the deposit required the development of a unique commercial process of extracting TiO_2 from the perovskite ore. In 1997, Teck operated a pilot plant to convert perovskite to TiO_2 pigment. According to the company, a feasibility study is expected to be initiated in 1998 (Teck Corp., 1998).

Metal.—Titanium sponge is the primary metal form of titanium. Production involves the chlorination of titanium-containing mineral feedstocks to produce titanium tetrachloride (TiCl₄). Titanium tetrachloride is purified and then reacted with magnesium to produce titanium sponge. Titanium sponge is produced in China, Japan, Kazakstan, Russia, and the United States. U.S. producers of titanium sponge include Johnson Matthey Refining Inc., Salt Lake City, UT; Oregon Metallurgical Corp. (Oremet), Albany, OR; and Titanium Metals Corp. (Timet), Henderson, NV. Domestic operating capacity of titanium sponge is estimated to be 21,600 tons per year. Domestic production of titanium sponge is withheld to avoid disclosing company proprietary data. (*See table 2.*)

Titanium ingot is produced by melting titanium sponge or scrap or a combination of both, usually with various other alloying elements such as aluminum and vanadium. Electron-beam, plasma, and vacuum-arc-reduction are the current commercial melting methods used to produce ingot. Currently, significant ingot production capacity exists in France, Germany, Japan, Russia, the United Kingdom, and the United States. In the United States, ingot is produced by the two sponge producers, Oremet and Timet, and by six other firms. U.S. production of ingot increased about 14% compared with that of 1996. (*See table 3.*)

Titanium mill products result from the drawing, forging, and rolling of titanium ingots or slabs into products of various sizes and shapes. These mill products include titanium billet, bar, rod, wire, plate, sheet, strip, extrusions, pipe and tube, etc. Major producers of titanium mill products are located primarily in the China, Europe, Japan, Russia, and the United States. Over 30 domestic companies are known to produce titanium mill products and castings from ingot and billet. In 1997, U.S. production of mill products increased by 12%, compared with that of 1996.

Titanium castings are produced by melting titanium ingot or billet and then pouring the molten metal into a mold. U.S. producers of titanium castings include Coastcast Corp., Rancho Dominguez, CA; Duriron Co., Dayton, OH; Howmet Corp., Whitehall, MI; Investicast, Ltd., Sweet Home, OR; Precision Cast Parts Corp., Portland, OR; Selmet Inc., Albany, OR; Timet Castings Corp., Albany, OR; and Wyman-Gordon Investment Castings, Inc., Groton, CT.

Ferrotitanium is produced through induction melting of titanium scrap with iron or steel. U.S. producers of ferrotitanium include Galt Alloys Inc., Canton, OH, and Shieldalloy Metallurgical Corp., Newfield, NJ. The two standard grades of ferrotitanium contain 40% and 70% titanium. Data on production of ferrotitanium were not collected.

In 1997, Allegheny Teledyne Inc. announced plans to expand its business in specialty metals through the acquisition of Oremet. Currently, Teledyne's subsidiaries in the titanium industry include Wah Chang, Albany, OR, and Allvac, Monroe, NC (Allegheny Teledyne Inc., 1997).

Allvac commissioned a new furnace at its Monroe, NC, facility for producing titanium ingot. The new 2,270-ton-per-year furnace is based on plasma-arc cold hearth melting technology (Metal Bulletin, 1997). Allvac's total melt capacity is estimated to be 10,000 to 12,000 tons per year with the addition of the new furnace.

Oremet began construction of a new electron-beam cold-hearth melting facility near Richland, WA. The facility, with a rated capacity of 10,000 tons per year, should begin commercial production by mid- to late 1998 (Haflich, 1997).

RMI Titanium Co. announced an agreement with speciality alloy producer Galt Alloys, Canton, OH, to acquire 90% of the common stock of Galt. As a result of the agreement, Galt is undertaking an expansion program that will include a new scrap preparation facility, a plasma consolidation furnace, and a plasma hearth furnace (RMI Titanium Co., 1997).

Timet began construction of a new furnace to expand the ingot capacity of its wholly owned subsidiary Titanium Hearth Technologies in Morgantown, PA. The new furnace is expected to produce up to 9,000 tons per year of titanium ingot using electron-beam cold hearth melting technology. In a separate action, Timet and Valinox Welded formed a joint-venture called Valimet that owns and operates the titanium tubing businesses of both companies. Timet produces welded tubing at its facilities in Morristown, TN, and Toronto, OH. Valinox produces welded tubing in Les Laumes, France, and holds a controlling interest in a producer in China. Timet is expected to be the primary supplier of titanium strip that the joint-venture will utilize to produce welded tubing. During 1997, Timet also acquired 20% interest in Titanium Memory Systems Inc. (TMS). TMS is developing a titanium substrate suitable for computer hard disk drives. When TMS enters into production, Timet is expected to be the primary supplier of titanium strip (Titanium Metals Corp., 1998).

Pigment.—Titanium dioxide pigments are produced as two major types: rutile and anatase. Rutile and anatase pigments are chemically similar but differ in crystal form. Rutile-type pigment is less reactive with the binders in paint when exposed to sunlight than is the anatase type and is preferred for use in outdoor paints. Anatase pigment has a bluer tone than the rutile type, is somewhat softer, and is used mainly in indoor paints and in paper manufacturing. Depending on the manner in which titanium pigment is produced and subsequently finished, titanium pigments can exhibit a range of functional properties, including opacity, durability, dispersion, and tinting.

Titanium dioxide pigment is produced using either the chloride process or the sulfate process. Either route may be used to produce rutile-grade or anatase-grade pigments. The decision to use one process over the other is based on a number of factors including raw material availability, freight, and waste disposal costs.

In the sulfate process, ilmenite or titanium slag is reacted with sulfuric acid, and a portion of the iron sulfate formed may be crystallized and removed. Titanium hydroxide is precipitated by hydrolysis, filtered, and calcined.

In the chloride process, rutile is converted to TiCl_4 by chlorination at 850° to 950°C in the presence of petroleum coke. Titanium tetrachloride may be used either in making pigment, or with additional purification, for reduction to metal. In making pigment, the TiCl₄ is oxidized with air or oxygen at about 1,000° C, and the resulting fine-size TiO₂ is calcined at 500° to 600° C to remove residual chlorine and any hydrochloric acid that may

have formed in the reaction. Aluminum chloride is added to the $TiCl_4$ to assure that virtually all of the titanium is oxidized in the rutile crystalline form.

Recoveries of TiO_2 in pigment are approximately 80% to 90%. The crude form of the pigment is milled to produce a controlled distribution of particle size and surface treated or coated to improve its functional behavior in different media. Some typical surface treatments include alumina, silica, and organic treatments.

U.S. producers of titanium dioxide pigments are DuPont, Kemira Inc., Kerr-McGee, Louisiana Pigment Co. LP, and Millennium Inorganic Chemicals Inc. (formerly SCM Chemicals Inc.). U.S. production of TiO₂ pigment in 1997 increased 10% compared with that of 1996. Capacity utilization for the domestic pigment industry was about 90%. (*See tables 4 and 5.*)

DuPont announced plans to idle its 36,000-ton-per-year pigment plant at Antioch, CA. However, finishing and slurry operations at the Antioch facility are expected to remain on-stream (European Chemical News, 1997). The Antioch pigment plant was opened in 1963 using DuPont's original chloride-process technology. Meanwhile, Kerr-McGee expanded chloride-route capacity at its Hamilton, MS, plant from 145,000 to 160,000 tons per year (Chemical Products Synopsis, 1997).

Consumption

Ores and Concentrates.—Increased production of titanium pigment resulted in a significant increase in the consumption of titanium mineral feedstocks. On a gross weight basis, U.S. reported consumption of TiO_2 in ilmenite and titanium slag was 1.52 million tons, an 8% increase compared with that of 1996. Following a slight decrease in 1996, consumption of natural and synthetic rutile increased 23%.

Consumption data for titanium concentrates are developed by the U.S. Geological Survey (USGS) from one voluntary survey of domestic operations. Of the 28 operations canvassed, 22 responded, representing 99% of the data in table 6. Data for nonrespondents were estimated based on prior-year consumption levels. (*See table 6.*)

Metal.-Increased ingot production resulted in higher consumption of titanium sponge and scrap. Sponge consumption increased by 13% compared with those of 1996. However, scrap consumption was nearly unchanged. Scrap supplied a calculated 48% of ingot feedstock. Increased demand for titanium mill products by the commercial aerospace and nonaerospace markets resulted in a 19% increase in ingot consumption and a 9% increase in net shipments of mill products. Reported shipments of titanium castings increased 42%. Estimated U.S. mill product usage by application was as follows: aerospace, 65%, nonaerospace uses, 35%. Nonaerospace uses include those in the specialty chemical, pulp and paper, oil and gas, marine, medical, and consumer goods industries. Reported consumption of titanium products in steel and other alloys decreased 11% compared with that of 1996. (See tables 3 and 7.)

Pigment.—Titanium dioxide pigments account for over 95% of all prime white pigments. The three largest end uses are paint and coatings, paper, and plastics. Other consuming industries included ceramics, fabrics and textiles, floor coverings, printing

ink, and rubber. In 1997, apparent domestic consumption of TiO_2 pigments was about 1.12 million tons, a 5% increase compared with that of 1996. (See tables 5 and 8.)

In the paint and coatings market, TiO_2 is used in white and color formulations. The industry is made up of original equipment manufacturers (OEM), architectural, and special-purpose applications. The OEM portion of the market includes automotive, appliances, containers, and wood. OEM applications require high brightness, gloss, and durability as well as resistance to abrasion, heat, and chemical attack. Architectural applications include interior and exterior coatings as well as lacquers and stains. Architectural applications demand high durability, gloss and hiding power. Special purpose coatings include marine, traffic, refinish, and aerosol coatings. The final TiO₂ content for paint and coatings varies.

The plastics industry primarily consumes rutile grades of pigment. Titanium dioxide pigments represent the majority of all inorganic pigments used in the plastics industry. TiO_2 pigments are used in the plastics industry in a variety of applications. They serve to provide opacity and act as barrier against ultraviolet light degradation. Most TiO_2 pigments are introduced as pelletized concentrates containing up to 50% TiO_2 in a carrier resin. However, liquid and dry concentrates also are used by the industry. The final TiO_2 content is normally in the 3% to 25% range of the finished product.

Titanium pigments are used in paper products to give opacity and brightness. Anatase-grade pigment is often used in the paper industry because it is less abrasive to paper-making machinery. The paper industry consumes TiO_2 pigments as filler and in coatings. Although paper products contain a high percentage of minerals as filler material, the typical TiO_2 content is estimated to be less than 5% of the dry weight of paper.

Stocks

On a gross weight basis, yearend consumer inventories of titanium ores and concentrates decreased 10% compared with those of 1996. Meanwhile, producer stocks of TiO_2 pigment were about 118,000 tons, an 11% increase from the 1996 level. Owing to a surge of imports, industry stocks of sponge increased 60%. Stocks of titanium scrap were moderately lower while stocks of titanium ingot decreased 8%. (See table 9.)

Prices

With the exception of titanium slag, prices for titanium mineral concentrates were moderately lower in 1997 compared with those of 1996. The yearend published price range for bulk rutile concentrates was \$500 to \$550 per ton, a 7% decrease compared with the range for 1996. The price range for bagged rutile concentrates used in the welding rod coatings market was \$650 to \$710 per ton, a decrease of 9% compared with that of 1996. Ilmenite prices decreased 14% with a yearend range of \$68 to \$81 per ton. Published prices for titanium slag were not available. However, based on the U.S. Customs value of imports, prices for Canadian slag increased 6%, while prices for South African slag increased 11% compared with those of 1996. (*See table 10.*)

Foreign Trade

Ores and Concentrates.—The United States is highly import dependent for titanium concentrates. During 1997, the largest import sources of titanium concentrates were Australia, India, and South Africa. Imports of ilmenite, rutile, slag, and synthetic rutile concentrates in 1997 were 522,000 tons, 183,000 tons, 430,000 tons, and 153,000 tons, respectively. Overall, imports of titanium concentrates in 1997 (on a gross weight basis) increased slightly compared with 1996. Exports of titanium ores and concentrates were 23,800 tons, a 54% increase compared with 1996. (*See tables 11 and 12.*)

Metal.—U.S. import reliance extends to titanium metal, primarily in the form of titanium sponge and scrap. Although a significant quantity of imported titanium scrap is consumed by the iron and steel industry, nearly all of the imported sponge is consumed by the titanium industry. Owing to increased demand and changes to antidumping duties, sponge imports increased significantly in 1997. The leading import sources of titanium sponge were China, Japan, Kazakstan, and Russia. The leading import sources of titanium waste and scrap were France, Japan, Russia, and the United Kingdom. *(See table 13.)*

Pigment.—The United States is a net exporter of titanium pigments. However, a significant quantity of titanium pigments is imported. During 1997, pigment imports increased 17%, and the leading import sources of titanium pigments were Canada and Germany. Imports of titanium pigments containing more than 80% TiO₂ were 134,000 tons, a 28% increase compared with those of 1996. Imports of other titanium pigments were 39,300 tons, nearly unchanged compared with those of 1996. Imports of titanium oxide were 21,400 tons, a 9% decrease compared with those of 1996. Exports of titanium pigments in 1997 were 362,000 tons, a 24% increase compared with those of 1996. Exports of titanium oxides (unfinished pigments) were 42,800 tons, a 6% increase compared with those of 1996. *(See tables 11 and 14.)*

World Review

World production of titanium concentrates, excluding the United States, was estimated to have increased 3% compared with that of 1996. Although ilmenite and slag production increased only slightly, rutile production increased 14% on a gross weight basis. Australia contributed most of the increased rutile production. During 1997, the titanium industry moved toward greater consolidation in the major industry sectors-mining, pigment, and metal production. The most significant among these was DuPont's agreement to acquire several of Imperial Chemical Industries PLC's (ICI) businesses including ICI's white pigment business outside of North America. Under the agreement, DuPont would acquire ICI subsidiary Tioxide's titanium pigment facilities in France, Italy, Malaysia, South Africa, Spain, and the United Kingdom. However, Tioxide's 50% interest in Louisiana Pigment Co., Lake Charles, LA, and its finishing operations in Quebec, Canada, are not included in the acquisition. The acquisition includes about 535,000 tons of annual capacity. At yearend, the acquisition was still pending approval from the Federal Trade Commission. (See table 15.)

Australia.—BHP Titanium Minerals Pty. Ltd. commissioned its mining operations at Beenup, Australia. Beenup's design production rate is 600,000 tons of ilmenite per year of which approximately 50% will be processed at the BHP-Tinfos jointventure slag operation in Tyssedal, Norway. The joint-venture is expected to produce 200,000 tons per year of chloride-grade slag and 40,000 tons per year of sulfate-grade slag. According to BHP, Beenup reserves defined by the mine plan are estimated to contain 12.4 million tons of ilmenite (BHP Minerals Global Report, 1997).

Westralian Sands Ltd. (WSL) commissioned a second synthetic rutile plant at its North Capel operation. According to the company, total production in 1997 was 145,800 tons, and production is targeted to increase to 280,000 tons per year by 2000. A cogeneration plant was incorporated into the new synthetic rutile plant supplying more than one-half of the North Capel operation's power requirements. WSL was in the process of constructing a new mineral separation plant at North Capel with the capacity to produce 650,000 tons per year of ilmenite. The company also plans to convert iron oxide waste from the North Capel synthetic rutile operations to pig iron feedstock for steel production. The pig iron plant is expected to be completed in 2000. WSL exploration program in the Swan Costal Plain resulted in an estimated heavy mineral resource of 38 million tons (Westralian Sands Ltd., 1998).

RGC discovered several new mineral sands deposits. Specifically, the company's efforts focused on the Kulwin and Woornack deposits in the Murray basin within the northwest region of Victoria. Initial drilling results indicated grades averaging between 3% and 16% heavy minerals. RGC has been granted tenements over 44,000 square kilometers of the Murray basin (Industrial Minerals, 1997a).

CRA Exploration Ltd. (CRA) identified a mineral sands deposit at Wedderburn, Victoria. CRA estimated the resource to be 876 million tons with 2.19% heavy minerals. The company plans to begin a drilling program to outline areas with higher grade heavy minerals.

According to industry reports, Monto Minerals NL is planning the development of the Goondicum Crater deposit in Queensland. The project includes two mines and a mineral separation plant producing 275,000 tons of ilmenite feedstock. Production is scheduled to begin in 1999 (Industrial Minerals, 1997b).

Belgium and Germany.—Kerr-McGee agreed to acquire Bayer AG's sulfate-route pigment plants in Antwerp, Uerdingen, and Düsseldorf. The company plans to convert these plants to use chloride-route technology (Kerr-McGee Corp., 1998).

Canada.—QIT-Fer et Titane Inc. completed construction of its upgraded slag plant. The new plant converts QIT's regular grade slag into an upgraded product called UGS slag containing 95% TiO₂. Initial annual production of 200,000 tons per year is expected to commence in 1998 (Rio Tinto Ltd., 1998).

China.—Pangang Group Titanium Works Co. announced plans to increase its production of titanium concentrates from 100,000 tons per year to 180,000 tons per year by 2000. The company also plans to increase its TiO_2 pigment capacity from 4,000 tons per year to 10,000 tons per year and is conducting research in titanium slag production (Platt's Metals Week, 1997).

Finland.—Kemira Pigments B.V. announced it would resume

a project to increase TiO_2 pigment capacity at Pori. The debottlenecking project will increase capacity from 100,000 to 120,000 tons per year and is scheduled to be completed by the end of 1999 (Kemira Pigments Oy. B.V., 1997a). In April, Kemira brought its Rotterdam, Netherlands, pigment facility back on-stream. An explosion in January had halted production at the 56,000-ton-per-year chloride route facility (Kemira Pigments Oy. B.V., 1997b).

France.—Millennium agreed to acquire Rhône-Poulenc's Thann et Mulhouse S.A. Rhône-Poulenc's TiO_2 operations are located in France at Le Havre and Thann. In addition to 138,000 tons per year of combined TiO_2 pigment capacity, the plants have 100,000 tons per year of capacity to produce specialty chemicals and intermediate chemicals (Millennium Chemicals Inc., 1997).

India.—The Indian Government approved the construction of a titanium sponge plant in the State of Tamil Nadu. The plant is scheduled for completion in 2000 with a capacity of 1,000 tons per year. India's Department of Atomic Energy and Defense Research and Development will run the facility (Light Metal Age, 1997).

Japan.—According to the Japan Titanium Society, Japan's titanium sponge and ingot production in 1997 were 24,461 tons and 16,630 tons, respectively. Exports of titanium sponge were 13,571 tons, a 28% increase compared with those of 1996. Mill product shipments were 13,286 tons, of which 7,127 tons was exported (Japan Titanium Society, 1998).

Kenya.—Tiomin Resources Inc. announced it had increased its estimate of Kwale ore reserves by 50% to 200 million tons of titanium and zirconium-bearing ore. According to the company, the reserve estimate was based on a 1% total heavy minerals cutoff grade (Tiomin Resources Inc., 1998).

South Africa.—Anglo American Corp. was proceeding with plans to expand its Namakwa Sands operation near Saldanha. The Namakwa expansion will add a second smelting furnace for the production of titanium slag, raising capacity from 97,000 tons per year to 230,000 tons per year. Rutile production also is expected to rise to 40,000 tons per year. The expansion is expected to be completed in 1999 with full production achieved in 2001 (African Mining, 1997).

Iscor Ltd. completed an environmental management report for the proposed KwaZulu-Natal Heavy Minerals Project near Richards Bay. In order for the project to proceed, the report must be approved by the Department of Mineral and Energy Affairs (Iscor Ltd., 1998).

Outlook

Owing to increased demand from titanium pigment producers, mineral concentrate producers are in the process of substantially increasing the supply of high-grade mineral concentrates suitable for use by chloride-route titanium pigment producers. In 1997, several projects were being commissioned to upgrade existing feedstock sources. As a result of the these upgrades, chloridegrade slag is now available from Canada, Norway, and South Africa. Previously, South Africa was the exclusive source of chloride-grade slag. Over the next few years, the development of new projects will substantially increase the availability of titanium concentrates. As it has been the case for several years, the ability of Sierra Leone to resume production of natural rutile remains unclear. Exploration and development activities are ongoing in Australia, Canada, Kenya, Madagascar, Russia, South Africa, Sri Lanka, and the United States. U.S. deposits currently under examination include Camden, TN; Escalante, UT; and Folkston, GA. On a global basis, adequate mineral supplies of TiO_2 exist or are being developed to meet increased demand.

Although flat demand for titanium pigment in 1996 caused many pigment producers to delay expansion projects, strong growth in 1997 has prompted the resumption of many expansion programs. Over the next decade, demand for TiO_2 pigment is forecast to grow at an average rate of 3% per year.

Global demand for titanium metal products is primarily driven by demand from the commercial and military aerospace industries. The recent surge in demand has been primarily the result of increased consumption from commercial aircraft. Demand in this sector is expected to remain high for the short term. However, long-term stable growth for titanium metal is expected to be reliant on growth from nonaerospace markets such as consumer goods, medical, oil and gas, and military armor.

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¹Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1 SALIENT TITANIUM STATISTICS 1/

(Metric tons unless otherwise specified)

	1993	1994	1995	1996	1997
United States:					
Ilmenite and titanium slag:					
Imports for consumption	777,000	808,000	861,000	939,000	952,000
Consumption 2/	1,240,000	W	1,410,000	1,400,000	1,520,000
Rutile concentrate, natural and synthetic:					
Imports for consumption	371,000	332,000	318,000	324,000	336,000
Consumption	465,000	510,000	480,000	398,000	489,000
Sponge metal:					
Production	W	W	W	W	W
Imports for consumption	2,160	6,470	7,560	10,100	16,100
Consumption	15,100	17,200	21,500	28,400	32,000
Price, Dec. 31, per pound	\$3.50-\$4.00	\$3.75-\$4.25	\$4.24-\$4.50	\$4.25-\$4.50	\$4.25-\$4.50
Titanium dioxide pigment:					
Production	1,160,000	1,250,000	1,250,000	1,230,000	1,340,000
Imports for consumption	172,000	176,000	183,000	167,000	194,000
Consumption, apparent 3/	1,030,000	1,090,000	1,080,000	1,070,000	1,130,000
Price, Dec. 31, dollars per pound:					
Anatase	.99	.9496	.9296	1.06-1.08	1.01-1.03
Rutile	.9295	.9294	.99-1.03	1.08-1.10	1.04-1.06
World production:					
Ilmenite concentrate 4/	3,990,000 r/	3,950,000 r/	3,970,000	3,930,000 r/	4,020,000 e/
Rutile concentrate, natural 4/	501,000	546,000	416,000	365,000 r/	415,000 e/
Titaniferous slag	1,550,000	1,510,000	1,810,000	1,830,000 r/	1,840,000 e/

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

1/ Data are rounded to three significant digits; except prices.

2/ Includes consumption to produce synthetic rutile.

3/ Production plus imports minus exports plus stock decrease or minus stock increase.

4/ Excludes U.S. production data to avoid disclosing company proprietary data.

TABLE 2U.S. TITANIUM METAL PRODUCTION CAPACITY IN 1997 1/2/

		Yearend	capacity		
		(metric	(metric tons)		
Company	Plant location	Sponge	Ingot 3/		
Allvac	Monroe, NC		11,800		
Howmet Corp., Titanium Ingot Div.	Whitehall, MI		3,200		
Johnson Matthey Refining Inc.	Salt Lake City, UT	340			
Lawrence Aviation Industries Inc.	Port Jefferson, NY		1,400		
Oregon Metallurgical Corp.	Albany, OR	6,800	10,000		
RMI Titanium Co.	Niles, OH		16,300		
Titanium Hearth Technologies Inc.:	Morgantown, PA		12,200		
	Verdi, NV		2,200		
Titanium Metals Corp. of America:	Henderson, NV	14,500	15,900		
	Pomona, CA		2,200		
Wah Chang	Albany, OR		900		
Wyman-Gordon Co.	Worcester, MA		2,300		
Total		21,600	78,200		

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Operating capacity based on 7-day-per-week full production.

3/ Includes 21,200 tons of cold hearth (electron-beam and plasma) capacity.

TABLE 3 COMPONENTS OF U.S. TITANIUM METAL SUPPLY AND DEMAND 1/

(Metric tons)

Component	1996	1997
Production:	_	
Sponge	W	W
Ingot	51,400	58,800
Mill products		34,300
Exports:		
Sponge	528	976
Other unwrought	471	429
Scrap	3,410	5,500
Ingot, slab, sheet bar, etc.	3,820	4,310
Other articles of titanium	4,540 r/	5,200
Total	12,800	16,400
Imports:		
Sponge	10,100	16,100
Scrap	16,400	10,700
Ingot and billet	2,590	5,410
Other unwrought	240	244
Other wrought (mill products)		4,270
Other articles of titanium	287 r/	323
Total	35,800	37,000
Stocks, yearend:	_	
Government: Sponge (total inventory)	33,200	33,100
Industry:		
Sponge	4,390	7,050
Scrap	15,900	15,200
Ingot	4,710	4,350
Other	W	W
Total industry	25,000	26,600
Reported consumption:		
Sponge	28,400	32,000
Scrap	26,300	26,400
Receipts:		
Home	14,400	15,600
Purchased	24,500	20,300
Ingot	38,300	45,500
Mill products (net shipments):	25,900	28,200
Forging and extrusion billet	11,200	12,600
Rod and bar	3,090 r/	3,390
Other 2/	11,600	12,200
Castings (shipments)	680	1,020

r/Revised. W Withheld to avoid disclosing company proprietary data.

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Data for sheet and strip, plate, extrusions (other than tubing), pipe and tubing, and other have been combined to avoid disclosing company proprietary data.

TABLE 4 CAPACITIES OF U.S. TITANIUM DIOXIDE PIGMENT PLANTS ON DECEMBER 31, 1997 1/

		Ye	Yearend capactiy		
		(met	(metric tons per year)		
		Sulfate	Sulfate Chloride		
Company	Plant location	process	process	Total	
E.I. du Pont de Nemours & Co. Inc.:	Antioch, CA		36,000	36,000	
	De Lisle, MS		280,000	280,000	
	Edgemoor, DE		145,000	145,000	
	New Johnsonville, TN		330,000	330,000	
Kemira, Inc.	Savannah, GA	54,000	91,000	145,000	
Kerr-McGee Chemical Corp.	Hamilton, MS		160,000	160,000	
Louisiana Pigment Co. LP	Lake Charles, LA		110,000	110,000	
Millennium Inorganic Chemicals Inc.:	Ashtabula, OH		190,000	190,000	
	Baltimore, MD	44,000	51,000	95,000	
Total		98,000	1,390,000	1,491,000	

1/ Table does not include Hitox Corp.'s Corpus Christi, TX, production capacity of about 16,400 tons per year of buff TiO2 pigments that is produced by refining and fine grinding of synthetic rutile.

TABLE 5 COMPONENTS OF U.S. TITANIUM DIOXIDE PIGMENT SUPPLY AND DEMAND 1/

(Metric tons unless otherwise specified)

			1996	1997	1
		Gross	TiO2	Gross	TiO2
		weight	content	weight	content
Production 2/		1,230,000	1,160,000	1,340,000	1,260,000
Shipments: 3/					
Quantity		1,330,000	1,250,000	1,360,000	1,270,000
Value ti	housands	\$2,520,000	\$2,520,000	\$2,400,000	\$2,400,000
Exports		332,000	312,000	405,000	381,000 e/
Imports for consumption		167,000	157,000	194,000	183,000 e/
Stocks, yearend		107,000	100,000	118,000	111,000 e/
Consumption, apparent 4/		1,070,000	1,010,000	1,130,000	1,050,000 e/

e/ Estimated.

 $1/\operatorname{Data}$ are rounded to three significant digits.

2/ Excludes production of buff pigment.

3/ Includes interplant transfers.

4/ Production plus imports minus exports plus stock decrease or minus stock increase.

Sources: Bureau of the Census and U.S. Geological Survey.

TABLE 6 U.S. CONSUMPTION OF TITANIUM CONCENTRATES 1/

(Metric tons)

	Ilmenite and titar	nium slag 2/ 3/	(natural and	synthetic)
	Gross	TiO ₂	Gross	TiO2
	weight	content	weight	content
1996:				
Pigments	1,400,000	1,010,000	372,000	341,000
Miscellaneous 4/	(5/)	(5/)	26,400	24,200
Total	1,400,000	1,010,000	398,000	365,000
1997:				
Pigments	1,520,000	1,410,000	459,000	406,000
Miscellaneous 4/	(5/)	(5/)	31,200	27,600
Total	1,520,000	1,410,000	490,000	434,000

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Includes a mixed product containing rutile, leucoxene, and altered ilmenite.

3/ Includes ilmenite consumed to produce synthetic rutile.

4/ Includes alloys, carbide, welding-rod coatings and fluxes, ceramics, chemicals, glass fibers, synthetic rutile, and titanium metal.

5/ Included with "Pigments" to avoid disclosing company proprietary data.

TABLE 7U.S. CONSUMPTION OF TITANIUM PRODUCTS 1/2/IN STEEL AND OTHER ALLOYS

(Metric tons)

	1996	1997
Carbon steel	3,090	3,020
Stainless and heat-resisting steel	1,550	1,510
Other alloy steel (includes HSLA)	690	147
Tool steel	W	W
Total steel	5,330	4,680
Cast irons	W	W
Superalloys	747	798
Alloys, other than above	63	34
Miscellaneous and unspecified	1,170	1,030
Total consumption	7,310	6,540

W Withheld to avoid disclosing company proprietary data; included wit "Miscellaneous and unspecified."

1/ Includes ferrotitanium, titanium scrap, and other titanium additives.

 $2/\operatorname{Data}$ are rounded to three significant digits; may not add to totals shown.

TABLE 8 U.S. DISTRIBUTION OF DOMESTIC TITANIUM PIGMENT SHIPMENTS, TITANIUM DIOXIDE CONTENT, BY INDUSTRY 1/

(Percent)

Industry	1996	1997
Ceramics	W	W
Coated fabrics and textiles	W	W
Floor coverings	0.3	0.9
Paint, varnish, lacquer	48.1	49.8
Paper	W	23.3
Plastics	19.0	18.0
Printing ink	.4	.5
Roofing granules	W	W
Rubber	1.2	1.6
Other 2/	31.0	5.9
Total	100.0	100.0

W Withheld to avoid disclosing company proprietary data; included with

"Other."

1/ Excludes exports.

2/ Includes agricultural, building materials, ceramics, coated fabrics and

textiles, cosmetics, food, and paper. Also includes shipments to distributors.

TABLE 9U.S. STOCKS OF TITANIUM CONCENTRATES AND PIGMENT,
DECEMBER 31 1/

(Metric tons)

	1996		1997	
	Gross	TiO2	Gross	TiO2
	weight	content	weight	content
Concentrates: 2/				
Ilmenite and titanium slag	353,000	267,000	330,000	234,000
Rutile, natural and synthetic	85,100	77,100	64,600	59,100
Titanium pigment 3/	107,000	100,000 e/	118,000	111,000 e/

e/ Estimated.

1/ Data are rounded to three significant digits.

2/ Consumer stocks.

3/ Data from Bureau of the Census. Producer stocks only.

TABLE 10 PUBLISHED PRICES OF TITANIUM CONCENTRATES AND PRODUCTS

		1996	1997
Concentrates:			
Ilmenite, f.o.b. Australian ports	per metric ton	\$82.00-\$92.00	\$68.00-\$81.00
Rutile, bagged, f.o.b. Australian ports	do.	700.00-800.00	650.00-710.00
Rutile, bulk, f.o.b. Australian ports	do.	525.00-600.00	500.00-550.00
Titanium slag, 80% TiO2 Canada 1/	do.	292.00	309.00
Titanium slag, 85% TiO2 South Africa 1/	do.	353.00	391.00
Metal:			
Sponge	per pound	4.25- 4.50	4.25- 4.50
Ferrotitanium	do.	1.68- 1.75	1.98- 2.08
Scrap: Turnings, unprocessed	do.	.8590	.7073
Pigment:			
Titanium dioxide pigment, f.o.b. U.S. plants, anatase	do.	1.06- 1.08	1.01- 1.03
Titanium dioxide pigment, f.o.b. U.S. plants, rutile	do.	1.08- 1.10	1.04- 1.06

1/ Unit value based on U.S. imports for consumption.

Sources: American Metal Market, American Paint and Coatings Journal, Chemical Marketing Reporter, Industrial Minerals (London), Metal Bulletin, Platt's Metals Week, and industry contacts.

	19	996	1997	
	Quantity	Value	Quantity	Value
Class	(metric tons)	(thousands)	(metric tons)	(thousands)
Metal:	i i i i i i i i i i i i i i i i i i i	· · ·	· · ·	i
Sponge	528	\$2,820	976	\$3,980
Scrap	3,410	9,050	5,500	12,900
Other unwrought:				
Billet	489	11,300	666	17,000
Blooms and sheet bars	3,060	59,300	3,030	70,200
Ingot	269	4,520	613	10,800
Other	471	9,140	429	12,700
Wrought:				
Bars and rods	1,400	46,100	1,340	61,000
Other	3,130	157,000	3,860	208,000
Total	12,800	299,000	16,400	396,000
Ores and concentrates	15,500	5,890	23,800	11,400
Pigment and oxides:				
Titanium dioxide pigments	292,000	460,000 r/	362,000	510,000
Titanium oxides	40,600	66,700 r/	42,800	66,500
Total	332.000	526.000 r/	405.000	576,000

TABLE 11 U.S. EXPORTS OF TITANIUM PRODUCTS, BY CLASS 1/

r/ Revised.

 $1/\operatorname{Data}$ are rounded to three significant digits, may not add to totals shown.

Source: Bureau of the Census.

TABLE 12 U.S. IMPORTS FOR CONSUMPTION OF TITANIUM CONCENTRATES, BY COUNTRY 1/

	199	1996		1997	
	Quantity	Value	Quantity	Value	
Concentrate and country	(metric tons)	(thousands)	(metric tons)	(thousands)	
Ilmenite:					
Australia	359,000	\$23,200	438,000	\$31,200	
India	114,000	8,390	56,300	3,850	
Sri Lanka	29,400	1,870			
Ukraine	15,800	1,180	27,100	2,200	
Total	518,000	34,600	522,000	37,200	
Titanium slag:					
Canada	11,500	3,370	49,700	15,400	
South Africa	410,000	146,000	380,000	153,000	
Other	2	1	41	34	
Total	421,000	149,000	430,000	168,000	
Rutile, natural:					
Australia	46,000	18,700	48,600	23,400	
South Africa	135,000	52,100	134,000	56,100	
Other	1,180	961	72	173	
Total	182,000	71,800	183,000	79,600	
Rutile, synthetic:					
Australia	108,000	41,200	141,000	56,700	
Canada	26,300 r/	1,190 r/			
Malaysia	6,850	3,850	6,920	4,080	
Ukraine			5,080	4,220	
Other	806 r/	443 r/	1	11	
Total	142,000	46,700	153,000	65,000	
Titaniferous iron ore: 2/					
Canada	90,200	7,920	43,900	7,960	

r/ Revised.

 $1/\operatorname{Data}$ are rounded to three significant digits; may not add to totals shown.

2/ Includes materials consumed for purposes other than production of titanium commodities, principally heavy aggregated and steel-furnace flux.

Source: Bureau of the Census. Data adjusted by the U.S. Geological Survey.

TABLE 13

U.S. IMPORTS FOR CONSUMPTION OF TITANIUM METAL, BY CLASS AND COUNTRY 1/

	1996		1997	
	Quantity	Value	Quantity	Value
Class and country	(metric tons)	(thousands)	(metric tons)	(thousands)
Unwrought:				
Sponge:				
China	833	\$5,790	413	\$3,200
Japan	4,400	36,000	6,370	56,900
Kazakstan	920	5,560	1,150	7,930
Russia	3,570	21,200	7,650	49,400
United Kingdom	71	502	507	3,890
Other	307 r/	1,810 r/	51	364
Total	10,100	70,800	16,100	122,000
Waste and scrap:				
Canada	408	1,400	262	640
France	847	4,650	1,160	6,130
Germany	559	3,000	478	2,590
Japan	2,620	11,600	1,970	7,340
Russia	5,490	32,000	1,920	10,900
United Kingdom	3,770	18,400	2,560	12,600
Other	2,680	11,000	2,560	9,440
Total	16,400	82,100	10,700	49,100
Ingot and billets:				
Russia	1,550	17,200	3,890	69,700
United Kingdom	635	9,910	1,070	16,200
Other	409	7,750	457	5,570
Total	2,590	34,800	5,410	91,500
Powder	240	3,180	244	2,840
Other: 2/				
Russia	222 r/	3,370	35	329
Other	65 r/	764 r/	81	1,010
Total	287 r/	4,130 r/	116	1,340
Wrought products and castings: 3/				
Japan	306	13,900	500	17,900
Russia	4,790 r/	51,200	3,400	36,000
United Kingdom	564	14,900	383	13,500
Other	546 r/	15,300	344	13,000
Total	6.210 r/	95,300	4.630	80,400

r/ Revised.

 $1/\operatorname{Data}$ are rounded to three significant digits; may not add to totals shown.

2/ Includes blooms, sheet, bars, slabs, and other unwrought.

3/ Includes bars, castings, foil, pipes, plates, profiles, rods, sheet, strip, tubes, wire, and other.

Source: Bureau of the Census.

TABLE 14 U.S. IMPORTS FOR CONSUMPTION OF TITANIUM PIGMENTS, BY COUNTRY 1/

	1996		1997	
	Quantity	Value	Quantity	Value
Country	(metric tons)	(thousands)	(metric tons)	(thousands)
80% or more titanium dioxide:				
Australia			3,710	\$5,700
Belgium	1,020	\$1,640	1,320	1,950
Canada	64,900	103,000	74,200	116,000
China	771	961	2,100	2,530
Finland	966	1,970	731	1,500
France	2,830	4,920	2,740	5,170
Germany	14,500	34,000	26,400	50,200
Japan	4,210	10,600	7,190	15,500
Norway	5,410	8,540	6,220	9,050
Poland	940	1,640	1,190	1,760
Singapore	4,340	6,990	3,300	5,110
Slovenia	1,450	2,310	2,340	3,670
United Kingdom	202	369	263	469
Other	2,620 r/	4,100 r/	1,910	3,020
Total	104,000	181,000	134,000	221,000
Other titanium dioxide:				
Canada	989	1,970	2,090	3,460
France	9,780	12,900	6,800	10,600
Germany	1,330	10,100	1,070	10,600
Italy	1,860	3,260	2,090	3,870
South Africa	5,790	7,900	7,550	10,800
Spain	13,900	18,000	14,000	22,300
United Kingdom	3,540	7,120	3,020	7,360
Other	2,240 r/	4,490 r/	2,670	8,130
Total	39,400	65,700	39,300	77,000
Titanium oxide:	-			
Belgium	2,290	3,470	2,190	3,300
Canada	2,930	4,920	84	142
China	1,370	1,510	1,530	1,580
Czech Republic	929	1,510	1,560	2,400
France	5,230	7,520	10,200	13,100
Germany	8,230	15,100	2,560	4,680
Other	2,520 r/	9,190 r/	3,190	10,700
Total	23,500	43,200	21,400	35,900
Grand total	167,000	290,000	194,000	334,000

r/ Revised.

 $1/\operatorname{Data}$ are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 15 TITANIUM: WORLD PRODUCTION OF CONCENTRATES (ILMENITE, LEUCOXENE, RUTILE AND TITANIFEROUS SLAG), BY COUNTRY 1/ 2/

(Metric tons)

Concentrate type and country	1993	1994	1995	1996	1997 e/
Ilmenite and leucoxene: 3/					
Australia:					
Ilmenite	1,804,000	1,782,000	1,980,000	2,028,000	2,233,000 4/
Leucoxene	21,000	35,000	31,000	33,000 r/	32,000 4/
Brazil 5/	90,567	97,439	102,125	97,955 r/	98,000
China e/	155,000	155,000	160,000	165,000	170,000
India e/	320,000	300,000	300,000	300,000	300,000
Malaysia	278,950 r/	116,696 r/	151,680	244,642	167,504 4/
Norway	713,000	826,391 r/	833,238 r/	746,583 r/	750,000
Portugal e/	25	20			
Sierra Leone	62,900	47,400	e/	e/	
Sri Lanka	76,930	60,445	49,655	62,810	18,970 4/
Thailand	20,821	1,677	33		
Ukraine	450,000 e/	530,000	359,000	250,000 r/ e/	250,000
United States	W	W	W	W	W
Total	3,990,000 r/	3,950,000	3,970,000	3,930,000 r/	4,020,000
Rutile:					
Australia	186,000	233,000	195,000	180,000	235,000 4/
Brazil	1,744	1,911	1,985	2,018 r/	2,020
India e/	13,900	14,000	14,000	14,000	15,500
Sierra Leone	152,000	137,000	e/	e/	
South Africa e/	85,000	78,000	90,000	115,000	110,000
Sri Lanka	2,643	2,410	2,697	3,532	2,970 4/
Thailand	87	49			
Ukraine	60,000 e/	80,000	112,000	50,000 r/ e/	50,000
United States	W	W	W	W	W
Total	501,000	546,000	416,000	365,000 r/	415,000
Titaniferous slag: 6/					
Canada 7/	653,000	764,000	815,000 e/	825,000 r/ e/	850,000
South Africa e/ 8/ 9/	892,000 4/	744,000	990,000	1,000,000 r/	990,000
Total	1,550,000	1,510,000	1,810,000	1,830,000 r/	1,840,000

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

1/World totals and estimated data are rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through August 5, 1998.

3/ Ilmenite is also produced in Canada and South Africa, but this output is not included here because an estimated 90% of it is duplicative of output reported under "Titaniferous slag," and the rest is used for purposes other than production of titanium commodities, principally steel furnace flux and heavy aggregate.

4/ Reported figure.

5/ Excludes production of unbeneficiated anatase ore.

6/ Slag is also produced in Norway but is not included under "Titaniferous slag" to avoid duplicative reporting. Beginning in 1990, about 25% of Norway's ilmenite production was used to produce slag containing 75% TiO2.

7/ TiO2 content in 1993-97 is not reported.

8/ Contains 85% TiO2.

9/ Excludes 42,000 to 48,000 metric tons of titanium slag from Highveld Steel.