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2005 Minerals Yearbook

RARE EARTHS

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RARE EARTHS

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In 2005, world rare-earth production was primarily from the mineral bastnäsite. Rare earths were not mined in the United States in 2005; however, the mine and plant at Mountain Pass, CA, was kept on care-and-maintenance status. Rare-earth ores were primarily supplied by China, with lesser amounts mined in Brazil, India, and Russia. Domestic stocks of previously produced bastnäsite concentrates, intermediate rare-earth concentrates, and separated products were available for purchase from Molycorp, Inc. at Mountain Pass. Consumption was estimated to have decreased as did imports of individual rare-earth compounds and mixed rare-earth compounds. U.S. imports of cerium compounds, ferrocerium and pyrophoric compounds, rare-earth chlorides, rare-earth metals and alloys, and yttrium compounds increased.

Domestic use of scandium increased slightly in 2005. Overall consumption of the commodity remained small. Demand was primarily for aluminum alloys used in baseball and softball bats. Scandium alloys, compounds, and metals were used in analytical standards, metallurgical research, and sports equipment. Minor amounts of high-purity scandium were used in semiconductors and specialty lighting.

Yttrium consumption decreased by about 6% in 2005 compared with that of 2004, according to data from the Port Import Export Reporting Service (PIERS) database of Commonwealth Business Media, Inc. (undated §[1]). Yttrium was used primarily in lamp and cathode-ray tube phosphors; lesser amounts were used in structural ceramics and oxygen sensors.

The rare earths are a moderately abundant group of 17 elements comprising the 15 lanthanides, scandium, and yttrium. The elements range in crustal abundance from cerium, the 25th most abundant element of the 78 common elements in the Earth's crust at 60 parts per million (ppm), to thulium and lutetium, the least abundant rare-earth elements at about 0.5 ppm (Mason and Moore, 1982, p. 46). In rock-forming minerals, rare earths typically occur in compounds as trivalent cations in carbonates, oxides, phosphates, and silicates.

The lanthanides comprise a group of 15 elements with atomic numbers 57 through 71 that include the following in order of atomic number: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Cerium, which is more abundant than copper (whose average concentration in the Earth's crust is 50 ppm), is the most abundant member of the group at 60 ppm, followed, in decreasing order, by yttrium at 33 ppm, lanthanum at 30 ppm, and neodymium at 28 ppm. Thulium and lutetium, the least abundant of the lanthanides at 0.5 ppm, occur in the Earth's crust in higher concentrations than antimony, bismuth, cadmium, and thallium.

Scandium, whose atomic number is 21, is the lightest rare-earth element. It is the 31st most abundant element in the Earth's crust, with an average crustal abundance of 22 ppm. Scandium is a soft, lightweight, silvery-white metal, similar in appearance and weight to aluminum. It is represented by the chemical symbol Sc and has one naturally occurring isotope. Although its occurrence in crustal rocks is greater than lead, mercury, and the precious metals, scandium rarely occurs in concentrated quantities because it does not selectively combine with the common ore-forming anions.

Yttrium, whose atomic number is 39, is chemically similar to the lanthanides and often occurs in the same minerals as a result of its similar ionic radius. It is represented by the chemical symbol Y and has one naturally occurring isotope. Yttrium's average concentration in the Earth's crust is 33 ppm and is the second most abundant rare earth in the Earth's crust. Yttrium is a bright silvery metal that is soft and malleable, similar in density to titanium.

The elemental forms of rare earths are iron gray to silvery lustrous metals that are typically soft, malleable, ductile, and usually reactive, especially at elevated temperatures or when finely divided. Melting points range from 798° C for cerium to 1,663° C for lutetium. The unique properties of rare earths are used in a wide variety of applications. The principal economic rare-earth ores are the minerals bastnäsite, loparite, and monazite and lateritic ion-adsorption clays (table 2).

Production

In 2005, Molycorp, Inc. (a wholly owned subsidiary of Unocal Corporation), remained open on a care-and-maintenance basis and sold from its stockpile of bastnäsite concentrates, intermediate concentrates, and separated compounds previously processed at its open pit operations at Mountain Pass. On August 10, Unocal Corporation (Molycorp's parent company) merged with Chevron Corporation. The merger created the world's fourth largest publicly traded energy company (Unocal Corporation, 2005).

Although Molycorp was not actively mining rare earths, the sales operation remained open, and several lanthanide products were packaged, sold, and shipped. Substantial stocks of lanthanide concentrates and intermediate and refined compounds were available. Lanthanide products available in 2005 from Molycorp were bastnäsite concentrate, cerium nitrate, lanthanum chloride, lanthanum hydrate, lanthanum-rich nitrate, and the oxides of cerium, erbium, europium, gadolinium, praseodymium, samarium, and yttrium.

Three companies processed intermediate rare-earth compounds to lanthanides in 2005. Grace Davison (a subsidiary of W.R. Grace & Co.) processed intermediate rare-earth compounds to produce cerium- and lanthanum-rich compounds used in making fluid-cracking catalysts for the petroleum industry and processed cerium and zirconia compounds

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

for automotive catalysts and catalyst supports. W.R. Grace announced an 8% increase in the prices of its fluid cracking catalysts and fluid cracking catalyst additives in January. The increase was required to keep pace with increased fuel and material costs (W.R. Grace & Co., 2005). At yearend 2005, Grace reported increased sales revenues based on increased demand for fluid cracking catalysts, especially those used to produce clean fuels (W.R. Grace & Co., 2006).

Santoku America, Inc. (a subsidiary of Santoku Corporation of Japan) produced rare-earth magnet and rechargeable battery alloys at its operations in Tolleson, AZ. Santoku America produced both types of high-strength permanent magnets, namely neodymium-iron-boron (NIB) and samarium-cobalt magnets. For the rechargeable battery industry, Santoku produced nickel-metal hydride (NiMH) alloys that incorporate specialty rare-earth mischmetals. The plant also produced a full range of high-purity rare-earth metals in cast and distilled forms, foils, and sputtering targets, including scandium and yttrium. The principal domestic producer of NIB magnet alloys was Santuko America. Leading U.S. producers of rare-earth magnets were Electron Energy Corporation, Landisville, PA; Hitachi Metals North Carolina, China Grove, NC; and VAC Magnetics Corporation [a subsidiary of Vacuumschmelze GMBH & Co. KG (a division of Morgan Crucible Company plc.)], Elizabethtown, KY. Hitachi Magnetics, closed its rare-earth magnet plant in Edmore, MI, in 2005 as a result of low-cost production from China (Associated Press, 2005§). Demand for rare earths used in NiMH batteries increased in 2005 as did overall demand for rechargeable batteries. Rechargeable batteries are used in camcorders, cellular telephones, PDAs, portable computers, and other portable devices. The principal world markets for rechargeable batteries are laptop computers and cellular telephones.

Santoku (33%) continued its joint venture Anan Kasei Ltd. with Rhodia Electronics and Catalysis, Inc. (67%). The joint-venture operations, located in Anan, Japan, produced ceramic capacitors; ferrites; fuel additive emission-reduction catalysts; microwave filters; phosphors used in CRTs, lamps, and PDP television; polishing compounds for electronic components, hard disks, lenses, mirrors, ophthalmic glass, and semiconductors; rare-earth-base nontoxic colorants and coatings for plastics; and three-way catalytic converter catalysts (Rhodia Japan—Anan Kasei Ltd., undated §).

On Septermber 9, Rhodia announced it would release its third generation of rare-earth-based additives for regeneration of diesel particulate filters (DPF). The enhanced EOLYS™ G3 fuel additive catalyst for diesel engines facilitates the regeneration of DPF with improved durability, faster regeneration, and a lower volume of additive (Rhodia Electronics and Catalysis Inc., 2005§). Rhodia also produced rare-earth-containing catalysts for automotive emission applications for gasoline engines. Rhodia's other operations produced finished rare-earth products from imported materials at its plant in Freeport, TX, and produced high-purity rare earths at its separation plant in La Rochelle, France. Additional rare-earth capacity was operated through Anan Kasei in Kobe, Japan. In 2005, Rhodia reported sales by market segment to be 56% electronics, 37% catalysis, and 7% new markets.

Two scandium processors operated in 2005. High-purity products were available in various grades, with scandium oxide having up to 99.999% purity. Boulder Scientific Co. processed scandium at its Mead, CO, operations. It refined scandium primarily from imported oxides to produce high-purity scandium compounds, including carbide, chloride, diboride, fluoride, hydride, nitride, oxalate, and tungstate.

Scandium also was purified and processed from imported oxides at Aldrich-APL, LLC in Urbana, IL, to produce high-purity scandium compounds, including anhydrous and hydrous chloride, fluoride, iodide, and oxide. The company also produced high-purity scandium metal.

All commercially produced purified yttrium was derived from imported compounds. The principal source was China.

Consumption

Data on domestic rare-earth consumption were developed by surveying various processors and manufacturers, evaluating import and export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths decreased in 2005 compared with that of 2004.

In 2005, yttrium consumption was estimated to have decreased to 582 t from 619 t in 2004. Yttrium information was based on data retrieved from the PIERS database. Yttrium compounds and metal were imported from several sources in 2005. Yttrium compounds and metal were imported from China (90.7%), Japan (3.39%), Belgium (3.37%), Austria (1.66%), and Hong Kong (0.88%). The estimated use of yttrium, based on imports, was primarily in lamp and cathode-ray tube phosphors, ceramics, and electronics (94.0%), and in specialty alloys (6.0%) (Commonwealth Business Media, Inc., undated §).

Stocks

All U.S. Government stocks of rare earths in the National Defense Stockpile (NDS) were shipped in 1998. Periodic assessments of the national defense material requirements may necessitate the inclusion of rare earths, including scandium and yttrium, in the NDS at a future date.

Prices

The prices of rare-earth materials either increased or were essentially unchanged in 2005 compared with those of 2004. The following estimates of prices were based on trade data from various sources or were quoted by rare-earth producers. All rare-earth prices remained nominal and subject to change without notice. The competitive pricing policies in effect in the industry caused most rare-earth product prices to be quoted on a daily basis from the producers and processors. The average price of imported rare-earth chloride was $2.37 per kilogram in 2005, a decrease from $2.41 per kilogram in 2004. Imported rare-earth metal prices averaged $6.68 per kilogram, an increase from $5.22 per kilogram in 2004. Mischmetal and specialty mischmetals composed most of the rare-earth metal imports. (Mischmetal is a natural mixture of rare-earth metals typically produced by metallothermic reduction of a mixed rare-earth chloride.) The price of basic mischmetal ranged from $2.88 to $3.75 per kilogram, and battery-grade mischmetal, from $4.26 to $5.01 per kilogram (metric ton quantities) in 2005, free on board (f.o.b.), China port (China Rare Earth Information, 2005). The domestic price of mischmetal at $10.00 per kilogram (metric ton quantities) was higher than the Chinese price because of shipping costs related to its classification as a hazardous material since it is pyrophoric. The average price for imported cerium compounds, excluding cerium chloride, decreased to $3.27 per kilogram in 2005 from $4.67 per kilogram in 2004. The primary cerium compound imported was cerium carbonate.

The 2005 nominal price for bastnäsite concentrate was $5.51 per kilogram of contained lanthanide oxide ($2.50 per pound of contained lanthanide oxide). The price of monazite concentrate, typically sold with a minimum 55% rare-earth oxide (REO) content, including contained thorium oxide, f.o.b., as quoted in U.S. dollars and based on the last U.S. import data, was unchanged at $400.00 per metric ton ($0.73 per kilogram of contained rare-earth oxide). In 2005, no monazite was imported into the United States. Prices for monazite remained depressed because the principal international rare-earth processors continued to process only thorium-free feed materials.

The nominal price range for basic neodymium metal for metric ton quantities decreased slightly to $11.89 to $13.14 per kilogram, f.o.b. shipping point (China Rare Earth Information, 2005). Most NIB alloy was sold with additions of cobalt (typically 4% to 6%) or dysprosium (no more than 4%). The cost of the additions was based on pricing before shipping and alloying fees; with the average cobalt price increasing to $35.19 per kilogram in 2005, the cost would be about $0.35 per kilogram for each percentage point addition. The price of dysprosium metal was about $59.54 per kilogram, which would cost about $0.60 per kilogram for each percentage point addition.

Rhodia's quoted rare earth prices net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 2005, are listed in table 3. No published prices for scandium oxide in kilogram quantities were available. Yearend 2005 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices for 2005 were essentially unchanged from those of 2004. The 2005 prices were as follows: 99% purity, $500 per kilogram; 99.9% purity, $1,300 per kilogram; 99.99% purity, $2,500 per kilogram; and 99.999% purity, $3,000 per kilogram.

Scandium metal prices for 2005 increased from those of 2004 and were as follows: 99.9% REO purity, metal pieces, distilled dendritic, ampouled under argon, $303 per 2 grams; 99.9% purity, metal ingot, $124 per gram; scandium rod, 12.7-millimeter (mm) diameter, 99.9% (metals basis excluding tantalum), $497 per 10 millimeters; and 99.9% REO purity foil, 0.025-mm thick, ampouled under argon, 25 x 25 mm, $141 per sheet (Alfa Aesar, undated §).

Scandium compound prices increased from 2004 and were as follows: scandium acetate hydrate 99.9% purity, $70.30 per gram; scandium chloride hydrate 99.99% purity, $92.80 per gram; scandium nitrate hydrate 99.9% purity, $111.50 per gram; and scandium sulfate pentahydrate 99.9% purity, $72.50 per gram. Prices for standard solutions for calibrating analytical equipment were $27.00 per 100 milliliters of scandium atomic absorption standard solution (Aldrich Chemical Co., 2005, p. 2083-2084).

Prices for kilogram quantities of scandium metal in ingot form have historically averaged about twice the cost of scandium oxide, and higher purity distilled scandium metal prices have averaged about five times that cost.

Foreign Trade

U.S. exports and imports decreased in quantity in 2005 compared with those of 2004. Data in this section are based on gross weight, while data in the tables may be converted to equivalent REO content, as specified. U.S. exports totaled 9,680 metric tons (t) valued at $50.9 million, a 20% decrease in quantity and a 6.6% decrease in value compared with those of 2004 (table 4). Imports totaled 22,300 t gross weight valued at $101 million, a 5.0% decease in quantity but a 2.9% increase in value compared with those of 2004 (table 5).

In 2005, U.S. exports of rare earths decreased in quantity in three out of four trade categories. Principal destinations in 2005, in descending order, were Germany, Canada, Estonia, and Japan. The United States exported 530 t of rare-earth metals valued at $5.18 million, a 37% decrease in quantity and a 14.3% decrease in value compared with that of 2004. Principal destinations of the rare-earth metals, in descending order by quantity, were Japan, China, Indonesia, and Germany. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, decreased by 2.7% to 2,220 t valued at $13.6 million. Major destinations, in descending order of quantity, were India, Egypt, the Republic of Korea, and Japan.

Exports of inorganic and organic rare-earth compounds decreased by 56.9% to 2,070 t in 2005 from 4,800 t in 2004, and the value of the shipments decreased by 25.4% to $14.1 million. Shipments, in descending order of quantity, were to Estonia, China, Canada, and the United Kingdom.

U.S. exports of ferrocerium and other pyrophoric alloys increased to 4,860 t valued at $18.0 million in 2005 from 4,190 t valued at $16.8 million in 2004. Principal destinations, in descending order of quantity, were Germany, Canada, the Netherlands, Saudi Arabia, the United Kingdom, and the United Arab Emirates.

In 2005, U.S. imports of compounds and alloys decreased in quantity for two out of the seven categories and are listed in table 5. China dominated the import market, especially for mixed and individual rare-earth compounds, followed by France, Japan, Russia, and Estonia (fig. 1). These five countries accounted for 95.3% of the domestic imports.

Imports of cerium compounds totaled 3,249 t valued at $10.6 million. The quantity of cerium compounds imported increased by 15.4% as a result of increased demand for automotive exhaust catalysts and the value declined by 19.3%. China was the major supplier for the 11th consecutive year, followed by Japan, France, and Hong Kong.

Imports of yttrium compounds that contained between 19 and 85 weight-percent yttrium (yttrium concentrate) increased by 64.5% to 372 t in 2005, but the value decreased by 0.84% to $3.48 million. China was the leading supplier of yttrium compounds, followed by Japan and France.

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, decreased by 24.8% compared with those of 2004. Rare-earth compound imports decreased to 11,400 t valued at $59.6 million. The major sources of individual rare-earth compounds, in decreasing order by quantity, were China, Japan, France, Russia, and the United Kingdom.

Imports of mixtures of rare-earth oxides, other than cerium oxide, decreased in quantity by 61.5% to 640 t valued at $6.3

million. The principal source of the mixed rare-earth oxides was China, with much smaller quantities imported from Italy, the United Kingdom, Austria, and Japan.

Imports of rare-earth metals and alloys into the United States totaled 733 t valued at $4.90 million in 2005, a 9.4% increase in quantity compared with 2004. The principal rare-earth metal source was China, with much smaller amounts from Japan and Austria.

In 2005, imports of rare-earth chlorides increased by 104% to 5,810 t valued at $13.8 million. Supplies of rare-earth chloride, in descending order by quantity, came from China, with minor amounts from Japan, the United Kingdom, and Belgium. In the United States, rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts.

Imports of ferrocerium and pyrophoric alloys increased to 147 t valued at $2.05 million from 118 t valued at $1.77 million in 2004. Principal sources of these alloys, in descending order by quantity, were France, Austria, and China.

World Review

Australia.—Lynas Corporation Ltd. announced that it had completed its feasibility study on its Mount Weld rare-earth deposit in Western Australia (Lynas Corporation Ltd., 2005b). A pilot plant was completed and achieved a 63% recovery of REO from the ore, producing a 40% REO concentrate. Lynas planned to truck the concentrate from Mount Weld, near Laverton, to the port of Esperance. The concentrate is anticipated to be shipped from Esperance, Western Australia, to Shandong Province, China, for processing. The mining plan for Mount Weld is to recover 121,000 metric tons per year (t/yr) of ore, grading 14.8% REO, by open pit methods followed by flotation processing to produce 31,500 t/yr of a 40% REO concentrate. The concentrate is designed to be acid leached to produce several intermediate rare-earth products, including a cerium chloride, lanthanum-praseodymium-neodymium chloride, samarium-europium-gadolinium mixed oxide, and a mixed heavy rare-earth oxide containing terbium and dysprosium (Lynas Corporation Ltd., 2005b). Reserves at Mount Weld are 6.2 Mt grading 12.4% REO for a total content of 769,000 t of REO. Inferred resources are an additional 1.5 Mt grading 9.9% REO (Lynas Corporation Ltd., 2005a).

In addition to the rare-earth deposit, a separate group of rare-metal ore bodies in the north and northeast region of the Mount Weld carbonatite contain additional mineral resources. The rare-metal sectors contain resources of 1.5 Mt of titanium oxide, 470,000 t of REO, 400,000 t of niobium oxide, 110,000 t of zirconium oxide, and 9,070 t of tantalum oxide. The Mount Weld rare-metals deposit would be ranked as the second largest niobium deposit in the world behind the niobium deposit at Araxa, Brazil (Lynas Corporation Ltd., 2005a).

Lynas, which had announced the purchase of 19.92% of AMR Technologies Inc. in 2004, dropped its takeover strategy in 2005 and sold its holdings (Lynas Corporation Ltd., 2005a). AMR is a Canadian company based in Toronto, Ontario, that operated two rare-earth plants in China and a rare-earth bonded magnetic powder plant in Thailand.

Australia remained one of the world's major potential sources of rare-earth elements from its alkaline intrusive deposit, heavy-mineral sands deposits, and rare-earth lateritic deposits. Monazite is a constituent in essentially all of Australia's heavy-mineral sands deposits. It is normally recovered and separated during processing but, in most cases, is either returned to tailings because of a lack of demand or stored for future sale.

Alkane Exploration Ltd. announced that measured resources at its Dubbo zirconia project in New South Wales were 35.7 Mt of ore grading 1.96% zirconia, 0.75% REO (excluding yttria), 0.46% columbium (niobium) pentoxide, 0.14% yttria, 0.04% hafnia, and 0.03% tantalum trioxide. Inferred resources were an additional 37.5 Mt. Planned capacity of the Dubbo operation was 200,000 t/yr of ore, producing 3,000 t/yr of zirconia equivalent, 600 t/yr of columbium (niobium) and tantalum concentrate, and 1,200 t/yr of REO (yttria and lanthanide oxides). A decision on development of the Dubbo zirconia project was expected by 2006 (Alkane Exploration Ltd., 2005§).

Brazil.—Reserves of rare earths were 44,000 t contained in various types of deposits, including alkaline intrusives, carbonatites, fluvial or stream placers, lateritic ores, and marine placers. The reserves, comprising measured and indicated quantities of monazite, were distributed in deposits primarily in the States of Minas Gerais (11,730 t), Bahia (5,949 t), Espirito Santo (2,527 t), and Rio de Janeiro (2,454 t) (Anuario Mineral Brasil, 2006). Brazil produced 731 t of monazite in 2004, the latest date for which Government data were available (Fabricio da Silva, 2006).

China.—Production of rare-earth concentrates in China was a record high 118,709 t of REOs in 2005, an increase from the 98,310 t in 2004 (table 6). China consumed 51,900 t of equivalent REO in a variety of applications.

Production of rare-earth magnets reached 35,200 t of which 33,000 t was sintered NIBs, 1,800 t bonded NIBs, and 400 t samarium-cobalt magnets (China Rare Earth Information, 2006a).

China produced 6,000 t of cerium polishing compounds in 2005, an increase from the 5,500 t produced in 2004. The principal applications were in polishing cathode ray tubes (CRTs) and liquid crystal displays (LCDs). Lesser amounts were used in artware and glass, optical components, and miscellaneous applications.

Rare-earth phosphor consumption in color CRTs for television and computer monitors was 1,650 t; long afterglow phosphor materials, 1,500 t; and trichromatic fluorescent lamps, 2,500 t (China Rare Earth Information, 2006b). About 5,500 t of rare-earth catalysts was used in fluid cracking catalysts by the Chinese oil industry. In China, automotive catalytic converters consumed 2,050 t of rare earths for use in 8.4 million units.

China produced 13,000 t of rare-earth hydrogen storage alloys for NiMH batteries and used 4,333 t of REO. The NiMH alloy was used in the production of 8 billion to 9 billion units (China Rare Earth Information, 2006b).

Japan.—Rare earths were produced from imported ores and intermediate raw materials. Imports of refined rare-earth products were 31,106 t, an increase from the revised 26,758 t imported in 2004. The value of imports increased to ¥24.422 billion in 2005 from a revised ¥20.774 billion in 2004. Japanese imports of refined rare-earth products increased for cerium oxide, cerium compounds, rare-earth metals, and ferrocerium and decreased for all other categories.

Production of Japanese rare-earth-bonded magnets in 2005 was estimated to be 530 t, a decrease from the 600 t in 2004

(Roskill's Letter from Japan, 2006b). Lower production of rare-earth-bonded magnets in 2005 was reportedly the result of an overall size reduction of spindle motors used in computer hard disk drives. Japanese production of NIB magnets in 2004, the latest available data, was 6,700 t, an increase from the 6,200 t produced in 2003. Magnet production consumed an estimated 4,200 t of neodymium metal and 420 t of dysprosium metal (Roskill's Letter from Japan, 2006d). China, however, was the world's principal producer of NIB magnets in 2005 with 27,510 t (Roskill's Letter from Japan, 2006c)

Japan also produced an estimated 8,500 t of rare-earth-sintered magnets in 2005, an increase from the 7,900 t produced in 2004 (Roskill's Letter from Japan, 2006d).

Japanese imports of rare earths from China were as follows: rare-earth metals, 8,385 t; cerium compounds (other than oxide), 5,317 t; cerium oxide, 5,206 t; rare-earth compounds, 5,140 t; lanthanum oxide, 1,758 t; yttrium oxide, 1,211 t; and ferrocerium, 262 t (Roskill's Letter from Japan, 2006d). China continued to be the leading source of rare-earth imports for Japan with 27,279 t in 2005, an increase from the revised 24,169 t imported in 2004.

Japanese imports of rare-earth refined products in 2005 were 31,106 t classified as follows: rare-earth metals, 8,387 t; cerium compounds (other than cerium oxide), 7,216 t; cerium oxide, 6,147 t; rare-earth compounds, 5,738 t; lanthanum oxide, 1,801 t; yttrium oxide, 1,226 t; and ferrocerium, 592 t (Roskill's Letter from Japan, 2006d).

Japan, the leading producer of rechargeable batteries in the world, produced 321 million units of rare-earth-containing NiMH batteries in 2005, a slight increase from the 319 million units produced in 2004 (Roskill's Letter from Japan, 2006a).

Current Research and Technology

Electron Energy Corporation announced that it had produced a short video featuring production of ultra-high-temperature samarium-cobalt magnets. The rare-earth permanent magnet is stable to 550° C and can operate continuously. Samarium-cobalt magnets are used in aerospace, electronics, instrumentation, medical, military, and motion control applications (Electron Energy Corporation, 2005§).

Outlook

Rare-earth use in automotive pollution control catalysts, permanent magnets, and rechargeable batteries are expected to continue to increase as future demand for conventional and hybrid automobiles, computers, electronics, and portable equipment grows. Rare-earth markets are expected to require greater amounts of higher purity mixed and separated products to meet the demand. Strong demand for cerium and neodymium for use in automotive catalytic converters and permanent magnets is expected to continue through 2010. Future growth is expected for rare earths in rechargeable NiMH batteries, especially those used in hybrid vehicles. NiMH demand is expected to increase (moderated by demand for lithium ion batteries) for use in portable equipment such as cell phones, laptop computers, portable DVD, CD, and MP3 players, and digital cameras and camcorders. Increased rare-earth use is expected in fiber optics, medical applications that include dental and surgical lasers, magnetic resonance imaging, medical contrast agents, medical isotopes, and positron emission tomography scintillation detectors. Future growth potential is projected for rare-earth alloys employed in magnetic refrigeration.

World reserves are sufficient to meet forecast world demand well into the 21st century. Several very large rare-earth deposits in Australia and China (for example Mianning in China and Mount Weld in Australia) have yet to be fully developed because world demand is currently being satisfied by existing production. Additionally, the Mountain Pass deposit in the United States contains sufficient resources to meet domestic demand if the foreign supply is compromised.

Domestic companies have shifted away from using naturally occurring radioactive rare-earth ores. This trend has resulted in ceased production and a loss of revenues for monazite-containing mineral sands operations worldwide. Long-term demand for monazite, however, is expected to increase because of its abundant supply and its recovery as a low-cost byproduct. Thorium's use as a nonproliferative nuclear fuel is considered a likely replacement for uranium in the future, especially in a world concerned with the threat of terrorism. As consumption of thorium increases, monazite could resume its role as a major source of rare earths. The cost and space requirements to dispose of radioactive waste products in the United States are expected to continue to increase, severely limiting domestic use of low-cost monazite and other thorium-bearing rare-earth ores.

Rare-earth producers outside of China, producing less than 5% of the world's supply, are expected to continue to struggle in competition with China's lower wages, inexpensive utilities, and fewer environmental and permitting requirements. China is expected to remain the world's principal rare-earth supplier. Economic growth in several developing countries will provide new and potentially large markets in India, Southeast Asia, and Eastern Europe.

The long-term outlook is for an increasingly competitive and diverse group of rare-earth suppliers. As research and technology continue to advance the knowledge of rare earths and their interactions with other elements, the economic base of the rare-earth industry is expected to continue to grow. New applications are expected to continue to be discovered and developed, especially in areas that are considered essential, such as energy and defense.

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TABLE 1
SALIENT U.S. RARE EARTH STATISTICS[1]

		2001	2002	2003	2004	2005
Production of rare-earth concentrates, rare-earth oxide (REO) basis[e, 2]	metric tons	W	W	--	--	--
Exports, REO basis:						
Cerium compounds	do.	4,120	2,740	1,910	2,280	2,220
Rare-earth metals, scandium, yttrium	do.	884	1,300	730	1,010	636
Rare-earth compounds, organic or inorganic	do.	1,600	1,340	1,790	4,800	2,070
Ferrocerium and pyrophoric alloys	do.	2,500	2,830	2,880	3,720	4,320
Imports for consumption, REO basis:[e]						
Cerium compounds	do.	3,850	2,540	2,430	1,880	2,170
Ferrocerium and pyrophoric alloys	do.	118	89	102	105	130
Metals, alloys, oxides, other compounds	do.	15,300	11,600	14,100	15,300	13,000
Prices, yearend:						
Bastnäsite concentrate, REO basis[e]	dollars per kilogram	$5.51	$5.51	$5.51	$5.51	$5.51
Monazite concentrate, REO basis[e]	do.	$0.73	$0.73	$0.73	$0.73	$0.73
Mischmetal, metal basis	do.	$16.00 [3]	$16.00 [3]	$10.00 [4]	$10.00 [4]	$10.00 [4]

[e]Estimated. W Withheld to avoid disclosing company prorietary data. -- Zero.
[1]Data are rounded to no more than three significant digits.
[2]Includes only the rare earths derived from bastnäsite as obtained from Molycorp, Inc.
[3]Source: Elements, TradeTech, Denver, CO.
[4]Source: Hefa Rare Earths Canada Co. Ltd., Vancouver, British Columbia, Canada.

TABLE 2
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS[1]

(Percentage of total rare-earth oxide)

Rare earth	Bastnäsite: Mountain Pass, CA, United States[2]	Bastnäsite: Bayan Obo, Inner Mongolia, China[3]	Monazite: North Capel, Western Australia[4]	Monazite: North Stradbroke Island, Queensland, Australia[5]	Monazite: Green Cove Springs, FL, United States[6]	Monazite: Nangang, Guangdong, China[7]
Cerium	49.10	50.00	46.00	45.80	43.70	42.70
Dysprosium	trace	0.1	0.7	0.60	0.9	0.8
Erbium	trace	trace	0.2	0.2	trace	0.3
Europium	0.1	0.2	0.053	0.8	0.16	0.1
Gadolinium	0.2	0.7	1.49	1.80	6.60	2.00
Holmium	trace	trace	0.053	0.1	0.11	0.12
Lanthanum	33.20	23.00	23.90	21.50	17.50	23.00
Lutetium	trace	trace	trace	0.01	trace	0.14
Neodymium	12.00	18.50	17.40	18.60	17.50	17.00
Praseodymium	4.34	6.20	5.00	5.30	5.00	4.10
Samarium	0.8	0.8	2.53	3.10	4.90	3.00
Terbium	trace	0.1	0.035	0.3	0.26	0.7
Thulium	trace	trace	trace	trace	trace	trace
Ytterbium	trace	trace	0.1	0.1	0.21	2.40
Yttrium	0.10	trace	2.40	2.50	3.20	2.40
Total	100	100	100	100	100	100

Rare earth	Monazite—Continued: Eastern coast, Brazil[8]	Monazite—Continued: Mount Weld, Australia[9]	Xenotime: Lahat, Perak, Malaysia[2]	Xenotime: Southeast Guangdong, China[10]	Rare earth laterite: Xunwu, Jiangxi Province, China[11]	Rare earth laterite: Longnan, Jiangxi Province, China[11]
Cerium	47.00	51.00	3.13	3.00	2.40	0.4
Dysprosium	0.4	0.2	8.30	9.10	trace	6.70
Erbium	0.1	0.2	6.40	5.60	trace	4.90
Europium	0.1	0.4	trace	0.2	0.5	0.10
Gadolinium	1.00	1.00	3.50	5.00	3.00	6.90
Holmium	trace	0.1	2.00	2.60	trace	1.60
Lanthanum	24.00	26.00	1.24	1.20	43.4	1.82
Lutetium	not determined	trace	1.00	1.80	0.1	0.4
Neodymium	18.50	15.00	1.60	3.50	31.70	3.00
Praseodymium	4.50	4.00	0.5	0.6	9.00	0.7
Samarium	3.00	1.80	1.10	2.20	3.90	2.80
Terbium	0.1	0.1	0.9	1.20	trace	1.30
Thulium	trace	trace	1.10	1.30	trace	0.7
Ytterbium	0.02	0.1	6.80	6.00	0.3	2.50
Yttrium	1.40	trace	61.00	59.30	8.00	65.00
Total	100	100	100	100	100	100

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

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[6]Analysis from RGC Minerals (USA), Green Cove Springs, FL.

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TABLE 3
RARE-EARTH OXIDE PRICES IN 2005

Product (oxide)	Purity (percentage)	Standard package quantity (kilograms)	Price (dollars per kilogram)
Cerium	96.00	25	19.20
Do.	99.50	900	31.50
Dysprosium	99.00	3	120.00
Erbium	96.00	2	155.00
Europium	99.99	1	990.00 [1]
Gadolinium	99.99	3	130.00
Holmium	99.90	10	440.00 [2]
Lanthanum	99.99	25	23.00
Lutetium	99.99	2	3,500.00
Neodymium	95.00	20	28.50
Praseodymium	96.00	20	36.80
Samarium	99.90	25	360.00
Do.	99.99	25	435.00
Scandium	99.99	1	6,000.00
Terbium	99.99	5	535.00
Thulium	99.90	5	2,300.00
Ytterbium	99.00	10	340.00
Yttrium	99.99	50	88.00

[1]Price for quantity greater than 40 kilograms is $900.00 per kilogram.
[2]Price for quantity less than 10 kilograms is $485.00 per kilogram.

Source: Rhodia Electronics & Catalysis, Inc.

TABLE 4
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2004 Gross weight (kilograms)	2004 Value	2005 Gross weight (kilograms)	2005 Value
Cerium compounds (2846.10.0000):				
Australia	5,830	$7,090	--	--
Austria	130,000	746,000	104,000	$633,000
Belgium	3,000	27,900	2,400	23,600
Brazil	55,700	311,000	123,000	661,000
Canada	47,800	270,000	22,900	263,000
China	25,800	254,000	78,600	582,000
Egypt	468,000	2,420,000	378,000	1,700,000
France	8,390	74,500	41,700	248,000
Germany	168,000	832,000	98,700	494,000
Hong Kong	91,200	782,000	92,100	793,000
India	295,000	1,760,000	508,000	2,690,000
Japan	180,000	1,350,000	165,000	1,410,000
Korea, Republic of	342,000	1,130,000	197,000	594,000
Malaysia	80,200	252,000	55,800	199,000
Mexico	203,000	1,080,000	141,000	964,000
Netherlands	16,000	142,000	13,900	164,000
Singapore	10,600	63,300	4,290	26,900
Taiwan	7,110	72,500	17,800	141,000
United Kingdom	38,700	375,000	54,100	582,000
Other	99,200 r	695,000 r	116,000	1,390,000
Total	2,280,000	12,600,000	2,220,000	13,600,000
Total estimated equivalent rare-earth oxide (REO) content	2,280,000	12,600,000	2,220,000	13,600,000
Rare-earth compounds[3] (2846.90.0000):				
Argentina	--	--	17,600	117,000
Austria	17,000	454,000	--	--
Brazil	5,330	146,000	51,100	363,000
Canada	1,960,000	3,860,000	266,000	719,000
China	23,100	155,000	273,000	1,170,000
Colombia	2,840	18,400	3,730	56,100
Estonia	1,800,000	1,030,000	846,000	406,000
France	38,100	1,100,000	47,900	1,190,000
Germany	255,000	775,000	20,400	497,000
Guatemala	--	--	63,900	30,900
Hong Kong	29,000	661,000	28,900	818,000
India	3,520	17,200	6,160	37,000
Italy	29,900	600,000	2,720	24,500
Japan	80,200	3,850,000	28,400	5,740,000
Korea, Republic of	145,000	1,150,000	63,200	508,000
Mexico	23,800	160,000	20,400	146,000
Netherlands	12,400	830,000	570	22,900
Poland	34,600	1,230,000	21,300	439,000
Russia	45,800	35,200	--	--
Singapore	5,290	165,000	523	71,600
Taiwan	83,900	1,660,000	30,400	712,000
United Kingdom	29,800	482,000	184,000	643,000
Other	184,000	530,000	92,900	389,000
Total	4,800,000	18,900,000	2,070,000	14,100,000
Total estimated equivalent REO content	4,800,000	18,900,000	2,070,000	14,100,000

See footnotes at end of table.

TABLE 4—Continued

U.S. EXPORTS OF RARE EARTHS, BY COUNTRY[1]

Category[2] and country	2004 Gross weight (kilograms)	2004 Value	2004 Gross weight (kilograms)	2004 Value
Rare-earth metals, including scandium and yttrium (2805.30.0000):				
Belgium	739	$28,800	750	$29,300
Brazil	8,410	188,000	300	10,800
China	105,000	1,610,000	24,700	340,000
Germany	4,040	214,000	5,970	326,000
Hong Kong	10	5,610	660	17,300
India	489	23,000	1,790	87,300
Indonesia	159,000	218,000	17,200	26,700
Japan	559,000	3,380,000	475,000	3,910,000
Mexico	699	58,500	1,660	70,100
Switzerland	226	31,300	305	69,600
Taiwan	1,460	58,600	955	67,600
Other	1,470 r	229,000 r	485	224,000
Total	840,000	6,050,000	530,000	5,180,000
Total estimated equivalent REO content	1,010,000	6,050,000	636,000	5,180,000
Ferrocerium and other pyrophoric alloys (3606.90.0000):				
Argentina	1,130	$10,700	24,600	$37,700
Australia	51,300	1,810,000	19,600	2,630,000
Bahrain	36,800	34,200	36,600	38,300
Canada	654,000	2,560,000	762,000	1,950,000
Cyprus	39,800	62,400	18,300	21,100
Egypt	115,000	106,000	105,000	104,000
France	56,900	181,000	115,000	474,000
Germany	1,110,000	5,780,000	1,510,000	2,080,000
Greece	57,100	65,400	62,000	113,000
Hong Kong	166,000	346,000	144,000	624,000
Israel	102,000	149,000	68,000	73,300
Japan	151,000	2,760,000	135,000	4,830,000
Jordan	50,600	41,600	60,800	60,100
Korea, Republic of	1,090	69,300	35,200	605,000
Kuwait	97,000	77,500	166,000	150,000
Mexico	32,400	136,000	23,900	146,000
Morocco	11,000	9,380	24,600	23,500
Netherlands	437,000	908,000	585,000	1,870,000
New Zealand	12,300	21,400	24,700	40,700
Portugal	19,100	34,900	21,500	42,500
Russia	25,000	33,000	46,200	73,300
Saudi Arabia	83,900	128,000	306,000	518,000
Singapore	13,600	69,000	7,560	90,000
Taiwan	6,820	44,600	8,840	60,600
Thailand	--	--	22,900	116,000
United Arab Emirates	259,000	237,000	195,000	223,000
United Kingdom	268,000	457,000	301,000	613,000
Other	326,000 r	708,000 r	32,000	422,000
Total	4,190,000	16,800,000	4,860,000	18,000,000
Total estimated equivalent REO content	3,720,000	16,800,000	4,320,000	18,000,000

[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 category numbers.

[3]Inorganic and organic.

Source: U.S. Census Bureau.

TABLE 5

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

Category[2] and country	2004 Gross weight (kilograms)	2004 Value	2005 Gross weight (kilograms)	2005 Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, oxalates (2846.10.0000):				
Austria	39,000	$371,000	18,300	$188,000
China	2,260,000	4,450,000	2,840,000	4,890,000
France	190,000	2,500,000	83,700	1,000,000
Hong Kong	--	--	36,000	77,500
Ireland	13,900	350,000	13,900	350,000
Japan	270,000	5,050,000	211,000	3,850,000
Korea, Republic of	41,400	369,000	25,900	59,500
Netherlands	8	4,660	449	13,400
United Kingdom	386	13,000	17,200	175,000
Other	931 r	40,100 r	1,220	11,100
Total	2,820,000	13,200,000	3,250,000	10,600,000
Total estimated equivalent rare-earth oxide (REO) content	1,880,000	13,200,000 r	2,170,000	10,600,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent (2846.90.4000):				
China	211,000	1,350,000	360,000	1,630,000
France	3,470	204,000	535	33,800
Japan	10,900	1,950,000	11,600	1,800,000
Other	462	16,700	140	26,000
Total	226,000	3,510,000	372,000	3,480,000
Total estimated equivalent REO content	136,000	3,510,000	223,000	3,480,000
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides (2846.90.8000):				
Austria	91,300	3,230,000	126,000	5,460,000
Canada	17	34,300	18,000	58,200
China	11,100,000	29,400,000	9,430,000	25,500,000
Estonia	440,000	428,000	76,000	80,000
France	1,990,000	13,600,000	518,000	9,290,000
Germany	23,600	714,000	8,000	521,000
Hong Kong	24,600	382,000	400	104,000
Japan	789,000	9,640,000	695,000	12,200,000
Russia	672,000	1,220,000	377,000	680,000
South Africa	--	--	10,600	63,600
United Kingdom	45,800	5,090,000	147,000	5,540,000
Other	25,200	315,000 r	366	92,300
Total	15,200,000	64,100,000	11,400,000	59,600,000
Total estimated equivalent REO content	11,400,000	64,100,000	8,550,000	59,600,000
Mixtures of REOs except cerium oxide (2846.90.2010):				
Austria	6,300	307,000	7,760	157,000
China	1,630,000	3,860,000	578,000	1,960,000
Germany	--	--	3,380	44,900
Ireland	--	--	1,270	141,000
Italy	--	--	34,500	3,720,000
Japan	9,540	524,000	3,540	140,000
Russia	143	91,000	51	10,800
United Kingdom	12,900	84,300	10,100	43,600
Other	248	67,100	1,780	103,000
Total	1,660,000	4,930,000	640,000	6,320,000
Total estimated equivalent REO content	1,660,000	4,930,000	640,000	6,320,000

See footnotes at end of table.

TABLE 5—Continued

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

Category[2] and country	2004 Gross weight (kilograms)	2004 Value	2005 Gross weight (kilograms)	2005 Value
Rare-earth metals, whether intermixed or alloyed (2805.30.0000):				
Austria	5,350	$115,000	28,500	$1,530,000
China	632,000	2,780,000	664,000	2,880,000
Germany	2,000	24,500	62	3,560
Italy	5,900	30,100	--	--
Japan	13,200	216,000	31,100	206,000
Russia	1,010	119,000	979	117,000
United Kingdom	10,400	177,000	7,660	164,000
Other	233	36,400	600	2,390
Total	670,000	3,500,000	733,000	4,900,000
Total estimated equivalent REO content	804,000	3,500,000	880,000	4,900,000
Mixtures of rare-earth chlorides, except cerium chloride (2846.90.2050):				
Belgium	13,000	122,000	10,000	26,200
China	2,750,000	2,670,000	5,760,000	6,420,000
France	10,900	83,400	--	--
Germany	247	158,000	138	92,700
Israel	1,000	879,000	--	--
Japan	24,500	483,000	22,700	6,990,000
Korea, Republic of	37,800	2,140,000	--	--
Mexico	--	--	960	28,800
Netherlands	15,000	83,100	--	--
Russia	1,140	222,000	54	98,700
United Kingdom	2,400	15,400	13,600	92,300
Other	12 r	6,570 r	19	17,800
Total	2,850,000	6,870,000	5,810,000	13,800,000
Total estimated equivalent REO content	1,310,000	6,870,000	2,670,000	6,330,000
Ferrocerium and other pyrophoric alloys (3606.90.3000):				
Austria	18,800	402,000	14,300	289,000
Belgium	2,300	39,200	--	--
China	--	--	12,300	86,100
France	97,100	1,330,000	119,000	1,640,000
Japan	211	5,430	--	--
South Africa	--	--	522	23,100
Other	--	--	392	7,520
Total	118,000	1,770,000	147,000	2,050,000
Total estimated equivalent REO content	105,000	1,770,000	130,000	2,050,000

[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 category numbers.

Source: U.S. Census Bureau.

TABLE 6
RARE EARTHS: ESTIMATED WORLD MINE PRODUCTION, BY COUNTRY[1, 2]

(Metric tons of rare earth oxide equivalent)

Country[3]	2001	2002	2003	2004	2005
Brazil	--	--	--	402 [4]	440
China	80,600	88,000	92,000	98,000	119,000
Commonwealth of Independent States[5]	NA	NA	NA	NA	NA
India	2,700	2,700	2,700	2,700	2,700
Kyrgyzstan:					
Compounds	NA	NA	NA	NA	NA
Metals	3,800	100	NA	NA	NA
Other	2,000	2,000	2,000	NA	NA
Malaysia	351 [4]	240	360	800 [r]	750
United States[6]	W	W	--	--	--
Total	89,500	93,000	97,000	102,000 [r]	123,000

[r]Revised. NA Not available. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- 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 13, 2006.

[3]In addition to the countries listed, rare-earth minerals are believed to be produced in some Commonwealth of Independent States countries besides Kyrgyzstan and in Indonesia, Nigeria, North Korea, and Vietnam, but information is inadequate for formulation of reliable estimates of output levels.

[4]Reported figure.

[5]Does not include Kyrgyzstan; information is inadequate for formulation of reliable estimates for individual producing countries, including Kazakhstan, Russia, and Ukraine.

[6]Comprises only the rare earths derived from bastnäsite.

TABLE 7
MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons, gross weight)

Country[3]	2001	2002	2003	2004	2005
Brazil	--	--	--	731 [4]	800 [p]
India	5,000	5,000	5,000	5,000	5,000
Malaysia	643 [4]	441 [4]	795 [4]	1,683 [r, 4]	700
Total	5,640	5,440	5,800	7,410 [r]	6,500

[p]Preliminary. [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 April 18, 2006.

[3]In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.

[4]Reported figure.

FIGURE 1
PRINCIPAL SOURCES OF U.S. IMPORTS OF RARE EARTHS, BY WEIGHT, IN 2005