RARE **E**ARTHS

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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.

In 2003, world rare-earth production was primarily from the rare-earth mineral bastnäsite. Rare-earth ores were mainly supplied by China, with lesser amounts mined in Brazil, India, and Russia. Bastäsite mining in the United States ceased by yearend 2002, and none was mined in 2003. Domestic stocks of previously produced bastäsite concentrates, intermediate rareearth concentrates, and separated products were available for purchase. Consumption was estimated to have increased as did imports of individual rare-earth compounds, mixed rare-earth compounds, and rare-earth chlorides. U.S. imports of cerium compounds and rare-earth metals and alloys decreased (table 5).

Yttrium demand increased by about 15.0% in 2003 compared with that of 2002, according to data from the Port Import/Export Research Service (PIERS) database of The Commonwealth Business Media, Inc. Yttrium was used primarily in lamp and cathode-ray tube phosphors; lesser amounts were used in structural ceramics and oxygen sensors.

The domestic use of scandium increased slightly in 2003. Overall consumption of the commodity remained small. Demand was primarily for aluminum alloys used in baseball and softball bats. Scandium alloys, compounds, and metal were used in analytical standards, metallurgical research, and sports equipment. Minor amounts of high-purity scandium were used in semiconductors and specialty lighting.

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 (Mason and Moore, 1982, p. 46). 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 bastäsite, loparite, and monazite and lateritic ion-adsorption clays (table 2).

The rare earths were discovered in 1787 by Swedish Army Lieutenant Karl Axel Arrhenius when he collected the black mineral ytterbite (later renamed gadolinite) from a feldspar and quartz mine near the village of Ytterby, Sweden. Because they have similar chemical structures, the rare-earth elements proved difficult to separate. It was not until 1794 that the first element, an impure yttrium oxide, was isolated from the mineral ytterbite by Finnish chemist Johann Gadolin (Weeks and Leicester, 1968, p. 667, 671).

Rare earths were first produced commercially in the 1880s in Sweden and Norway from the rare-earth mineral monazite. Production in Scandinavia was prompted by the invention in 1884 of the Welsbach incandescent lamp mantle, which initially required the oxides of lanthanum, yttrium, and zirconium, with later improvements requiring only the oxides of thorium and cerium. The mantles also used small amounts of neodymium and praseodymium oxides as an indelible brand-name label. The first rare-earth production in the United States was recorded in 1893 in North Carolina; however, a small tonnage of monazite was reportedly mined as early as 1887. South Carolina began production of monazite in 1903. Production of monazite occurred in Brazil as early as 1887, and India began recovery of the ore in 1911.

Production

In 2003, the one mining operation in California ceased production of bastäsite but remained open on a care-and-

maintenance basis. Molycorp, Inc. (a wholly owned subsidiary of Unocal Corporation) sold from its stockpile of bastäsite concentrates, intermediate concentrates, and separated compounds previously processed at its open pit operations at Mountain Pass, CA. In 2003, the minerals sector of Unocal reported sales revenue of \$25 million (unaudited), a decrease of \$6 million from the \$31 million (unaudited) in 2002 (Unocal Corporation, 2004, p. 28). Unocal's minerals sector included minerals other than the lanthanides [such as carbon, molybdenum, and columbium (niobium)] and is undifferentiated in Unocal's report. Although the company was not actively mining, 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.

Based on economic conditions, Molycorp was prepared to restart its rare-earth refining operations. Ongoing programs to further develop the mine include filing an environmental impact report, the building of evaporation ponds, decommissioning of an old tailings pond, and developing a plan for a new tailings pond with an environmentally acceptable reduced-water-use fill technology.

Lanthanide products available in 2003 from Molycorp were cerium nitrate, bastäsite concentrate, lanthanum chloride, lanthanum hydrate, lanthanum-rich nitrate, and the oxides of cerium, erbium, europium, gadolinium, praseodymium, samarium, and yttrium.

Molycorp continued to decommission and decontaminate its closed rare-earth processing facilities at Washington and York, PA. Limited amounts of naturally occurring low-level radioactive material (thorium) were planned for removal to approved disposal sites. Funds for environmentally related expenses, including remediation, were \$140 million in 2003, a decrease of \$30 million from the 2002 level (costs include expenses for non-rare-earth locations, such as the Guadalupe oilfield in California) (Unocal Corporation, 2004, p. 50).

Three companies processed intermediate rare-earth compounds to lanthanides in 2003. 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 for automotive catalysts and catalyst supports (Grace Davison, 2004§¹).

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. Santoku Corporation (33%) continued its joint venture Anan Kasei Ltd. with Rhodia Electronics and Catalysis, Inc. (67%). The joint venture operations, located in Anan, Japan, produced fuel additive emission-reduction catalysts, phosphors, polishing compounds, rare-earth-base nontoxic colorants and coatings for plastics, and three way catalytic converter catalysts (Santoku America, Inc., undated§).

Rhodia's operations produced finished rare-earth products from imported materials at its plant in Freeport, TX. Rhodia continued to operate its large-scale rare-earth separation plant in La Rochelle, France, and had additional capacity at its joint venture in Kobe, Japan. These plants provide Rhodia's U.S. operations with a majority of their rare-earth supply. Rhodia produced rare-earth containing catalysts for automotive emission applications including the three-way catalyst (precious metals, alumina, and ACTYLYSTM rare-earth-base catalyst) for gasoline engines and the EOLYSTM fuel additive catalyst for diesel engines (facilitates the regeneration of particulate filters) (Rhodia Electronics and Catalysis Inc., undated§). Rhodia reported sales by market segment to be 56% electronics, 37% catalysis, and 7% new markets.

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

Two scandium processors operated in 2003. High-purity products were available in various grades, with scandium oxide produced at up to 99.999% purity. Boulder Scientific Co. processed scandium at its Mead, CO, operations. It refined scandium primarily from imported oxides to produce highpurity 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 highpurity scandium compounds, including anhydrous and hydrous chloride, fluoride, iodide, and oxide. The company also produced high-purity scandium metal.

The principal domestic producer of NIB magnet alloys was Santuko America. Leading U.S. producers of rare-earth magnets were VAC Magnetics Corporation (a subsidiary of Vacuumschmelze GMBH & Co. KG, a division of Morgan Crucible Company plc.), Elizabethtown, KY; Electron Energy Corporation, Landisville, PA; Magnequench UG, Valparaiso, IN (closed); and Magnetic Materials Division of Hitachi Metal America, Ltd., Edmore, MI, and China Grove, NC. In 2002, Magnequench International, Inc. closed its operations in Anderson, IN, and relocated the equipment and production for NIB magnet powder-metal production to Tianjin, China (Magnequench International, Inc., 2003§). Magnequench UG, which was purchased by Magnequench International, Inc. in August 2000, started closing its operations beginning in the summer of 2003 and was relocating its magnet equipment and production to China. Rare-earth magnets produced at the Valparaiso plant were components in servomotors used in precision-guided missiles produced for the U.S. Department of Defense's Joint Directed Airborne Munitions (JDAM) program (Wheeler, 2003§).

Demand for rare earths used in NiMH batteries decreased; despite an increase in demand for lithium ion batteries, overall demand for rechargeable batteries declined in 2003. Rechargeable batteries are used in cellular telephones, portable computers, personal digital assistants (PDAs), camcorders, and other portable devices. Japan, the leading producer of rechargeable batteries, produced 379.6 million units of rare-

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

earth-containing NiMH batteries in 2003, a decrease from the 538.3 million produced in 2002. Based on production in 2003, lithium ion batteries were the leading rechargeable battery product (762.8 million units), followed by nickel-cadmium (392.2 million units) and NiMH (379.6 million units) batteries. The average cost of a lithium ion battery was about 3 times the cost of a NiMH battery (Roskill's Letter from Japan, 2004d).

Consumption

Statistics 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 increased in 2003 compared with that of 2002.

In 2003, yttrium consumption was estimated to have increased to 384 metric tons (t) from 334 t in 2002. Yttrium information was based on data retrieved from the PIERS database. Yttrium compounds and metal were imported from several sources in 2003. Yttrium compounds and metals were imported from China (87.6%), Japan (5.9%), Austria (4.04%), the Netherlands (0.93%), the United Kingdom (0.72%), the Republic of Korea (0.42%), and Germany (0.39%). The estimated use of yttrium, based on imports, was primarily in lamp and cathode-ray tube phosphors (77.3%), miscellaneous (17.8%), and alloys (4.9%).

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 2003 compared with 2002. 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 products to be quoted on a daily basis. The average price of imported rare-earth chloride was \$1.50 per kilogram in 2003, an increase from \$1.43 per kilogram in 2002. In 2003, imported rareearth metal prices averaged \$6.97 per kilogram, a decrease from \$8.25 per kilogram in 2002. 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 \$3.14 to \$3.87 per kilogram, and low-zinc, low-magnesium mischmetal, from \$4.59 to \$5.07 per kilogram (in metric ton quantities) in 2003, free-on-board, China port (China Rare Earth Information, 2003). The domestic price of mischmetal, at \$10.00 per kilogram in 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 (table 1). The average price for imported cerium compounds,

excluding cerium chloride, decreased to \$4.15 per kilogram in 2003 from \$5.03 per kilogram in 2002. The primary cerium compound imported was cerium carbonate.

The 2003 nominal price for bastäsite 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), including contained thorium oxide, free-on-board (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 2002, 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 for basic neodymium metal for metric ton quantities remained around \$8 per kilogram (\$3.63 per pound), f.o.b. shipping point, and for kilogram quantities was \$28.50 per kilogram (\$12.93 per pound) (China Rare Earth Information, 2003; table 3). Most neodymium-iron-boron 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 about \$20.72 per kilogram (\$9.40 per pound) in 2003, the cost would be about \$0.21 per kilogram (\$0.09 per pound) for each percentage point addition.

Rhodia's quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of entry, in effect at yearend 2003, are listed in table 3. No published prices for scandium oxide in kilogram quantities were available. Yearend 2003 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices decreased for the lower-purity scandium oxides and were unchanged for the higher purity material. The 2003 prices were as follows: 99% purity, \$500 per kilogram; 99.9% purity, \$1,300 per kilogram; 99.99% purity, \$2,500 to \$6,000 per kilogram; and 99.999% purity, \$3,200 to \$20,000 per kilogram.

Scandium metal prices for 2003 increased from those of 2002 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 mm; and 99.9% REO purity foil, 0.025 mm thick, ampouled under argon, 25 mm by 25 mm, \$141 per sheet (Alfa Aesar, undated§).

Scandium compound prices were as follows: scandium acetate hydrate 99.9% purity, \$66.30 per gram; scandium chloride hydrate 99.99% purity, \$85.00 per gram; scandium nitrate hydrate 99.9% purity, \$73.90 per gram; and scandium sulfate pentahydrate 99.9% purity, \$65.80 per gram. Prices for standard solutions for calibrating analytical equipment were \$25.70 per 100 milliliters of scandium atomic absorption standard solution and \$420.30 per 100 milliliters of scandium plasma (ICP/DCP) standard solution (Aldrich Chemical Co., 2002, p. 1639-1641).

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. imports of rare earths increased in 2003 and exports declined compared with those of 2002 (U.S. International Trade Commission, 2003§). 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 7,550 t valued at \$44.0 million, a 9.5% decrease in quantity and a 11.7% decrease in value when compared with those of 2002 (table 4). Imports totaled 23,200 t gross weight valued at \$93.9 million, a 17.0% increase in quantity and a 0.44% increase in value compared with those of 2002 (table 5).

In 2003, U.S. exports of rare earths decreased in two of the four trade categories. Principal destinations in 2003, in descending order, were Germany, Canada, Japan, and Brazil. The United States exported 609 t of rare-earth metals valued at \$3.25 million, a 44% decrease in quantity and a 45% decrease in value compared with those of 2002. Principal destinations, in descending order of quantity, were Japan, China, the Republic of Korea, and Germany. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, decreased by 30.4% to 1,910 t valued at \$10.1 million. Major destinations, in descending order of quantity, were Germany, Mexico, Malaysia, the United Kingdom, and Japan.

Exports of inorganic and organic rare-earth compounds increased by 34.1% to 1,790 t in 2003 from 1,340 t in 2002, and the value of the shipments decreased by 6.1% to \$19.9 million. Shipments, in descending order of quantity, were to Brazil, Canada, Germany, and the Republic of Korea (table 4).

U.S. exports of ferrocerium and other pyrophoric alloys increased to 3,250 t valued at \$10.8 million in 2003 from 3,180 t valued at \$8.86 million in 2002. Principal destinations, in descending order of quantity, were Germany, Canada, the United Kingdom, and the United Arab Emirates.

In 2003, U.S. imports of compounds and alloys increased in quantity and value for five out of seven categories and are listed in table 5. China and France dominated the import market, especially for mixed and individual rare-earth compounds, followed by Japan and India (figure 1).

Imports of cerium compounds totaled 3,630 t valued at \$15.1 million. The quantity of cerium compounds imported decreased by 4.6% as a result of decreased demand for automotive exhaust catalysts. China was the major supplier for the 9th consecutive year, followed by Japan, Austria, and France.

Imports of yttrium compounds that contained between 19 and 85 weight-percent (yttrium concentrate) increased by 18.0% to 86,600 kilograms (kg) in 2003, and the value increased by 11.9% to \$4.33 million. China was the leading supplier of yttrium compounds, followed by Japan and France (table 5).

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, increased by 32.0% compared with those of 2002. Rare-earth compound imports increased to 12,800 t valued at \$55.5 million. The major sources of individual rare-earth compounds, in decreasing order by quantity, were China, France, Russia, Japan, and Estonia. Imports of mixtures of rare-earth oxides, other than cerium oxide, increased in quantity by 63.9% to 1,710 t valued at \$6.1 million. The principal source of the mixed rare-earth oxides was China, with much smaller quantities imported from Japan, Austria, and Germany. Imports of rare-earth metals and alloys into the United States totaled 737 t valued at \$5.14 million in 2003, a 39.2% decrease in quantity compared with 2002. The principal rare-earth metal sources, in descending order of quantity, were China and Japan. In 2003, imports of rareearth chlorides increased by 5.7% to 4,150 t valued at \$6.21 million. Supplies of rare-earth chloride, in descending order of quantity, came from China, with minor amounts from Israel, India, and France. 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 115 t valued at \$1.65 million. Principal sources of these alloys, in descending order of quantity, were France and Austria.

World Review

Australia.—Lynas Corporation Ltd. continued with development of its Mount Weld rare-earth deposit 30 kilometers (km) south of Laverton, Western Australia (Matthew James, Lynas Corporation Ltd., June 17, 2003, oral commun.). Updated measured reserves at Mount Weld are 1.2 million metric tons (Mt) grading 15.6% REO, and indicated reserves are an additional 5 Mt grading 11.7% REO. Inferred resources are 1.5 Mt grading 9.8% REO (Lynas Corporation Ltd., undated§). The light-group rare-earth elements (LREE) deposit has an expected mine life of at least 20 years based on mining 3.2 Mt of ore at an average grade of 14.3% REO. Naturally occurring radioactive mineral content at Mount Weld is a low 0.05%. In June, Lynas raised \$1.95 million to fund further development of the mine. Pilot plant testing of the ore produced a 40% rareearth concentrate at a recovery rate greater than 60% (Lynas Corporation Ltd., 2003).

Lynas announced that China-based China Iron and Steel Industry Trade Group (CSG) would become the major shareholder of Lynas with a 42.5% holding in exchange for a 40% holding in CSG's joint-venture Channar Iron Ore Mine in Western Australia; Rio Tinto plc's subsidiary Hamersley Iron controlled the remaining 60% (Brombay, 2003). Rio Tinto has filed suit in Australia against CSG over CSG's plan to sell its shareholdings and to block the release of company proprietary data. In October, Rio Tinto obtained an injunction to block the transaction and protect its company proprietary information (Weir, 2003§). At yearend, the proposed plan was unresolved.

Australia remained one of the world's major potential sources of rare-earth elements from its alkaline intrusive deposit, heavy-mineral sand deposits, and rare-earth lateritic deposits. Monazite is a constituent in essentially all of Australia's heavymineral 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. In 2003, major producers of heavy-mineral sand concentrates in Australia, in order of production, were Iluka Resources, Ltd.; Tiwest Joint Venture; Consolidated Rutile, Ltd. (CRL); RZM/Cable Sands, Ltd. (CSL); Mineral Deposits Ltd. (MDL); Currumbin Minerals Pty. Ltd.; and Murray Basin Titanium Pty. Ltd. (Mineral Sands Report, 2004a). Iluka operated 10 mines worldwide, 8 of which were in Australia (6 on the west coast and 2 on the east coast), and 2 were in the United States. Iluka's Australian subsidiary WA Titanium Minerals operated 6 mines in Western Australia in 2003. Iluka's other mining operations were the North West Mine near Capel, the North and South Mines near Eneabba, and the Yoganup, Yoganup Extended, and Busselton Mines in the southwestern region. Mining of the Yoganup Extended Mine's remaining heavy-mineral sands was scheduled to begin in 2003.

Iluka's two east coast mines, the Yarraman and Ibis Mines, were operated by CRL on North Stradbroke Island, New South Wales. Production from the Yarraman Mine reportedly increased as a result of improvements to the tailings circuit in the last half of 2002; however, by yearend 2003, production was lower as a result of dredge repairs at Yarraman and lower ore grades at both mines (Iluka Resources, Ltd., 2003a§; Folwell, 2004§). Dry mining commenced at the Yarraman Mine to offset the reduced production while the dredge was repaired. The dredge was repaired and recommissioned in July (Industrial Minerals, 2003b). CRL operated a dry separation plant at Pinkenba, near Brisbane, Queensland.

Iluka continued to explore and delineate heavy-mineral resources, including monazite and xenotime, in the Murray Basin area of New South Wales and Victoria. The company completed a prefeasibility study of the Douglas heavy-mineral sands project that it acquired from Basin Minerals Limited (BML) in 2002 (Iluka Resources, Ltd., 2003b§). Iluka paid A\$139 million for BML's extensive heavy-mineral sands interests, including the Culgoa and Douglas deposits. BML's major deposit includes the Douglas mineral-sands project in southwestern Victoria. Iluka was creating plans to develop the Douglas deposit and construct a heavymineral sands separation plant near Horsham, Victoria, in 2005. The Douglas deposit covers an area of 5,860 square kilometers and has a resource of 22.4 Mt of heavy minerals. Five strandline deposits within the Douglas deposit contain 11.3 Mt of ilmenite (including leucoxene), 1.26 Mt of rutile, and 1.62 Mt of zircon (Mineral Sands Report, 2002).

BeMaX Resources N.L. continued development of its Ginkgo Mineral Sands Project (GMSP) located in the Murray Basin near Pooncarie, New South Wales. The GMSP contains reserves of 184 Mt of ore grading 3.2% heavy minerals. The GMSP is reportedly the first heavy-mineral sands deposit in the fully permitted New South Wales part of the Murray Basin (DuPont Titanium Technologies, 2003). An analysis of a bulk sample of the heavyminerals fraction showed the deposit to be depleted of monazite but enriched, in decreasing order of abundance, in ilmenite, rutile, leucoxene, pseudorutile, zircon, and tourmaline (Resource Equity Consultants Pty. Ltd., 2002§).

In October, BeMaX, Sons of Gwalia Ltd., and Nissho Iwai Corp. signed a merger agreement. The assets of the companies will be wholly owned by BeMaX and include the mining operations of RZM/CSL and the Murray Basin Titanium joint venture with combined production of 350,000 metric tons per year (t/yr) of heavy-mineral concentrates (Industrial Minerals, 2003a).

Southern Titanium NL completed development of a mine plan and will seek financing to develop its Mindarie deposit in the Murray Basin. Zircon was expected to provide 60% of the revenue from the project (Southern Titanium NL, 2003§). Mindarie reported reserves of 1.9 Mt of heavy minerals contained in paleoplacers of Pliocene and Tertiary age. The Pliocene ore is in the Loxton-Parilla sands at shallow depth on an uplifted block on a former strand plain, while the Tertiary ore is in multiple strand lines of a paleobeach placer (Placer Stockfile, undated§). The deposit contains economic quantities of ilmenite, rutile, zircon, and anatase and noneconomic amounts of tourmaline, kyanite, andalusite, and monazite.

MDL ceased operation of its dredge at Fullerton, New South Wales, and began preparations to ship the dredge to Beach Mineral Company's (BMC) Kuttam mineral sands deposit in India. MDL's Hawk Nest dry mill will reportedly continue operating and will receive part of its nonmagnetic heavymineral feed from BMC's Indian mine. Mining at MDL's Viney Creek deposit in New South Wales, ceased on January 30, 2003, and the dredge and a wet concentrator were put on a careand-maintenance program while the company assessed local and worldwide mineral resources (Mineral Deposits Limited, 2003§). The New South Wales heavy-mineral deposits have historically been a source of monazite.

Brazil.—Reserves of rare earths were 109,000 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 Rio de Janeiro (24,570 t), Bahia (10,186 t), and Espirito Santo (4,136 t) (Fabricio da Silva, 2004). The main placer reserves were in the States of Minas Gerais (24,396 t), Espirito Santo (11,372 t), and Bahia (3,481 t). In 2001, total reserves of rare earths in Brazil were about 6 Mt grading 0.5% contained REO. Brazil did not produce rare earths (monazite) in 2002, the latest available Government data (Fabricio da Silva, 2004).

China.—According to the China Rare Earth Information Centre, production of rare-earth concentrates in China was 92,000 t of REOs in 2003 (table 6). Production of 54,000 t of REOs from Inner Mongolia accounted for the majority of the rare earths produced. Jiangxi Province's ion adsorption ores were second with 23,000 t of REOs, and other mines in China produced 15,000 t of REOs (Roskill's Letter from Japan, 2004b).

In 2003, exports of rare-earth products were as follows: rareearth oxides, 24,250 t of REOs; rare-earth chlorides, 17,776 t of REOs; rare-earth metals, 6,110 t of REOs; and rare-earth alloys, 3,974 t of REOs (Roskill's Letter from Japan, 2004b). Exports of rare-earth magnets were 5,617 t, with principal destinations in order of decreasing weight, Hong Kong (1,208 t), Italy (787 t), the United States (596 t), the Republic of Korea (552 t), and Singapore (279 t).

Production of refined and processed products increased to 78,000 t of REOs, which included production of individual high-purity rare-earth products. China's production of NIB permanent magnets increased substantially, reaching 15,000 t in 2003 compared with 8,500 t in 2002. Production of samarium-cobalt magnets also increased in 2003, reaching 200 t compared with 150 t in 2002 (Roskill's Letter from Japan, 2004b). Output reached 3,650 t for lighting phosphors; 1,650 t for cathode ray tubes, 1,400 t for fluorescent lighting, and 600 t for luminescence storage fluorescent powder. Hydrogen-storage alloy production was 4,300 t in 2003 (China Rare Earth, 2004§).

Jiangxi Province reported 2002 production, the latest available data, of 4,255 t of mixed rare-earth oxides and 3,091 t of rare-earth metals (China Rare Earth, 2003d§). The major rare-earth producer in the Province was Jiangxi Rare Earth Metal Tungsten Group Co.

Baotou Huamei Rare Earth Products Co. Ltd. of Baotou, Inner Mongolia, planned to begin operation of its rare-earth alloy powder and rare-earth permanent magnet plant by midyear. The plant has the capacity to produce 600 t of rare-earth alloy powder and 200 t of magnets. Baotou Huamei's rare-earth plant cost \$14.86 million to build and was expected to reach full capacity in 2004 (China Rare Earth, 2003a§).

In another attempt to control rare-earth production, the Chinese Ministry of Land and Resources (CMLR) announced it would regulate production of antimony, rare earths, and tin. CMLR will reportedly close all unlicensed mines and those operations that violate environmental, industry, and safety policies. Local CMLR offices were to compile a list of companies in their region and require them to provide copies of mining permits and health and safety certificates (China Rare Earth, 2003b§). A definitive list of qualified producers was to be compiled and published by CMLR.

Eight new rare-earth investment projects in the Baotou region of Inner Mongolia were scheduled to achieve full production in 2003. The four principal projects included Hefa Group's \$6.8 million rare-earth metal hydride powder alloy plant to supply the increasing demand for rechargeable batteries. Hefa's plant was completed in June 2002. The Ningbo Yunsheng Group invested \$8 million in a NIB magnet plant, which started pilot plant production in July 2002. Baotou Jingwei Rare Earth Co.'s MC nylon project was constructed in the first half of 2002 at a cost of \$6.7 million to produce a rare-earth modified MC nylon with high strength and improved abrasion and corrosion resistance. The largest project was the \$84.5 million jointventure NiMH battery plant created by Baotou Rare Earth Hi-Tech Co. Ltd. and Showa Denko K.K. The new company, Baotou Showa Rare Earth Hi-Tech New Material Co. Ltd., will produce 10 million NiMH cylinders per year, equivalent to 1,500 t of batteries (China Rare Earth, 2003c§).

A new compound of ytterbium, gallium, and germanium was developed that reportedly does not expand or contract under a wide temperature range. The compound, developed in China, is able to withstand temperatures in excess of 2,000° C. The material is expected to be used for heat-insulation for manned space craft (China Rare Earth, 2003e§).

Japan.—Japan refined 5,502 t of rare earths in 2003, an increase from the 5,423 t produced in 2002. The rare earths were produced from imported ores and intermediate raw materials. Imports of refined rare-earth products were 25,705 t, an increase from the 22,571 t imported in 2002. The value of imports, however, decreased slightly to ± 16.351 billion in 2003 from ± 16.457 billion in 2002 (Roskill's Letter from Japan, 2004c). Japanese imports of refined rare-earth products increased in all categories except ferrocerium. Imports of refined rare-earth products from the United States decreased to 347 t in 2003 from 512 t in 2002.

Production of Japanese rare-earth-bonded magnets in 2003 increased by 8% to 540 t, the first increase since 1999. Shipments of rare-earth-bonded magnets were valued at \$7.0 billion in 2003, a decrease from the \$7.3 billion in 2002 (Roskill's Letter from Japan, 2004a).

Japanese imports of rare earths from China were as follows: rare-earth compounds, 6,116 t; cerium compounds (other than oxide), 5,898 t; cerium oxide, 3,928 t; rare-earth metals, 3,538 t; lanthanum oxide, 1,955 t; yttrium oxide, 1,204 t; and ferrocerium, 104 t (Roskill's Letter from Japan, 2004c). China continued to be the leading source of rare-earth imports for Japan with 22,743 t in 2003, an increase from the 19,789 t imported in 2002.

In 2003, the supply of Japanese rare earths was based on domestic production of 5,502 t and imports of 28,162 t. Imported rare-earth materials included bastäsite, rare-earth chlorides, and rare-earth refined products. Bastäsite concentrate imports were unchanged from the previous year at 2,000 t, and rare-earth chloride imports were 467 t, an increase from the 437 t in 2002 (Roskill's Letter from Japan, 2004c). Japanese imports of rare-earth refined products in 2003 were 25,705 t classified as follows: cerium compounds (other than oxide), 6,609 t; rareearth metals, 6,119 t; rare-earth compounds, 4,802 t; cerium oxide, 4,241 t; lanthanum oxide, 2,241 t; yttrium oxide, 1,235 t; and ferrocerium, 485 t.

Kenya.—Tiomin Resources Inc. of Toronto, Ontario, Canada, announced the completion of a pilot plant at its Kwale deposit and the production of 20 t of mixed heavy-mineral sands concentrate. Tiomin had leased 607 hectares (ha) (1,500 acres) for the mine as of yearend 2003 and was in final negotiations with the Government of Kenya for an additional 223 ha (550 acres) (Tiomin Resources Inc., 2003). Monazite occurs in the Kwale deposit in low quantities and will be recovered, blended with the tailings, and returned to the mining area (Tiomin Resources Inc., undated§).

Madagascar.—Iluka began a drilling program on its Farafangana heavy-mineral prospect on the southeastern coast (Iluka Resources, Ltd., 2004a§). The initial air core drilling program was expected to be completed in the first half of 2004. The region is known to contain monazite and has previously reported reserves in the Tolagnaro deposits in the south and southeast of Madagascar of 50,000 t and 260,000 t, respectively.

Ticor Limited announced it was studying the feasibility of mining the heavy-mineral sand holdings of Madagascar Resources NL on the west coast. Exploration of the deposits was planned, and initial samples indicated zircon and slagquality ilmenite (Industrial Minerals, 2003e).

Mozambique.—Kenmare Resources PLC received permits from the Government of Mozambique to commence construction of the Moma heavy-mineral sands project in 2002 and received funding guarantees from the Multilateral Investment Guarantee Agency (a member of the World Bank) in 2003. Development of the project was expected to take 2 years with production scheduled to begin in 2005 (Industrial Minerals, 2003d). Monazite was not scheduled for production but was to be monitored in the process streams.

Russia.—Solikamsk Magnesium Works (SMZ) reported that it has been producing rare-earth chlorides from loparite

concentrate, equivalent to 3,000 to 4,000 t/yr of REOs. Previously, the rare-earth chloride intermediate product that contains naturally occurring radioactive material (NORM) was sent for processing and refining to Estonia and Kazahkstan. Regulations and costs attached to shipping and handling compounds containing NORM prompted SMZ to construct a facility to process the material into 3,000 to 4,000 t/yr of rareearth carbonate without significant radioactive content. Phase two of SMZ's plan was to produce a 90%-to-96%-pure cerium carbonate or hydroxide, an 80%-to-98%-pure lanthanum concentrate, and concentrates containing neodymium, praseodymium, and samarium. SMZ's produces two mixed rare-earth compounds—a rare-earth chloride with a minimum content of 38% REO and a rare-earth carbonate with a minimum content of 45% REO (Solikamsk Magnesium Works, 2003§).

South Africa.—Richards Bay Minerals (RBM) was the second leading producer of heavy-mineral sands in the world in 2003 from its Richards Bay Mine (Mineral Sands Report, 2004b). RBM did not produce monazite in 2003.

Ticor South Africa [a mining venture between Kumba Resources Ltd. of South Africa (60%) and Ticor Limited (40%)] produced heavy-mineral sands in 2003 (Mineral Sands Report, 2004b). Anglo American plc increased its shareholdings in Kumba Resources Ltd. to more than 35% from 20.1% by purchasing shares on the open market (Industrial Minerals, 2003e). Although the deposit contains monazite, mineral products will be ilmenite, rutile, and zircon.

Namakwa Sands Pty. Ltd. (a wholly owned subsidiary of Anglo American) was a major producer of heavy mineral sands in 2003 from its mine at Brand-se-Baai (Mineral Sands Report, 2004b). A portion of the dry mill at Koekenaap was destroyed by fire in October and reportedly will affect production of ilmenite, rutile, and zircon (Industrial Minerals, 2003c). Namakwa's Brand-se-Baai Mine has a remaining mine life of about 32 years. The deposit was initially discovered in 1985-90 by Anglo American as part of program to locate monazite.

In September, Mineral Commodities Limited (MRC) of Australia announced that its permit for the Xolobeni heavymineral sands deposit in Eastern Cape Province, South Africa, was not within the boundaries of the proposed Pondoland wildlife park. MRC's permit covers an area between the Mtentu and Mzamba Rivers about 200 km south of Durban on the Natal coast. The company stated that Xolobeni resources were about 310 Mt of ore (Mineral Commodities Limited, 2003a§). The ore is contained in a series of inland paleodunes of wellsorted, medium-grained sands that are rounded to subrounded. The four areas of the deposit (two measured resources, one indicated, and one inferred) total about 310 Mt of ore grading 5.4% heavy minerals with a cutoff grade of 1.5%. An early prefeasibility study proposed a 17-year mine life (Mineral Commodities Limited, 2003b§).

Outlook

The use of rare earths, especially in automotive pollutioncontrol catalysts, permanent magnets, and rechargeable batteries, is expected to continue to increase as future demand for 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 forecast for rare earths in rechargeable NiMH batteries (moderated by demand for lithium ion batteries), fiber optics, and medical applications that include dental and surgical lasers, magnetic resonance imaging (MRI) contrast agents, medical isotopes, and positron emission tomography (PET) scintillation detectors. Long-term growth is expected for rare earths in magnetic refrigeration alloys.

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. World resources should be adequate to satisfy demand for the foreseeable future.

Domestic companies have shifted away from using naturally occurring radioactive rare-earth ores. This trend has had a negative impact on monazite-containing mineral-sands operations worldwide. Future long-term demand for monazite, however, is expected to increase because of its abundant supply and its recovery as a low-cost byproduct. 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 thoriumbearing rare-earth ores.

World rare-earth markets are expected to continue to be very competitive in competing 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 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.

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TABLE 1 SALIENT U.S. RARE EARTH STATISTICS¹

(Metric tons of rare-earth oxides unless otherwise specified)

1999	2000	2001	2002	2003
W	W	W	W	
3,960	4,050	4,490	2,740 r	1,910
1,600	1,650	891	1,310	730
1,690	1,760	1,680	1,340 r	1,790
2,360	2,300	2,540	2,830 ^r	2,880
5,970	6,450	3,870	2,540	2,430
120	118	118	89	102
17,200	17,300	15,200	11,600	15,100
\$4.85	\$5.51	\$5.51	\$5.51	\$5.51
\$0.73	\$0.73	\$0.73	\$0.73	\$0.73
\$16.00 ³	\$16.00 ³	\$16.00 ³	\$16.00 ³	\$10.00 4
	1999 W 3,960 1,600 1,690 2,360 5,970 120 17,200 \$4.85 \$0.73 \$16.00 ³	1999 2000 W W 3,960 4,050 1,600 1,650 1,690 1,760 2,360 2,300 5,970 6,450 120 118 17,200 17,300 \$4.85 \$5.51 \$0.73 \$0.73 \$16.00 ³ \$16.00 ³	1999 2000 2001 W W W W 3,960 4,050 4,490 1,600 1,650 891 1,690 1,760 1,680 2,360 2,300 2,540 5,970 6,450 3,870 120 118 118 17,200 17,300 15,200 \$4.85 \$5.51 \$5.51 \$0.73 \$0.73 \$0.73 \$16.00 ³ \$16.00 ³ \$16.00 ³	$\begin{array}{c c c c c c c c c c c c c c c c c c c $

^eEstimated. ^rRevised. W Withheld to avoid disclosing company prorietary data. -- Zero.

¹Data are rounded to no more than three significant digits, except prices.

²Includes only the rare earths derived from bastnasite as obtained from Molycorp, Inc.

³Source: Elements, TradeTech, Denver, CO.

⁴Source: Hefa Rare Earths Canada Co. Ltd., Vancouver, British Columbia, Canada.

TABLE 2

RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS¹

(Percentage of total rare-earth oxide)

	Bastna	aesite		Monaz	ite	
	Mountain Pass,	Bayan Obo, Inner	North Capel,	North Stradbroke Island,	Green Cove Springs,	Nangang,
Rare earth	CA, United States ²	Mongolia, China ³	Western Australia ⁴	Queensland, Australia ⁵	FL, United States ⁶	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

See footnotes at end of table.

TABLE 2--Continued RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS¹

	MonaziteC	Continued	Xe	notime	Rare eart	h laterite
	Eastern coast,	Mount Weld,	Lahat, Perak,	Southeast	Xunwu, Jiangxi	Longnan, Jiangxi
	Brazil ⁸	Australia ⁹	Malaysia ²	Guangdong, China ¹⁰	Province, China ¹¹	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

(Percentage of total rare-earth oxide)

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

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p. 205-210.

⁴Westralian Sands Ltd., 1979, Product specifications, effective January 1980: Capel, Australia, Westralian Sands Ltd. brochure, 8 p.

⁵Analysis from Consolidated Rutile Ltd.

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

⁷Xi, Zhang, 1986, The present status of Nd-Fe-B magnets in China—Proceedings of the Impact of Neodymium-Iron-Boron Materials on Permanent Magnet Users and Producers Conference, Clearwater, FL, March 2-4, 1986: Clearwater, FL, Gorham International Inc., 5 p.

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 ⁹Kingsnorth, Dudley, 1992, Mount Weld—A new source of light rare earths—Proceedings of the TMS and Australasian Institute of Mining and Metallurgy Rare Earth Symposium, San Diego, CA, March 1-5, 1992, Sydney, Australia, Lynas Gold NL, 8 p.

¹⁰Nakamura, Shigeo, 1988, China and rare metals—Rare earth: Industrial Rare Metals, no. 94, May, p. 23-28.

¹¹Introduction to Jiangxi Rare-Earths and Applied Products, 1985, Jiangxi Province brochure: International Fair for Rare Earths, Beijing, China, September 1985, 42 p. (in English and Chinese).

TABLE 3RARE-EARTH OXIDE PRICES IN 2003

		Standard package	Price
	Purity	quantity	(dollars per
Product (oxide)	(percentage)	(kilograms)	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
a a .			

See footnotes at end of table.

TABLE 3--Continued RARE-EARTH OXIDE PRICES IN 2003

		Standard package	Price
	Purity	quantity	(dollars per
Product (oxide)	(percentage)	(kilograms)	kilogram)
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			

¹Price for quantity greater than 40 kilograms is \$900.00 per kilogram.

²Price 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 COUNTRY¹

	200	2002		3
	Gross weight		Gross weight	
$Category^2$ and country	(kilograms)	Value	(kilograms)	Value
Cerium compounds (2846.10.0000):	(0)		(
Australia	1,930	\$32,200	1,680	\$14,200
Belgium	14,200	220,000	41,000	55,500
Brazil	185,000	430,000	50,900	263,000
Canada		1.260.000 r	46.200	336.000
France	- 4,960	289,000	12,500	224,000
Germany	528,000	1,490,000	318,000	1,050,000
Hong Kong	24,500	179,000	47,000	416,000
India	62,900	371,000	73,900	436,000
Japan	172,000 r	1,290,000 r	106,000	895,000
Korea, Republic of	620,000	2,600,000	104,000	466,000
Malaysia	174,000	792,000	126,000	465,000
Mexico	273,000	1,850,000	235,000	1,140,000
Netherlands	- 11,400	166,000	30,900	220,000
Singapore	53,200	79,400	20,300	118,000
South Africa	3,940	422,000	6,850	142,000
Taiwan	73,900	417,000	30,200	210,000
United Kingdom	98,200	387,000	123,000	566,000
Other	284,000	1,620,000	533,000	3,090,000
Total	2,740,000 r	13,900,000 r	1,910,000	10,100,000
Total estimated equivalent rare-earth oxide (REO) content	2,740,000 r	13,900,000 r	1,910,000	10,100,000
Rare-earth compounds ³ (2846.90.0000):			<i>. </i>	· · ·
Austria	61,800 ^r	1,570,000 r	47,900	1,190,000
Brazil	27,500	235,000	418,000	575,000
Canada	237,000 r	2,940,000 r	264,000	3,790,000
China	412,000 r	724,000 ^r	93,700	92,900
Colombia	2,430	21,000	3,780	9,120
Finland	15,400	275,000		
France	17,600	527,000	36,400	1,460,000
Germany	59,900	1,880,000	145,000	1,320,000
India	1,640	8,310	1,980	22,500
Japan		6,820,000 r	32,300	7,410,000
Korea, Republic of	157,000 r	1,050,000 r	139,000	841,000
Mexico	36,600	459,000 r	20,500	157,000
Taiwan	62,300	1,550,000	35,800	920,000
United Kingdom	41,000	1,230,000	8,200	182,000
Other	150,000 r	1,900,000 r	547,000	1,930,000
Total	1,340,000 r	21,200,000 r	1,790,000	19,900,000
Total estimated equivalent REO content		21,200,000 r	1,790,000	19,900,000

See footnotes at end of table.

TABLE 4--Continued U.S. EXPORTS OF RARE EARTHS, BY COUNTRY¹

	2002	2002		3
	Gross weight		Gross weight	
Category ² and country	(kilograms)	Value	(kilograms)	Value
Rare-earth metals, including scandium and yttrium (2805.30.0000):				
China	106,000 r	\$731,000 r	6,660	\$223,000
France	1	5,900	72	7,990
Germany	6,260	196,000	1,220	66,200
Japan	652,000	1,900,000	550,000	2,170,000
Korea, Republic of	957 ^r	112,000 r	2,060	104,000
Taiwan	1	7,050	39	4,560
United Kingdom	1,320	208,000	158	20,700
Other	319,000 r	2,730,000 r	48,000	656,000
Total	1,090,000	5,900,000 r	609,000	3,250,000
Total estimated equivalent REO content	1,310,000	5,900,000 r	730,000	3,250,000
Ferrocerium and other pyrophoric alloys (3606.90.0000):				
Argentina			2,040	5,730
Australia	13,100	414,000	48,900	1,740,000
Brazil	1,190	47,000	1,440	61,700
Canada	803,000 r	2,170,000 r	704,000	3,270,000
Chile	32,900	37,000	2,140	27,400
Colombia	9,610	12,400	119	2,890
France	1,120	91,200	11,400	112,000
Germany	861,000	1,540,000	957,000	1,300,000
Greece	43,300	65,800	57,000	108,000
Hong Kong	206,000	269,000	177,000	307,000
Italy	289	8,170	1,130	15,300
Japan	151,000	1,290,000	110,000	1,430,000
Korea, Republic of	2,050	74,400	2,150	55,900
Kuwait	82,300	82,200	82,300	71,500
Mexico	190,000 r	1,180,000	90,500	163,000
Netherlands	77,100	208,000	134,000	359,000
New Zealand	36,700	62,800		·
Saudi Arabia	13,500	17,300	50,000	61,900
Singapore	3,390	92,700	1,480	44,100
South Africa	´		246	6,620
Spain	188	16,700		·
Taiwan	23,000	110,000	986	64,500
United Arab Emirates	168,000	156,000	207,000	203,000
United Kingdom	267.000	574.000	251.000	741.000
Other	199,000 r	341,000 r	354,000	579,000
Total	3,180,000 r	8,860,000 r	3,250,000	10,700,000
Total estimated equivalent REO content	2.830.000 r	8.860.000 r	2.880.000	10,700,000
	,,	,,	,,-	- , , /

^rRevised. -- Zero.

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

²Harmonized Tariff Schedule of the United States category numbers.

³Inorganic and organic.

Source: U.S. Census Bureau.

 TABLE 5

 U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY¹

	200	2002 200		13	
	Gross weight		Gross weight		
Category ² and country	(kilograms)	Value	(kilograms)	Value	
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides,					
oxalates (2846.10.0000):	_				
Austria	76,500	\$337,000	166,000	\$677,000	
China	2,770,000	9,050,000	3,050,000	7,170,000	
France	725,000	4,420,000	155,000	2,390,000	
Japan	162,000	4,980,000	172,000	4,290,000	
Other	73,600	348,000	80,300	533,000	
Total	3,800,000	19,100,000	3,630,000	15,100,000	
Total estimated equivalent rare-earth oxide (REO) content	2,540,000	19,100,000	2,430,000	15,100,000	
Yttrium compounds content by weight greater than 19% but less than 85%					
oxide equivalent (2846.90.4000):					
China	57,300	858,000	63,000	941,000	
France	4,680	160,000	6,330	216,000	
Germany	10	10,100	4	4,790	
Japan	11,100	2,820,000	8,880	2,870,000	
United Kingdom					
Other	238	25,400	8,320	303,000	
Total	73,300	3,870,000	86,600	4,330,000	
Total estimated equivalent REO content	44,000	3,870,000	51,900	4,330,000	
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds					
except chlorides (2846.90.8000):					
Austria	75,200	1,550,000	76,700	2,690,000	
China	5,670,000	18,700,000	8,210,000	21,000,000	
Estonia	1,270,000	1,510,000	520,000	515,000	
France	1,600,000	11,800,000	2,080,000	15,700,000	
Germany	13,600	635,000	5,010	1,090,000	
Hong Kong	65,000	169,000	13,100	241,000	
Japan	231,000	3,780,000	536,000	5,460,000	
Norway	1,730	2,520,000	6	3,750	
Russia	571,000	1,140,000	1,020,000	1,860,000	
Taiwan	9	5,750	1	3,490	
United Kingdom	157,000	6,480,000	185,000	5,860,000	
Other	25,200	916,000	129,000	1,070,000	
Total	9,670,000	49,200,000	12,800,000	55,500,000	
Total estimated equivalent REO content	7,260,000	49,200,000	9,580,000	55,500,000	
Mixtures of REOs except cerium oxide (2846.90.2010):					
Austria	4,230	97,600	11,900	652,000	
China	1,010,000	3,220,000	1,670,000	4,740,000	
France	- 740	66,600			
Germany	- 		8,800	163,000	
Japan	19,700	994,000	17,600	458,000	
Russia	336	36,100	115	16,000	
United Kingdom	4,600	52,300	1,600	12,000	
Other	1,540	47,300	3,240	58,800	
Total	1,040,000	4,510,000	1,710,000	6,100,000	
Total estimated equivalent REO content	1,040,000	4,510,000	1,710,000	6,100,000	
Rare-earth metals, whether intermixed or alloyed (2805.30.0000):					
China	580,000	3,130,000	539,000	2,270,000	
Hong Kong	540	13,300			
Japan	536,000	5,870,000	176,000	1,600,000	
Russia	5	2,250	1,040	150,000	
United Kingdom	10,700	403,000	7,960	226,000	
Other	84,400	575,000	12,300	891,000	
Total	1,210,000	9,990,000	737,000	5,140,000	
Total estimated equivalent REO content	1,450,000 r	9,990,000	884,000	5,140,000	

See foonotes at end of table.

TABLE 5--Continued U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY¹

	200	2	200	3
	Gross weight		Gross weight	
Category ² and country	(kilograms)	Value	(kilograms)	Value
Mixtures of rare-earth chlorides, except cerium chloride (2846.90.2050):				
China	2,270,000	\$3,350,000	3,910,000	\$3,640,000
France	26,400	222,000	35,200	522,000
India	599,000	734,000	80,000	75,600
Israel	951,000	542,000	100,000	896,000
Japan	3,260	123,000	7,360	499,000
Netherlands	18,800	128,000	5,130	62,900
United Kingdom	18,600	89,700	2,400	26,200
Other	33,300	416,000	2,930	488,000
Total	3,920,000	5,600,000	4,150,000	6,210,000
Total estimated equivalent REO content	1,800,000	5,600,000	1,910,000	6,210,000
Ferrocerium and other pyrophoric alloys (3606.90.3000):				
Australia	2,310	32,100		
Austria	13,800	269,000	20,300	396,000
France	81,900	877,000	93,600	1,230,000
Other	2,780	38,700	804	29,600
Total	101,000	1,220,000	115,000	1,650,000
Total estimated equivalent REO content	89,500	1,220,000	102,000	1,650,000

-- Zero.

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

²Harmonized 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	1999	2000	2001	2002	2003
China	70,000	73,000	80,600	88,000	92,000
Commonwealth of Independent States ⁴	2,000	2,000	2,000	2,000	2,000
India	2,700	2,700	2,700	2,700	2,700
Kyrgyzstan:					
Compounds	956 ⁵	NA	NA	NA	NA
Metals	5,159 ⁵	7,736 5	3,800	100	NA
Malaysia	625 ⁵	446 5	351 5	240 ^r	200
Sri Lanka	120				
United States ⁶	W ^r	W ^r	W ^r	W ^r	
Total	81,600 ^r	85,900 ^r	89,500 ^r	93,000 r	96,900

^rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total." NA Not available. -- Zero.

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

²Table includes data available through June 13, 2004.

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

⁴Does not include Kyrgyzstan; information is inadequate to formulate reliable estimates for individual producing countries, including Kazakhstan, Russia, and Ukraine.

⁵Reported figure.

⁶Comprises only the rare earths derived from bastnaesite.

TABLE 7

MONAZITE CONCENTRATE: ESTIMATED WORLD PRODUCTION, BY COUNTRY $^{\rm l,\,2}$

(Metric tons of gross weight)

Country ³	1999	2000	2001	2002	2003
Brazil	200	200	200	200	200
India	5,000	5,000	5,000	5,000	5,000
Malaysia	1,147 4	818 4	643 ^{r, 4}	509 ^{r, 4}	450
Sri Lanka	200				
Total	6,550	6,020	5,840 ^r	5,710 ^r	5,650

Revised. -- Zero.

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

²Table includes data available through April 18, 2004.

³In 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. ⁴Reported figure.



FIGURE 1 PRINCIPAL SOURCES BY WEIGHT OF U.S. IMPORTS OF RARE EARTHS IN 2003