

# RARE EARTHS

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Rare earths were first produced commercially in the 1880s with the mining in Sweden and Norway of the rare-earth thorium-phosphate mineral monazite. Production in Scandinavia was prompted by the invention in 1884 of the Welsbach incandescent lamp mantle, which initially required the oxides of zirconium, lanthanum, and yttrium, with later improvements requiring only the oxides of thorium and cerium. The mantles also used small amounts of neodymium and praseodymium 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. Foreign production of monazite occurred in Brazil as early as 1887, and India began recovery of the ore in 1911. In 2000, rare-earth production was primarily from China, with lesser amounts in Brazil, India, Russia, and the United States.

The principal economic rare-earth ores are lateritic ion-adsorption clays and the minerals bastnäsite, loparite, and monazite (table 2). The rare earths are a moderately abundant group of 17 elements composed of scandium, yttrium, and the 15 lanthanides. 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. In rock-forming minerals, rare earths typically occur in compounds as trivalent cations in carbonates, oxides, phosphates, and silicates.

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 lanthanides comprise a group of 15 elements with atomic numbers 57 through 71 that include the following: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). 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,

## Rare Earths in the 20th Century

In 1900, rare earths were produced to supply materials for lighting applications. Cerium was recovered as a byproduct of processing the rare-earth thorium-phosphate mineral monazite for its thorium content. A small amount of cerium (1%) was added to thorium to create the mixture used to produce an incandescent lamp mantle. When heated, the oxides of thorium and cerium glowed a brilliant white and allowed homes, businesses, and factories a low-cost way to illuminate the evening hours. U.S. monazite production in 1900 was mainly from North Carolina, with a smaller amount from South Carolina, amounting to 412 metric tons valued at \$48,805. Rare earths also were mined for yttrium at the start of the 20th century. The yttrium-bearing minerals gadolinite and fergusonite and lesser amounts of zirconolite (zircon variety) were mined at Barringer Hill, TX, for use in the Nernst lamp. The incandescent lamp mantle industry was established in 1884 with mantles of zirconium, lanthanum, and yttrium oxides. By 1900, the zirconium oxide mantle mixture had been replaced with an improved, brighter oxide mixture of thorium and cerium. That same year, the Nernst lamp came into use and used rods or "glowers" made of 25% yttrium oxide and 75% zirconium oxide, essentially an yttria stabilized zirconia. In

this lamp, it was necessary to heat the glowers with an auxiliary device to about 700° C, at which point it became conductive and glowed with a brilliant white incandescence caused by the ceramic's resistance. With the advent of the electric incandescent lamp around 1912, yttrium oxide's use in Nernst glowers declined. The first large-scale use of rare-earth metals occurred in 1903 with the development of iron-bearing mischmetal (a natural mixture of rare-earth metals) in a pyrophoric cerium-rich alloy (ferrocium) for lighter flints.

In 2000, rare earths were produced in the United States by only one mine at Mountain Pass, CA. The mine produced rare-earth concentrates from the ore mineral bastnäsite. China was the world's leading producer of rare earths, producing most of its rare earths from ores of bastnäsite, monazite, and ion adsorption clays. Over the past 100 years, the use of rare earths grew from hundreds of tons in 1900 to tens of thousands of tons in 2000. The principal applications in 2000 were in automotive catalytic converters; glass polishing and ceramics; permanent magnets; petroleum refining catalysts; metallurgical additives and alloys, including rechargeable batteries; and phosphors for color monitors, televisions, and energy-efficient fluorescent lighting.

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.

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 (Weeks and Leicester, 1968, p. 667). 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. 671).

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.

In 2000, consumption was estimated to have increased as imports of individual rare-earth compounds increased. Production of bastnäsite continued in the United States as production of cerium concentrates resumed on a limited scale. As a result, imports of cerium compounds decreased (table 1). Since March 1998, refinery production at the Mountain Pass, CA, site of Molycorp, Inc., has been suspended because of low rare-earth prices on world markets and unresolved regulatory and permitting requirements for a wastewater system (Unocal Corp., 2000, p. 15).

Demand decreased for rare earths used in petroleum fluid cracking catalysts and in rare-earth phosphors for television, x-ray intensifying, and fluorescent and incandescent lighting. Yttrium was used primarily in lamp and cathode-ray tube phosphors, and lesser amounts were used in structural ceramics and oxygen sensors.

The domestic use of scandium increased in 2000, but overall consumption remained small. Commercial demand increased primarily as a result of increased demand for baseball and softball bats. Most scandium metal, alloys, and compounds were used in sporting goods equipment, metallurgical research, and analytical standards. Minor amounts were used in specialty lighting and semiconductors.

## Production

In 2000, one mining operation in California accounted for all domestic mine production of rare earths. Molycorp, a wholly owned subsidiary of Unocal Corp., mined bastnäsite, a rare-earth fluorocarbonate mineral, by open pit methods at Mountain Pass, CA. Mine production was estimated to be 5,000 metric tons (t) of rare-earth oxide (REO) in concentrates.

Refined lanthanides were processed by two companies in 2000. Molycorp ceased production of refined compounds from bastnäsite at its separation plant at Mountain Pass in 1998. Unocal's higher environmental-related expenses in 2000 were in part related to the decontamination and decommissioning of Molycorp's Washington, PA, rare-earth metals site. Unocal also set aside \$64 million for the future cost of the remediation of its operating oil and gas fields; this amount includes funds for Molycorp's Mountain Pass operation (Unocal Corp., 2001, p. 41-42).

Santoku Metal Industry Co., Ltd., of Japan was renamed Santoku Corp. in April 2000 (Santoku America, Inc., 2000, About us—Our history and our future, accessed July 18, 2001, at URL <http://www.santoku.com/About%20Us.htm>). Its U.S.

subsidiary, Santoku America, Inc., produced rare-earth magnet and rechargeable battery alloys at its operations in Tolleson, AZ. Santoku America produced both major types of high strength permanent magnets, namely neodymium-iron-boron and samarium-cobalt. For the rechargeable battery industry, Santoku produced nickel-metal hydride (Ni-MH) alloys incorporating specialty rare-earth mischmetals. The plant also produced a full range of rare-earth metals in cast and distilled forms.

Rhodia Rare Earths Inc. announced it would change its name effective January 1, 2001, to Rhodia Electronics and Catalysis, Inc. The new name reflects Rhodia's mission to be a development partner and supplier of rare earths and advanced materials for the electronics and catalysis markets worldwide (Rhodia Rare Earths, Inc., December 18, 2000, La lettre du president, accessed July 17, 2001, at URL <http://www.rhodia.ext.imagnet.fr/fr/index.htm>).

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 Anan Kasei, Ltd. (Rhodia Rare Earths, 67%, and Santoku Metal Industry Co., Ltd., 33%) in Kobe, Japan. These plants provide Rhodia's U.S. operations with most of their supply.

Grace Davison, a division of W.R. Grace & Co., refined rare earths from rare-earth chlorides and other rare-earth compounds for petroleum fluid cracking catalysts at Chattanooga, TN. Grace Davison also produced rare-earth compounds for chemical catalysis and polishing compounds.

Essentially all purified yttrium was derived from imported compounds. The minor amounts of yttrium contained in bastnäsite from Mountain Pass, CA, are not recovered as a separate product.

Three scandium processors operated in 2000. High-purity products were available in various grades, with scandium oxide produced at up to 99.999% purity. Sausville Chemical Co. refined scandium at its facilities in Knoxville, TN. The company expected to produce high-purity scandium compounds, including oxide, fluoride, nitrate, chloride, and acetate. Boulder Scientific Co. processed scandium at its Mead, CO, operations. It refined scandium primarily from imported oxides to produce high-purity scandium compounds, including diboride, carbide, chloride, fluoride, hydride, nitride, oxalate, and tungstate.

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

Principal domestic producers of neodymium-iron-boron magnet alloys were Magnequench International, Inc., Anderson, IN; and Santoku America, Inc. (previously Rhodia, Inc.), Tolleson, AZ. Leading U.S. producers of rare-earth magnets were Crumax Magnetics, Inc., Elizabethtown, KY; Electron Energy Corp., Landisville, PA; Magnaquench UG (previously Ugimag, Inc.), Valparaiso, IN; Magnequench, Inc. (MQ), Anderson, IN; and the Magnetic Materials Division of Hitachi Metal America, Ltd., Edmore, MI, and China Grove, NC.

World production of neodymium-iron-boron magnets in 1999, for which the latest data are available, was 13,500 t for sintered magnets and 2,740 t for bonded magnets (Roskill's Letter from Japan, 2001c). Since 1990, the growth rates for magnets have been 28.6% per year for the sintered and 25.7% for the bonded. Similar growth in demand occurred over the past decade (1990-1999) for the principal rare-earth magnet component neodymium and the alloying additive dysprosium.

In the last quarter of 1999, Moltech Corp. announced it had acquired Energizer Power Systems from Eveready Battery Co., forming the new wholly owned subsidiary Moltech Power Systems. Moltech Power Systems produced Ni-MH rechargeable batteries (Rare-earth Information Center Insight, 2000a).

MQ of Anderson, IN, announced it had purchased two companies related to its rare-earth magnet business. First, MQ purchased Ugimag's sintered samarium-cobalt and neodymium-iron-boron (Nd-Fe-B) permanent magnet operations in Singapore, Switzerland, the United Kingdom, and the United States (Valpariso, IN), from the Carbone Lorraine Group in November (Magnaquench, Inc., 2000a). In the second acquisition, MQ purchased Widia Magnet Engineering from Milacron, Inc. The new company was renamed Magnaquench GmbH. It is a wholly owned subsidiary of MQ. Located in Essen, Germany, the plant produces injection molded bonded magnets (Magnaquench, Inc., 2000b).

Demand increased for rare earths used in Ni-MH batteries. The rechargeable batteries are used in cellular phones, notebook computers, personal data assistants (PDAs), camcorders, and other portable devices. Japan, the leading producer, shipped 1.021 billion units in 2000, a 19% increase compared with 1999 (Roskill's Letter from Japan, 2001a). Ni-MH batteries were the leading rechargeable battery product, followed distantly by nickel-cadmium and lithium-ion types.

TradeTech L.L.C. announced the sale of its newsletter and rare earths and specialty metals business to High Tech Materials of Longmont, CO. The company's electronic monthly newsletter Elements is available by e-mail subscription via URL <http://www.RareEarthsMarketPlace.com>.

Cerac, Inc., was purchased by its chief executive officer in conjunction with the private equity group Facilitator Capital Fund.

Etrema Products, Inc., a wholly owned subsidiary of Edge Technologies, Inc., of Ames, IA, and the sole supplier of the giant magnetostrictive alloy TERFENOL-D<sup>®</sup>, signed an agreement with Westport Innovations, Inc., of Canada to supply the alloy for use in diesel engines. Westport Innovations plans to use the "smart" material to control fuel flow in natural gas fuel injectors in light-duty diesel engines. Smart materials have the ability to adapt to outside influences, such as external magnetic fields. TERFENOL-D<sup>®</sup> is an alloy of iron and the rare-earth elements terbium and dysprosium that expands or contracts with the application or removal of an external magnetic field. It is used in actuators, acoustic devices, sonar, ultrasonics, and other smart materials for the oil and gas industry (Etrema Products, Inc., 2000a).

## Consumption

Statistics on domestic rare-earth consumption were developed by surveying various processors and manufacturers, evaluating import-export data, and analyzing U.S. Government stockpile shipments. Domestic apparent consumption of rare earths increased in 2000 compared with that of 1999. Domestic consumption of rare-earth metals and alloys also increased in 2000, especially for those used in permanent magnets and rechargeable batteries.

Based on information supplied by U.S. rare-earth refiners and selected consumers and an analysis of import data, the approximate distribution of rare earths by use was as follows: automotive catalytic converters, 22%; glass polishing and ceramics, 39%; permanent magnets, 16%; petroleum refining catalysts, 12%; metallurgical additives and alloys, 9%; rare-

earth phosphors for lighting, televisions, computer monitors, radar, and x-ray intensifying film, 1%; and miscellaneous, 1%.

In 2000, yttrium consumption was estimated to have increased to 454 t from 428 t in 1999. Yttrium compounds and metal were imported from several sources in 2000. Yttrium was imported from China (73.8%); Japan (21.9%); the United Kingdom (2.7%); Germany (1.3%); and France (0.3%). The estimated use of yttrium, based on imports, was primarily in lamp and cathode-ray tube phosphors (92.5%), structural ceramics and abrasives (5.2%), and alloys (2.3%).

## Tariffs

In 2000, U.S. tariff rates specific to the rare earths, including scandium and yttrium, were unchanged from 1999 (U.S. International Trade Commission, 2000). Selected rare-earth tariff rates for countries with normal-trade-relations and non-normal-trade-relations status, respectively, were as follows: Harmonized Tariff Schedule of the United States (HTS) code 2805.30.0000 (rare-earth metals, including scandium and yttrium, whether intermixed or interalloyed), 5.0% ad valorem and 31.3% ad valorem; HTS code 2846.10.0000 (cerium compounds), 5.5% ad valorem and 35% ad valorem; HTS code 2846.90.2010 (mixtures of rare-earth oxides except cerium oxide), free and 25% ad valorem; HTS code 2846.90.2050 (mixtures of rare-earth chlorides), free and 25% ad valorem; HTS code 2846.90.4000 (yttrium-bearing materials and compounds containing by weight greater than 19% but less than 85% yttrium oxide equivalent), free and 25% ad valorem; HTS code 2846.90.8000 [individual rare-earth compounds, including oxides, nitrates, hydroxides, and chlorides (excludes cerium compounds, mixtures of REO, and mixtures of rare-earth chlorides)], 3.7% ad valorem and 25% ad valorem; HTS code 3606.90.3000 (ferrocium and other pyrophoric alloys), 5.9% ad valorem and 56.7% ad valorem; HTS code 7202.99.5040 [ferroalloys, other (including rare-earth silicide)], 5.0% ad valorem and 25% ad valorem; and HTS code 7601.20.9090 [aluminum alloys, other (including scandium-aluminum alloys)], free and 10.5% ad valorem.

Special rare-earth tariffs for Canada and Mexico were the result of Presidential Proclamation 6641, implementing the North American Free Trade Agreement, effective January 1, 1994. Under the agreement, tariff rates for most rare-earth products from Canada and Mexico were granted duty free status, and those that were scheduled for staged reductions have achieved duty free status. Tariff rates for most other foreign countries were negotiated under the Generalized Agreement on Tariffs and Trade Uruguay Round of Multilateral Trade Negotiations.

## 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 in the NDS at a future date.

## Prices

Rare-earth prices increased in 2000. The following estimates of prices were based on trade data from various sources. 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 \$1.38 per kilogram in 2000, a decrease from \$2.09 per kilogram in 1999. In 2000, imported rare-earth metal prices averaged \$11.52 per kilogram, a decrease from \$12.44 per kilogram in 1999. Mischmetal and specialty mischmetals comprised most 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 range of basic mischmetal was from \$5.00 to \$7.00 per kilogram (in metric ton quantities) at yearend 2000, unchanged from the yearend 1999 price range (Elements, 2000). The average price for imported cerium compounds, excluding cerium chloride, increased to \$4.57 per kilogram in 2000 from \$4.43 per kilogram in 1999. The primary cerium compound imported was cerium carbonate.

The estimated market price for bastnäsite concentrate was \$5.51 per kilogram (\$2.50 per pound). The price of monazite concentrate, typically sold with a minimum 55% rare-earth oxide content, including 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. In 2000, 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 Nd-Fe-B alloy, calculated from data supplied by several U.S. producers, was \$15.50 per kilogram (\$7.03 per pound), f.o.b. shipping point, 2,000-pound minimum. Most 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 decreasing to \$33.42 per kilogram (\$15.16 per pound) in 1999, the cost would be about \$0.33 per kilogram (\$0.15 per pound) for each percent addition.

Rhodia 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 2000, are listed in table 3. No published prices for scandium oxide in kilogram quantities were available. Yearend 2000 nominal prices for scandium oxide were compiled from information provided by several domestic suppliers and processors. Prices decreased from those of the previous year for most grades and were listed as follows: 99% purity, \$700 per kilogram; 99.9% purity, \$2,000 per kilogram; 99.99% purity, \$3,000 per kilogram; and 99.999% purity, \$6,000 per kilogram.

Scandium metal prices for 2000 were unchanged from those of 1999 (Alfa Aesar, 1999, p. 1023-1024) and were as follows: 99.99% REO purity lump, sublimed dendritic, ampouled under argon, \$175 per gram; 99.9% REO purity less-than-250-micron powder, ampouled under argon, \$395 per 2 grams; 99.9% purity lump, sublimed dendritic, ampouled under argon, \$267 per 2 grams; and 99.9% REO purity foil, 0.025-millimeter (mm) thick, ampouled under argon, 25 mm by 25 mm, \$98.80 per item.

Scandium compound prices as listed by Aldrich Chemical Co. (2000, p. 1476-1477) were as follows: scandium acetate hydrate 99.9% purity, \$61.40 per gram; scandium chloride hydrate 99.99% purity, \$53.80 per gram; scandium nitrate hydrate 99.9% purity, \$63.30 per gram; and scandium sulfate pentahydrate 99.9% purity, \$61.00 per gram. Prices for standard solutions for calibrating analytical equipment were \$23.80 per 100 milliliters of scandium atomic absorption standard solution and \$360.50 per 100 mm of scandium plasma standard solution.

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

## Foreign Trade

U.S. exports of rare earths declined slightly and imports increased in 2000 compared with those of 1999. U.S. exports totaled 9,490,000 kilograms (kg) valued at \$58.5 million, a slight decrease in quantity and an 8.5% increase in value compared with those of 1999 (table 4). Imports totaled 28,800,000 kg gross weight valued at \$142 million, a 4.7% increase in quantity and a 1% decrease in value compared with those of 1999 (table 5).

In 2000, U.S. exports of rare earths were mixed with cerium compounds, which remained essentially unchanged; exports of rare-earth compounds and ferrocium and pyrophoric alloys decreased; and exports of rare-earth metals increased. Principal destinations in 2000, in descending order, were Japan, Canada, the Republic of Korea, and Germany. The United States exported 1,370,000 kg of rare-earth metals valued at \$9.6 million, a 2.6% increase in quantity compared with that of 1999. Principal destinations, in descending order of quantity, were Japan, the Republic of Korea, the United Kingdom, and Germany. Exports of cerium compounds, primarily for glass polishing and automotive catalytic converters, were essentially unchanged at 3,950,000 kg valued at \$18.2 million. Major destinations, in descending order of quantity, were the Republic of Korea, Germany, Taiwan, and Mexico.

Exports of inorganic and organic rare-earth compounds decreased to 1,650,000 kg in 2000 from 1,690,000 kg in 1999, and the value of the shipments increased by 19% to \$23.4 million. Shipments, in descending order of quantity, were to Taiwan, the Republic of Korea, China, and Canada.

U.S. exports of ferrocium and other pyrophoric alloys decreased to 2,530,000 kg valued at \$7.39 million in 2000 from 2,660,000 kg valued at \$10.7 million in 1999. Principal destinations, in descending order of quantity, were Canada, the United Arab Emirates, Hong Kong, and Japan.

In 2000, U.S. imports of compounds and alloys increased for three out of seven categories, as 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 6,450,000 kg valued at \$29.4 million. After a decrease in imports in 1999, the quantity of cerium compounds imported increased by 8%, as a result of increased demand for automotive exhaust catalysts and despite the increased production from the major domestic producer. China was the major supplier for the sixth year in a row, followed by France, Japan, and Austria.

Imports of yttrium compounds containing between 19% and 85% of weight oxide equivalent (yttrium concentrate) decreased by 64% to 97,400 kg in 2000, and the value declined by 19% to \$2.59 million. China was the leading supplier of yttrium compounds, followed by Japan, France, and Germany.

Imports of individual rare-earth compounds, traditionally the major share of rare-earth imports, increased by 45% compared with those of 1999. Rare-earth compound imports increased to 15,000,000 kg valued at \$71.3 million. The major sources of individual rare-earth compounds were China, France, Estonia, and Japan. Imports of mixtures of rare-earth oxides, other than cerium oxide, decreased by 63% to 2,190,000 kg valued at \$9.5 million. The principal source of the mixed rare-earth oxides was

China, with smaller quantities imported from the United Kingdom, Japan, and Germany. Imports of rare-earth metals and alloys into the United States totaled 2,060,000 kg valued at \$23.7 million in 2000, a 39% increase in quantity compared with those of 1999. The principal rare-earth metal sources, in descending order of quantity, were China and Japan. Metal imports increased as demand for mischmetal for steel additives and specialty mischmetals for rechargeable batteries increased.

In 2000, imports of rare-earth chlorides decreased by 13% to 2,900,000 kg valued at \$3.98 million. Supplies of rare-earth chloride, in descending order of quantity, came from China, India, the United Kingdom, and Japan. In the United States, rare-earth chloride was used mainly as feed material for manufacturing fluid cracking catalysts. Imports of ferrocerium and pyrophoric alloys decreased by 2.3% to 133,000 kg valued at \$1.56 million. France was the principal supplier, with smaller amounts imported from Austria and Brazil.

## World Review

China, France, India, and Japan were major import sources of rare-earth chlorides, nitrates, and other concentrates and compounds (table 5). Thorium-free intermediate compounds as refinery feed were still in demand as industrial consumers expressed concerns with the potential liabilities of radioactive thorium, the costs of complying with environmental monitoring and regulations, and costs at approved waste disposal sites. In 2000, demand for rare earths increased in the United States, and imports increased by 4.6%. Consumption in China increased at a similar rate at 4.3%, while Japanese imports increased substantially by 11.6%.

In 2000, estimated world production of rare earths increased slightly to 83,300 t of REO (table 6). Production of monazite concentrate production was estimated to be 6,200 t (table 7).

World reserves of rare earths were estimated by the U.S. Geological Survey to be 100 million metric tons (Mt) of contained REO in 2000. China, with 43%, had the largest share of those world reserves. Australia's reserves include rare earths contained in monazite owing to its widespread availability as a very low-cost byproduct of heavy-mineral sands processing.

**Australia.**—Australia remained one of the world's major potential sources of rare-earth elements from its heavy-mineral sands and rare-earth laterite 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. In 2000, major producers of heavy-mineral sand concentrates, in order of potential production, in Australia were Iluka Resources, Ltd. (formerly RGC, Ltd., and Westralian Sands, Ltd.), Tiwest Joint Venture, Consolidated Rutile, Ltd. (CRL), and Cable Sands, Ltd.

Anaconda Nickel, Ltd., entered into an agreement with Ashton Mining, Ltd., and Lynas Corp., Ltd., to acquire all outstanding shares of the Mount Weld companies from Ashton. The Mount Weld deposit is a world-class rare earth carbonatite deposit with tantalum, niobium, and titanium content. After purchasing all issued shares of the three subsidiaries, Anaconda agreed to pay A\$3.2 million to Ashton on completion, to provide 50% of A\$7.5 million when the deposit is developed, and to receive from Lynas A\$3.2 million from the sale of Mount Weld Rare Earths Pty., Ltd. Lynas will contribute 50% of the A\$7.5 million and has appointed Anaconda to complete the final feasibility studies. A royalty, limited to \$A10.7 million is to be shared equally between Mount Weld Rare Earths Project and the Mount Weld Metals Project payable after all project and

financing costs are paid and based on a rate of 1% per year of revenues (Anaconda Nickel, Ltd., November 21, 2000, Anaconda reaches agreement with Ashton and Mount Weld, accessed August 27, 2001, at URL [http://new.anaconda.com.au/company\\_releases/0011/22111.pdf](http://new.anaconda.com.au/company_releases/0011/22111.pdf)).

Iluka was one of the world's largest producers of heavy-mineral sands in 2000 (Iluka Resources, Ltd., 2001, p. 9). The company operated eight mines in Australia and two in the United States. Iluka's Australian subsidiary, WA Titanium Minerals, operated six mines in Western Australia, two of which opened in 2000. The company commissioned the Capel North West Mine in January near Capel. In October, WA Titanium brought online its second operation, the North Mine and Newman concentrator near Eneabba. Other mining operations were the South Mine near Eneabba and the Yoganup, the Yoganup Extended, and the Busselton mines in the southwestern region. Iluka's two east coast mines, in which it had a 43% interest, were operated by CRL on North Stradbroke Island, New South Wales.

Iluka upgraded the ore grade at its Ouyen deposit in northwestern Victoria by 28%. The inferred resource at Ouyen was increased by 1.7 Mt to 7.7 Mt grading 11.4% heavy minerals, containing 40% ilmenite, 15% rutile, and 9% zircon (Iluka Resources, Ltd., 2000, p. 3-4).

Iluka calculated resources for two of its heavy-mineral sands deposits in the Perth Basin of Western Australia. The Red Gully deposit to the north and the Dandalup deposit to the south of Perth displayed resources of 942,000 t of heavy minerals (Iluka Resources, Ltd., 2000).

Australian Zirconia, Ltd., a wholly owned subsidiary of Alkane Exploration, Ltd., announced it had produced a 99.3% zirconium oxide and hafnium oxide product from its Dubbo hard-rock rare-earth-and-zirconium-bearing deposit in New South Wales. DEMA Pty., Ltd., was the feasibility study manager and consultant for the project. The multiminerals deposit is located on the Toongi alkaline intrusive that contains hafnium, lanthanides, niobium, tantalum, yttrium, and zirconium in the igneous rock trachyte. Based on a planned 200,000-metric-ton-per-year (t/yr) sulfuric acid leach process, the plant was expected to produce 3,500 t/yr zirconium oxide (and hafnium oxide), 500 t/yr to 1,500 t/yr of yttrium-lanthanide concentrate, and 900 t/yr of tantalum-niobium pentoxide concentrate (Australian Zirconia, Ltd., December 2000, Dubbo zirconia project, accessed May 8, 2001, at URL <http://www.alkane.com.au/zirconia.html>).

Basin Minerals, Ltd., announced the completion of a prefeasibility study of its Douglas heavy-mineral sands deposit in the Murray Basin in western Victoria. The Douglas deposit covers an area of 5,860 square kilometers and has a resource of 22.4 Mt of heavy minerals. The area contains the Acapulco, Bondi, Bondi East, and Echo strandline deposits containing 11.3 Mt of ilmenite (including leucoxene), 1.26 Mt of rutile, and 1.62 Mt of zircon. The project had an anticipated projected startup date of 2003 (Basin Minerals, [undated], Mineral sands exploration overview—Douglas project, accessed May 2, 2001, at URL <http://www.basinminerals.com.au/projects.html>).

Basin Minerals explored five heavy-mineral sands deposits in the Murray Basin area of South Australia, Victoria, and New South Wales. The principal deposits were the Douglas project in Victoria, the Culgoa project in northern Victoria, the Baranald-Swan Hill in New South Wales and Victoria, the Oakville in northern South Australia, and the Pooncarie in western New South Wales. Total resources of the Douglas and the Culgoa deposits were 24.4 Mt of heavy-mineral concentrates contained in 393 Mt of ore grading 6.2% heavy minerals,

including monazite (Basin Minerals, [undated], Mineral sands exploration overview—Table 1, accessed May 2, 2001, at URL <http://www.basinminerals.com.au/projects.html>).

Basin Minerals acquired additional land adjacent to its Douglas deposit in Victoria. The State of Victoria awarded successful bids to Basin Minerals for block 2 in the Murray Basin which includes the former CRL WIM 100 deposit with 860 Mt of ore grading 5.9% heavy minerals (Mineral Sands Report, 2000b).

BeMaX Resources NL announced the results of its pilot plant at its Ginkgo Mineral Sands Joint Venture (MSJV). The MSJV partners were BeMaX (50%), Imperial Mining (Aust) NL (25%), and Probo Mining Pty. Ltd. (25%). Located 120 kilometers (km) north of Mildura, Victoria, the Ginkgo deposit has an inferred resource of 260 Mt grading 2.6% heavy minerals. Initial tests showed product suitable for market including ilmenite, rutile, leucosene, and zircon (BeMaX Resources NL, April 3, 2000, Update—Ginkgo mineral sands deposit, accessed March 13, 2001, via URL <http://www.bemax.com.au/Announcements00.html>).

BeMaX purchased Imperial Mining's 25% share of MSJV, raising BeMaX's holdings to 75%. Imperial Mining was a wholly owned subsidiary of Imperial One, Ltd. (BeMaX Resources NL, October 10, 2000, Completion of purchase of Imperial Mining (Aust) NL, accessed March 13, 2001, via URL <http://www.bemax.com.au/Announcements00.html>).

BeMaX released information on a heavy-mineral strandline discovery that straddles BeMaX's BIP Joint Venture property and the property of Iluka Resources in the Murray Basin. The adjacent Snapper (BeMaX) and Trelega (Iluka) deposits straddle the mining exploration claims at the southwest edge of BIP Joint Venture's EL5474 property in Victoria (BeMaX Resources NL, October 10, 2000, Mineral Sands discovery straddles boundary of BeMaX's and Iluka's Properties, accessed March 13, 2001, via URL <http://www.bemax.com.au/Announcements00.html>).

Mineral Deposits, Ltd. (MDL), stated that it would restart its Viney Creek dredge mine in New South Wales in 2001 because of increased demand for heavy minerals and a weak Australian dollar against the U.S. dollar. The 2,500-ton-per-hour dredge was placed on standby in April 1999 because of weak demand for rutile and zircon. The dredge will be refurbished in the last quarter of 2000. MDL's Hawks Nest dry mill continued to operate with feed from its smaller dredge operation at Fullerton, New South Wales (Mineral Sands Report, 2000c).

Tiwest Joint Venture, an Australian collaboration of U.S.-based Kerr McGee Chemical LLC's subsidiary KMCC Western Australia Pty., Ltd., and Australian-based Ticor Resources Pty., Ltd., produced heavy-mineral sands from its Cooljarloo Mine in Western Australia. In 2000, Tiwest processed 918,000 t of heavy-mineral concentrates compared with 548,498 t of heavy-mineral concentrates in 1999 (Mineral Sands Report, 2001c). The large increase in production was the result of the Cooljarloo Mine upgrade project in 2000. The capacity of heavy-mineral concentrates at Cooljarloo was increased to 675,000 t/yr from 535,000 t/yr, a 20% gain. Tiwest's expansion cost was A\$20 million and was designed and implemented by contractor HBH Consultants (The Institution of Engineers, Australia, 2001, Australian Engineering Excellence Awards 2000—Cooljarloo Mine upgrade project for the Tiwest joint venture, accessed March 22, 2001, at URL [http://www.ieaust.org.au/events/aeaa\\_entrants/aeaa\\_entrantdetails8.html](http://www.ieaust.org.au/events/aeaa_entrants/aeaa_entrantdetails8.html)).

RZM Pty., Ltd., purchased Western Metals, Ltd.'s 30% stake in the Wemen heavy-mineral sands project in the Murray Basin, Victoria, for A\$5 million. Following the buyout, RZM entered

into a 50-50 joint venture with the Australian company Sons of Gwalia for its Murray Basin mineral resource tenements and freehold land and a 50% share of RZM's heavy-mineral sands processing equipment and operations at Tomago, New South Wales. Production from the deposit is scheduled for 2001. Wemen is forecast to produce heavy-mineral sands over the 6 years of the mine's life (Industrial Minerals, 2000a).

**Austria.**—Treibacher Industrie AG announced it was being purchased for more than \$100 million by August Finck Group of Munich, Germany. Treibacher AUERMET Produktionsges m.b.H, the rare-earth subsidiary of Treibacher Industrie AG, is expected to continue its planned expansion. Treibacher's capacity was 8,000 t/yr of rare-earth products and alloys and produced lighter flints, mischmetal, hydrogen storage alloys for batteries, vacuum alloys, mixed rare-earth compounds for fluid cracking catalysts, ceramic materials, additives for glass and ceramics, and specialty pure metals and alloys (Rare-earth Information Center News, 2000a).

**Brazil.**—Reserves of monazite contained in marine alluvial deposits were 42,000 t, and in stream placers, 40,000 t in 1999, the latest available data. The reserves of marine origin were distributed in deposits primarily in the States of Rio de Janeiro (26,730 t), Bahia (10,186 t), and Espírito Santo (4,136 t). The main placer reserves were in the States of Minas Gerais (24,396 t), Espírito Santo (11,372 t), and Bahia (3,481 t) (Fabricio da Silva, 2000, p. 107-108).

**China.**—Production of rare-earth concentrates in China was 70,000 t REO in 1999, the latest available data. Refined and processed products reached 60,000 t REO. Production of individual high-purity rare-earth compounds and metals was 25,000 t REO, an increase of 66% from those of 1998. Consumption within China increased by 4.3% in 1999 to about 16,000 t REO. Metallurgical applications, the major domestic use, consumed 5,200 t of equivalent REO (China Rare Earth Information, 2000a).

In 1999, China produced 160 million Ni-MH batteries containing 500 t of rare-earth metals. Rare-earth-containing steel consumed 400 t of rare earths as an alloying agent in 700,000 t of steel. Cast iron, a traditional application of rare-earth metals, consumed 3,800 t in making 1.1 Mt of metal in 1999. Nonferrous alloys, including aluminum wire and cable, used 800 t of rare earths, primarily for grain refinement and improved conduction. Consumption of rare earths by the oil industry was 3,800 t in fluid-cracking catalysts (China Online, [April 2000], China's consumption rare earth to rise 10%/yr, accessed October 11, 2000, at URL [http://www.chinaonline.com/industry/metal\\_mining/NewsArchive/Secure/april/B200032214a.asp](http://www.chinaonline.com/industry/metal_mining/NewsArchive/Secure/april/B200032214a.asp)).

Inner Mongolian Rare Earth Group, Inc. (IMREG), was established in Baotou, Inner Mongolia, in November 1999 to address the status of the industry. Its primary goals were to integrate rare-earth research and development, production, and trade; to provide quality products; and to monitor the rare-earth industry of the region. The state-owned entity will also control the rate of rare-earth concentrate production and adjust the product structure to the market. IMREG expects to strengthen the development of the downstream processes and products and plans to improve international cooperation (China Rare Earth Information, 2000c).

Sichuan Panxi Rare Earth, Ltd., was declared bankrupt in May 2000. The company had capacity to process 2,000 t/yr of bastnäsite concentrate. Sichuan Panxi operated from May 1996 until January 1998 in Xi-xiang Village, Xichang City, in Sichuan Province (China Rare Earth Information, 2000b). The availability of rare earths from China continues to be strong,

especially from Inner Mongolia. The rare-earth content of the iron ore mined at Baiyun Obo, Inner Mongolia, ranges from 400,000 t/yr to 500,000 t/yr REO (China Rare Earth Information, 2000d). Only a portion of this material is processed annually to recover rare earths.

Rhodia Rare Earths announced the formation of a joint venture with Beijing Founder Group Co., Ltd., and Liyang Licheng Economic General Industrial Co., Ltd., to group the holdings of the Liyang rare-earth plant and to develop new manufacturing units using Rhodia's expertise. Located in Jiangsu Province near Shanghai, the joint venture will be called Liyang Rhodia Founder Rare Earth New Material Co., Ltd. Rhodia Rare Earths will have a 45% share in the new company, which plans to develop products for the electronic, automotive, glass, and chemical markets (Rhodia Rare Earths, Inc., September 7, 2000, Rhodia develops its rare-earth activities in China, accessed July 17, 2001, at URL <http://www.rhodia.ext.imagnet.fr/fr/index.htm>).

**France.**—Rhodia of France and CTI, Inc., of the United States have signed an agreement to develop and supply rare-earth compounds used in medical imaging devices based on positron emission tomography (PET). Medical imaging with PET is based on recording the positron emissions from an intravenous tracer (Rhodia Rare Earths, Inc., June 21, 2000, Rhodia/CTI, Inc. agreement for the use of rare earths in state-of-the-art medical imaging, accessed July 18, 2001, at URL <http://www.rhodia.ext.imagnet.fr/fr/index.htm>). CTI manufactures whole-body 2D and 3D PET scanning devices that incorporate the rare-earth compound lutetium oxyorthosilicate (LSO) as a photon detector crystal. CTI grows LSO scintillation crystals and produces the PET detectors that incorporate the crystals (CTI, Inc., [2000], Detector systems, accessed July 19, 2001, at URL [http://www.cti-pet.com/cti\\_detector.html](http://www.cti-pet.com/cti_detector.html)).

**India.**—Exploration for heavy-mineral sands has increased. Australian-based MDL and Iscor, Ltd., have formed an alliance to complete feasibility studies on three deposits in the State of Tamil Nadu at Kudiraimozhi, Sattankulam, and Navaladi (Mineral Sands Report, 2001b).

MDL and Iscor have signed a memorandum of understanding to form an alliance to develop two heavy-mineral sands deposits in Tamil Nadu State. The Tamil Nadu deposits at Kudiraimozhi and Navaladi-Sattankulam contain 1 billion metric tons of ore grading 6.2% ilmenite, 0.4% rutile, and 0.7% zircon (Mineral Deposits, Ltd., November 1, 2000, Announcements—Indian mineral sands project, accessed June 14, 2001, via URL <http://www.mineraldeposits.com.au/Announcements2000.html>).

Kerala Minerals and Metals, Ltd. (KMML), is planning an expansion of its operations at Chavara. KMML has reserves of 18 Mt grading up to 50% heavy minerals. The heavy minerals contain 65% to 75% ilmenite, 5% to 7% rutile, and 4% to 8% zircon (Titanium Minerals Outlook, 2000).

**Japan.**—Japan refined 5,625 t of rare earths in 2000 from imported ores and intermediate raw materials, an increase of 10% from that of 1999 (Roskill's Letter from Japan, 2001d). Imports of rare earths during the year were 26,928 t, an increase of 18% from those of 1999. The value of imports increased to ¥23,843 million in 2000 from ¥17,812 million in 1999. Japanese rare-earth imports of yttrium oxide, cerium oxide, lanthanum oxide, rare-earth metals, and cerium compounds (other than cerium oxide) increased. Imports of rare-earth compounds (including intermediate raw materials) and ferrocenium decreased. Imports from the United States were 530 t, a decrease from the 609 t imported in 1999.

China continued as the leading source of rare-earth imports

for Japan with 22,431 t, representing 81% of the total. Imports from China in 2000 were as follows: rare-earth metals, 6,993 t; cerium compounds, 4,977 t; cerium oxide, 3,821 t; rare-earth compounds, 3,786 t; lanthanum oxide, 1,568 t; yttrium oxide, 1,181 t; rare-earth chlorides, 77 t; and ferrocenium, 28 t (Roskill's Letter from Japan, 2001b).

**Kenya.**—Tiomin Resources, Inc., of Toronto, Canada, raised Can\$5 million through the private offering of warrants for investments in its Kwale heavy-mineral sands deposit. The money was expected to be used to acquire surface mining rights at its Kwale deposit and to finalize detailed engineering plans for the heavy-mineral sands mine (Mineral Sands Report, 2000e). The Kwale deposit is divided into three economic zones of Pliocene age: the North Dune, the Central Dune, and the South Dune. Monazite and other heavy minerals are contained in the Magarini Sands Formation. The magarini sands form a belt of low hills believed to be aeolian in origin. Resources of the Kwale deposit are 200 Mt of ore (Tiomin Resources, Inc., [undated], Kwale (rutile, ilmenite and zircon), accessed May 16, 2001, via URL <http://www.tiomin.com/s/Properties.asp?PropertyInfoID=316&PropertyMapID=1034>).

Based on the results of a feasibility study by LTA Process Engineering Pty., Ltd., of South Africa and Ausenco of Australia, Tiomin planned to start construction at Kwale in 2001. During its first 6 years, the mine is expected to produce 37,000 t/yr of zircon. Kwale has a mine life of 14 years (Industrial Minerals, 2000e).

**Mozambique.**—Kenmare Resources plc of Dublin, Ireland, bought the heavy-mineral sands dry separation plant from BHP, Ltd.'s Beenup Mine in Western Australia, which closed in 1999 after being in operation less than a year (Industrial Minerals, 2000d). The 650,000 t/yr plant was purchased for \$4.7 million and was expected to be installed at the Moma Titanium Minerals Project in Mozambique (Kenmare Resources plc, 2000a).

Kenmare had previously purchased BHP's wet concentrator in January for \$1.4 million (Industrial Minerals, 2000c). The acquisition of both plants from the Beenup Minsands Project is expected to save Kenmare in excess of \$60 million in capital expenditures. The Moma Titanium Minerals Project is scheduled to begin production in late 2002 (Kenmare Resources plc, 2000b).

**South Africa.**—Iskor announced it would begin development of its Hillendale Mine in Kwazulu Natal Province in the second quarter of 2001. Full production capacity of the mine, expected to be reached in 2003, will be 550,000 t/yr ilmenite, 100,000 t/yr zircon, 40,000 t/yr rutile, and 10,000 t/yr leucogene. Reserves at the Hillendale deposit are 73 Mt grading 5.6% valuable heavy minerals (excluding magnetite) (Iskor, Ltd., [undated], Heavy minerals—Hillendale, accessed April 22, 2001, via URL <http://www.iscor.com/mainframe.asp?imgname=01>).

Construction of the Hillendale Mine and wet concentrator plant began in April at a cost of \$137 million. Construction also began on a central mineral separation plant at Empangeni, 20 km from the mine site. The separation plant was expected to come on-stream in the third quarter (Industrial Minerals, 2000b).

Ticor, Ltd., announced in October that it began a review of Iskor's heavy-mineral sands deposits in South Africa. Ticor was interested in acquiring a 50% share of the project, which has reserves of 16 Mt of heavy minerals. The project consists of three deposits: the Hillendale, the Fairbreeze, and the Gravelotte. The Hillendale was scheduled to be the first mine developed. The mine life of the three deposits is at least 20 years (Mineral Sands Report, 2000d).

Namakwa Sands (Pty), Ltd., a wholly owned subsidiary of Anglo American plc, increased its heavy-mineral sands

production as a result of the completion of its phase two expansion. Construction of the project, which was funded at 1.2 billion rand in 1997, was completed in 1999. Heavy-mineral sands were produced from its mine at Brand-se-Baai. Heavy-mineral concentrates were produced from its dry mill at Koekenaap (Mineral Sands Report, 2001a). The phase two expansion increased ore capacity to 12 million metric tons per year (Mt/yr) from 4 Mt/yr. The mine life of the deposit is 35 years.

Richard Bay Minerals completed construction of a new heavy-mineral sands processing plant. Completed in October 1999, the plant is designated mining plant E (Joseph, 2001).

## Current Research and Technology

Rare-earth Ni-MH batteries are finding increased use in automobiles. The batteries are a powder alloy of mischmetal [nickel (Ni), cobalt (Co), manganese (Mn), and aluminum (Al)] pasted on a Ni-plated sheet. The principal alloy is produced by rapid solidification followed by a heat treatment and chemical of physical modification to increase the reactive Ni surface area. The Ni electrode is made of a spherical powder alloy of nickel-zinc-cobalt hydroxide (Ni, Zn, Co) (OH)<sub>2</sub> within a foamed Ni or Ni-fiber layer with a cobalt oxyhydroxide (CoOOH) coating. Ni-MH batteries are used in both hybrid electric vehicles (HEV) and pure electric vehicles (PEV). Commercially available HEVs in the United States in 2000 were the 1-liter, 3-cylinder-engine Honda Insight and the 1.5-liter, 4-cylinder-engine Toyota Prius. The Prius' Ni-MH battery produces 274 volts, and the Insight's outputs 144 volts. PEVs are produced internationally by Daihatsu, Honda, Mazda, Mitsubishi, Nissan, Subaru, Suzuki, and Toyota. Driving ranges of the PEVs vary from 55 km to 240 km (Rare-earth Information Center News, 2000b).

Yttria-stabilized zirconia (YSZ), a material extensively used as an oxygen sensor in automobile engines, has been adapted for use as a sulfur dioxide (SO<sub>2</sub>) sensor. The sensor is a layered device with a silver-coated platinum grid, a layer of silver sulfate-based salt, a YSZ ceramic layer, and a platinum electrode. To detect SO<sub>2</sub>, the compound must first be oxidized to SO<sub>3</sub> on the platinum grid. In the presence of SO<sub>3</sub>, the O<sub>2</sub> is dissociated on the platinum reference electrode, and the O<sup>2-</sup> is conducted through the YSZ. The reaction  $2Ag + O^{2-} + SO_3 = Ag_2SO_4 + 2e^-$  occurs at the sensing electrode. This electron imbalance causes a linear electromagnetic field (EMF) to occur between the reference electrode and the sensing electrode that is based on the SO<sub>2</sub> concentration. The concentration of SO<sub>2</sub> can be calculated from 1 ppm to 1,000 ppm using the Nernst equation and the linear slope of the EMF (Rare-earth Information Center Insight, 2000b).

Sixteen years after the first quasicrystalline material was discovered, researchers created the first binary quasicrystal using metallic ytterbium and cadmium. Until the development of the cadmium-ytterbium compound (Cd<sub>5</sub>Yb), it was believed that three or more elements were required to form a quasicrystal. Quasicrystals have long-range atomic ordering but do not have a periodic lattice like a normal crystal. The rare-earth quasicrystal exhibits primitive icosahedral (fivefold) symmetry, and unlike previously stable quasicrystals that are peritectic, it is a congruently melting compound (Tsai and others, 2000).

A rare-earth compound was developed that may be used as a scintillation detector. The lanthanum chloride compound was doped with 10% trivalent cerium and emits at 330 and 352 nanometers. The compound cerium-doped lanthanum chloride

reportedly had better energy resolution and improved response times than the thallium-doped sodium iodine, the most commonly used scintillation detector material. Scintillation detectors are used to detect x rays and gamma rays by emitting an optical photon, which is a decay product that results from being struck by the incoming radiation. Future uses are likely to be in situations that require high-energy resolution (Loef and others, 2000, p. 1467-1468).

Components for the next generation of the U.S. Navy's hybrid sonar system are being developed using rare earths by Etrema Products, Inc. Using TERFENOL-D<sup>®</sup>, an iron-terbium-dysprosium alloy, the sonar system combines traditional piezoceramic technology to produce an improved detector system for the Navy's new class of destroyers. The new hybrid materials reportedly created smaller sonar sound sources with higher power and broader bandwidth (Etrema Products, Inc., 2000b).

A new technique for separating rare earths was created using selective reduction and fractional distillation. The process creates separation factors two orders of magnitude greater than those for solvent extraction (SX) (liquid-liquid extraction). The separation is based on the fact that rare-earth trichlorides can be selectively reduced to dichlorides by specific dihalide-reducing agents. The unreduced trichlorides are distilled off creating a two-group separation (Uda and others, 2000). Although the authors claim a large advantage in separation, others believe the technique is a batch process, while SX is a continuous process. A potential drawback of the process was high energy consumption; the new technique's reduction process requires keeping the rare earth at 700° C to 800° C for several hours, followed by vacuum distillation at about 900° C, and deposited at 600° C to 700° C (Rare-earth Information Center Insight, 2001b).

Researchers developed a new process that will allow the rare earth cerium dioxide to be used as a sunscreen. The process coats the cerium dioxide particles with a 10 nanometer layer of boron nitride which eliminated agglomeration, passivated the cerium catalytic activity, and produced a slippery feel. When incorporated into an organic thin film, the coated cerium particles had higher transparency and greater UV blocking than either titanium dioxide or zinc oxide, the commonly used sunscreen ingredients. The improved sunscreen reportedly reduced sunburn, reduced skin aging, and reduced the potential causes of skin cancer (Rare-earth Information Center Insight, 2001a).

A red-emitting rare-earth phosphor (lithium-doped Gd<sub>2</sub>O<sub>3</sub>:Eu<sup>3+</sup>) was developed by researchers in Korea for color flat panel field emission displays. The phosphor reportedly had higher cathodoluminescence than either europium-doped yttrium oxide and europium-doped yttrium oxysulfide, the widely used commercial phosphors. The addition of lithium provided two material advances: first, it improved the sol-gel produced morphology from irregularly shaped 0.5 micron shapes to consistently sized pseudospherical particles of 2 to 3 microns; and second, it is believed to become incorporated into the crystal structure as a coactivator, transferring electron beam energy to the trivalent europium (Eu<sup>3+</sup>) and creating a higher efficiency than that of Eu<sup>3+</sup> by itself (Park and others, 2000).

The U.S. Department of Energy (DOE) announced the construction of the world's first hybrid fuel cell manufactured by Siemens Westinghouse Power Corp. The 220-kilowatt fuel cell and microturbine powerplant incorporate rare earths. The powerplant uses a solid oxide fuel cell (SOFC) to convert natural gas directly to electricity with nearly zero emissions. Power is produced electrochemically by passing a hydrogen-rich



fuel over an anode and air over a cathode and separating the two by an electrolyte. In producing electricity, the only byproducts of the SOFC are heat, water, and carbon dioxide. Operating at 1,800° F, the SOFC's waste exhaust gas will power a microturbine and enhance performance by 10%. The culmination of the government-industry partnership program will be a 1-megawatt (1,000-kilowatt) fuel-cell-microturbine powerplant to be completed in late 2002 at Fort Meade, MD (U.S. Department of Energy, April 17, 2000, Department of Energy announces world's first "hybrid" fuel cell-turbine, accessed August 1, 2001, at URL [http://fossil.energy.gov/techline/tl\\_fc\\_solidox\\_fat.html](http://fossil.energy.gov/techline/tl_fc_solidox_fat.html)).

Research on the characterization and development of magnetic refrigeration alloys had been funded by the DOE. Scientists at the Ames Laboratory, where the materials were first developed, were rewarded with a 4-year project to study promising alloys. A team of 10 metallurgists, physicists, and chemists will explore the properties of the magnetic refrigeration group of gadolinium-silicon-germanium alloys. Ames Laboratory scientists Vitalij K. Pecharsky and Karl Gschneidner, Jr., first uncovered the energy-efficient characteristics of the alloys. A substantial advance in energy science, the use of these rare-earth alloys in automobile and home cooling and heating systems will provide substantial environmental benefits and energy savings (Ames Laboratory, 2000).

## Outlook

The use of rare earths, especially in automotive pollution catalysts, permanent magnets, and rechargeable batteries, is expected to continue to increase as future demand for automobiles, electronics, computers, 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 throughout the decade. Future growth is forecast for rare earths in rechargeable Ni-MH batteries, fiber optics, and medical applications, including magnetic resonance imaging contrast agents, PET scintillation detectors, medical isotopes, and dental and surgical lasers. Long-term future 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 world-class rare-earth deposits in Australia and China have yet to be developed because world demand is currently [2000] being satisfied by existing production (Singer, 1995). World resources should be adequate to fulfill 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 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.

World markets are expected to continue to be very competitive based on lower wages 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 STATISTICS 1/

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

	1996	1997	1999	1999	2000
Production of rare-earth concentrates 2/	20,400	10,000 e/	5,000 e/	5,000 e/	5,000 e/
Exports:					
Cerium compounds	6,100	5,890	4,640	3,960	4,050
Rare-earth metals, scandium, yttrium	250	991	724	1,600	1,650
Ores and concentrates	2	--	--	--	--
Rare-earth compounds, organic or inorganic	2,210	1,660	1,630	1,690 r/	1,760
Ferrocerium and pyrophoric alloys	4,410	3,830	2,460	2,360	2,300
Imports for consumption: e/					
Monazite	56	11	--	--	--
Cerium compounds	3,180	1,820	4,940	5,970 r/	6,450
Ferrocerium and pyrophoric alloys	107	121	117	120	118
Metals, alloys, oxides, other compounds	14,000	10,000	8,950	17,200	17,300
Stocks, producers and processors, yearend	NA	NA	NA	NA	NA
Consumption, apparent	NA	NA	NA	NA	NA
Prices, yearend, per kilogram:					
Bastnäsitate concentrate, REO basis	\$2.87	\$3.53 e/ r/	\$4.19 e/ r/	\$4.85 e/ r/	\$5.51 e/
Monazite concentrate, REO basis	\$0.48	\$0.73	\$0.73	\$0.73 e/	\$0.73 e/
Mischmetal, metal basis	\$8.75 3/	\$8.45 3/	\$16.00 3/	\$16.00 3/	\$16.00 3/
Employment, mine and mill	NA	NA	NA	NA	NA
Net import reliance as a percentage of apparent consumption 4/	(5/)	(5/)	(5/)	(5/)	(5/)

e/ Estimated. r/ Revised. NA Not available. -- Zero.

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

2/ Comprises only the rare earths derived from bastnäsitate as obtained from Molycorp, Inc.

3/ Source: Elements, TradeTech, Denver, CO.

4/ Imports minus exports plus adjustments for Government and industry stock changes.

5/ Net importer.

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

(Percentage of total rare-earth oxide)

Rare earth	Bastnasite, Mountain Pass, CA USA 2/	Bastnasite, Bayan Obo Inner Mongolia China 3/	Monazite, North Capel, Western Australia 4/	Monazite, North Stradbroke Island, Queensland Australia 5/	Monazite, Green Cove Springs, FL, USA 6/	Monazite, Nangang, Guangdong, China 7/
Cerium	49.10	50.00	46.00	45.80	43.70	42.70
Dysprosium	trace	.1000	.7000	.6000	.9000	.8000
Erbium	trace	trace	.2000	.2000	trace	.3000
Europium	.1000	.2000	.0530	.8000	.1600	.1000
Gadolinium	.2000	.7000	1.49	1.80	6.60	2.00
Holmium	trace	trace	.0530	.1000	.1100	.1200
Lanthanum	33.20	23.00	23.90	21.50	17.50	23.00
Lutetium	trace	trace	trace	.0100	trace	.1400
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	.8000	.8000	2.53	3.10	4.90	3.00
Terbium	trace	.1000	.0350	.3000	2600	.7000
Thulium	trace	trace	trace	trace	trace	trace
Ytterbium	trace	trace	.1000	.1000	.2100	2.40
Yttrium	0.10	trace	2.40	2.50	3.20	2.40
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

See footnotes at end of table.

TABLE 2--Continued  
RARE EARTH CONTENTS OF MAJOR AND POTENTIAL SOURCE MINERALS 1/

(Percentage of total rare-earth oxide)

	Monazite, east coast, Brazil 8/	Monazite, 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	4000
Dysprosium	.4000	.2000	8.30	9.10	trace	6.70
Erbium	.1000	.2000	6.40	5.60	trace	4.90
Europium	.1000	.4000	trace	.2000	.5000	0.10
Gadolinium	1.00	1.00	3.50	5.00	3.00	6.90
Holmium	trace	.1000	2.00	2.60	trace	1.60
Lanthanum	24.00	26.00	1.24	1.20	43.40	1.82
Lutetium	not determined	trace	1.00	1.80	.1000	.4000
Neodymium	18.50	15.00	1.60	3.50	31.70	3.00
Praseodymium	4.50	4.00	.5000	.6000	9.00	.7000
Samarium	3.00	1.80	1.10	2.20	3.90	2.80
Terbium	.1000	.1000	.9000	1.20	trace	1.30
Thulium	trace	trace	1.10	1.30	trace	.7000
Ytterbium	.0200	.1000	6.80	6.00	.3000	2.50
Yttrium	1.40	trace	61.00	59.30	8.00	65.00
Total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

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

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TABLE 3  
RHODIA RARE EARTH OXIDE PRICES IN 2000

Product (oxide)	Percentage purity	Standard package quantity (kilograms)	Price (dollars per kilogram)
Cerium	96.00	25	19.20
Do.	99.50	900	20.85
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	2,500.00
Ytterbium	99.00	10	230.00
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.

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

Category and country 2/	1999		2000	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
<b>Cerium compounds: (2846.10.0000)</b>				
Australia	8,060	\$42,200	5,630	\$39,000
Belgium	111,000	1,540,000	86,000	1,580,000
Brazil	51,900	486,000	205,000	337,000
Canada	96,200	684,000	201,000	1,520,000
France	135,000	807,000	124,000	515,000
Germany	828,000	1,870,000	832,000	2,460,000
Hong Kong	31,000	193,000	60,100	359,000
India	5,190	38,900	4,070	37,800
Japan	150,000	1,320,000	213,000	1,550,000
Korea, Republic of	1,230,000	5,340,000	1,150,000	4,950,000
Malaysia	320,000	1,710,000	178,000	889,000
Mexico	75,700	548,000	216,000	1,490,000
Netherlands	38,600	231,000	206,000	697,000
Singapore	24,800	85,200	15,100	83,100
South Africa	43,800	579,000	6,000	108,000
Taiwan	237,000	1,060,000	237,000	976,000
United Kingdom	480,000	1,170,000	133,000	400,000
Other	93,800	650,000	172,000	997,000
Total	3,960,000	18,400,000	4,050,000	19,000,000
Total estimated equivalent REO content.	3,960,000	18,400,000	4,050,000	19,000,000
<b>Rare-earth compounds: (2846.90.0000)</b>				
Austria	16,700	566,000	80,000	\$2,230,000
Brazil	78,400	168,000	10,000	45,400
Canada	151,000	1,860,000	208,000	2,850,000
China	515,000	1,040,000	197,000	369,000
Colombia	18,600	44,600	13,100	3,100
Finland	73,100	2,120,000	82,000	2,720,000
France	365	57,900	60,900	936,000
Germany	11,300	578,000	48,600	1,010,000
India	152,000	652,000	76,800	231,000
Japan	73,400	2,730,000	39,100	1,410,000
Korea, Republic of	150,000	974,000	204,000	1,550,000
Mexico	8,160	95,500	8,080	114,000
Taiwan	192,000	4,900,000	284,000	7,980,000
United Kingdom	20,100	1,140,000	47,900	656,000
Other	233,000	2,700,000	401,000	2,590,000
Total	1,690,000	19,600,000	1,760,000	24,700,000
Total estimated equivalent REO content.	1,690,000	19,600,000	1,760,000	24,700,000
<b>Rare-earth metals, including scandium and yttrium: (2805.30.0000)</b>				
China	6,450	530,000	299	74,000
France	563,000	1,120,000	125	4,510
Germany	6,710	177,000	2,270	155,000
Japan	657,000	1,720,000	1,180,000	3,110,000
Korea, Republic of	9,450	276,000	19,700	192,000
Taiwan	2,160	39,400	996	18,600
United Kingdom	2,170	212,000	15,000	250,000
Other	89,400	1,200,000	149,000	6,030,000
Total	1,340,000	5,280,000	1,370,000	9,830,000
Total estimated equivalent REO content.	1,600,000	5,280,000 r/	1,650,000	9,830,000
<b>Ferrocerium and other pyrophoric alloys: (3606.90.0000)</b>				
Argentina	42,100	72,900	26,600	61,500
Australia	3,260	24,300	3,600	107,000
Brazil	21,200	76,100	436	11,000
Canada	1,060,000	1,810,000	1,020,000	2,100,000
Chile	13,900	27,700	25,100	31,300
Colombia	3,020	11,700	1,000	3,510
Costa Rica	--	--	831	3,000
France	4,310	164,000	3,580	153,000
Germany	19,400	63,500	55,100	155,000
Greece	28,600	121,000	30,700	73,600
Hong Kong	172,000	449,000	240,000	547,000
Ireland	--	--	227	3,900

See footnotes at end of table.

TABLE 4--Continued  
U.S. EXPORTS OF RARE EARTHS, BY COUNTRY 1/

Category and country 2/	1999		2000	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Ferrocerium and other pyrophoric alloys--Continued:				
Italy	998	\$128,000	3,340	\$82,300
Japan	175,000	1,570,000	213,000	1,230,000
Korea, Republic of	10,100	7,380	1,890	41,700
Kuwait	37,800	51,500	38,200	74,900
Mexico	27,300	401,000	85,500	699,000
Netherlands	87,500	511,000	83,100	270,000
New Zealand	24,900	53,900	12,900	36,900
Saudi Arabia	136,000	2,910,000	225	5,890
Singapore	41,200	133,000	37,100	112,000
South Africa	16,100	28,300	1,550	137,000
Spain	457	11,000	12	8,320
Taiwan	132,000	221,000	40,300	77,000
United Arab Emirates	283,000	431,000	262,000	316,000
United Kingdom	37,000	225,000	39,400	177,000
Other	285,000	1,190,000	365,000	1,090,000
Total	2,660,000	10,700,000	2,590,000	7,620,000
Total estimated equivalent REO content.	2,360,000	10,700,000 r/	2,300,000	7,620,000

r/ Revised. -- Zero.

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

2/ U.S. International Trade Commission Harmonized Tariff Schedule of the United States category number.

Source: U.S. Census Bureau.

TABLE 5  
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY 1/

Category and country 2/	1999		2000	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Cerium compounds, including oxides, hydroxides, nitrates, sulfate chlorides, oxalates: (2846.10.0000)				
Austria	36,700	\$396,000	49,600	\$468,000
China	3,570,000	13,400,000	3,470,000	13,500,000
France	2,160,000	7,640,000	2,390,000	7,130,000
Japan	188,000	4,360,000	410,000	7,820,000
Other	22,000	373,000	134,000	561,000
Total	5,970,000	26,200,000	6,450,000	29,400,000
Total estimated equivalent REO content	3,990,000	26,200,000 r/	4,310,000	29,400,000
Yttrium compounds content by weight greater than 19% but less than 85% oxide equivalent: (2846.90.4000)				
China	231,000	2,640,000	47,600	847,000
France	36,000	505,000	16,000	260,000
Germany	--	--	8,000	250,000
Japan	612	50,800	18,600	1,080,000
United Kingdom	1	4,010	623	8,410
Other	--	--	6,640	144,000
Total	268,000	3,200,000	97,400	2,590,000
Total estimated equivalent REO content	161,000	3,200,000 r/	58,400	2,590,000
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides: (2846.90.8000)				
Austria	27,500	928,000	23,600	732,000
China	7,000,000	19,500,000	7,840,000	21,400,000
Estonia	16,000	21,900	560,000	335,000
France	2,720,000	13,800,000	6,090,000	16,400,000
Germany	1,100	242,000	9,700	855,000
Hong Kong	1,000	10,700	524	34,200
Japan	468,000	10,900,000	327,000	10,700,000
Malaysia	5,040	569,000	--	--

See footnotes at end of table.

TABLE 5 --Continued  
U.S. IMPORTS FOR CONSUMPTION OF RARE EARTHS, BY COUNTRY 1/

Category and country 2/	1999		2000	
	Gross weight (kilograms)	Value	Gross weight (kilograms)	Value
Rare-earth compounds, including oxides, hydroxides, nitrates, other compounds except chlorides--Continued:				
Norway	35,600	\$18,500,000	22,000	\$12,800,000
Russia	101	90,600	2,430	42,200
Taiwan	19,000	152,000	--	--
United Kingdom	53,300	6,720,000	84,300	7,820,000
Other	1,220	136,000	3,810	205,000
Total	10,300,000	71,600,000	15,000,000	71,300,000
Total estimated equivalent REO content	7,760,000	71,600,000 r/	11,200,000	71,300,000
Mixtures of rare-earth oxides except cerium oxide: (2846.90.2010)				
Austria	29,400	1,800,000	6,950	348,000
China	5,910,000	9,690,000	2,120,000	5,070,000
France	1,920	31,400	445	14,500
Germany	4,350	280,000	7,570	191,000
Japan	21,300	3,610,000	24,300	3,450,000
Russia	21	6,480	75	33,700
United Kingdom	3,540	73,800	25,100	376,000
Other	1,230	46,400	6,210	54,500
Total	5,980,000	15,500,000	2,190,000	9,530,000
Total estimated equivalent REO content	5,980,000	15,500,000	2,190,000	9,530,000
Rare-earth metals, whether intermixed or alloyed: (2805.30.0000)				
China	963,000	9,090,000	1,420,000	13,600,000
Hong Kong	30,100	541,000	33,600	526,000
Japan	439,000	7,840,000	555,000	8,480,000
Russia	872	203,000	10	7,000
United Kingdom	26,800	442,000	42,100	982,000
Other	25,500	357,000	3,240	139,000
Total	1,480,000	18,500,000	2,060,000	23,700,000
Total estimated equivalent REO content	1,780,000 r/	18,500,000 r/	2,470,000	23,700,000
Mixtures of rare-earth chlorides, except cerium chloride: (2846.90.2050)				
China	3,150,000	3,950,000	1,800,000	1,820,000
France	114	5,980	17,200	332,000
India	81,900	106,000	913,000	756,000
Japan	79,700	2,730,000	21,800	660,000
United Kingdom	12,100	65,000	56,100	221,000
Other	3,410	94,000	83,600	192,000
Total	3,330,000	6,960,000	2,900,000	3,980,000
Total estimated equivalent REO content	1,530,000	6,960,000 r/	1,330,000	3,980,000
Ferrocium and other pyrophoric alloys: (3606.90.3000)				
Austria	9,020	207,000	15,300	262,000
Brazil	3,000	56,100	3,000	56,500
France	120,000	1,580,000	107,000	1,130,000
Other	3,780	78,100	7,630	112,000
Total	136,000	1,920,000	133,000	1,560,000
Total estimated equivalent REO content	120,000	1,920,000 r/	118,000	1,560,000

r/ Revised. -- Zero.

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

2/ U.S. and International trade commission of harmonized code tariff category number.

Source: U.S. Census Bureau.

TABLE 6  
RARE EARTHS: WORLD MINE PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons of rare earth oxide equivalent)

Country 3/	1996	1997	1998	1999	2000 e/
China e/	55,000	53,000	60,000	70,000	73,000
India e/	2,700	2,700	2,700	2,700	2,700
Malaysia	340	418	350 e/	625	450
Sri Lanka e/	120	120	120	120	120
Thailand	--	12	-- e/	--	--
U.S.S.R. e/ 4/	2,000	2,000	2,000	2,000	2,000
United States e/ 5/	20,400 6/	10,000	5,000	5,000	5,000
Total	80,600	68,300	70,200	80,400	83,300

e/ Estimated. -- Zero.

1/ World totals, U.S. data, and estimated data have been rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through May 27, 2001.

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

4/ Dissolved in December 1991; however, information is inadequate to formulate reliable estimates for individual producing countries, including Kazakhstan, Krygystan, Russia, and Ukraine.

5/ Comprises only the rare earths derived from bastnäsite as reported from company sources.

6/ Reported figure.

TABLE 7  
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons, gross weight)

Country 3/	1996	1997	1998	1999	2000 e/
Brazil e/	-- r/	460 r/	-- r/	-- r/	--
India e/	5,000	5,000	5,000	5,000	5,000
Malaysia	618	767	517 r/	1,147 r/	1,000
Sri Lanka e/	200	200	200	200	200
Thailand	--	12	--	--	--
Total	5,820 r/	6,440 r/	5,720 r/	6,350 r/	6,200

e/ Estimated. r/ Revised. -- Zero.

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

2/ Table includes data available through April 18, 2001.

3/ In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and countries of the former Soviet Union may produce monazite; available general information is inadequate for formulation of reliable estimates of output levels.



FIGURE 1  
PRINCIPAL SOURCES OF U.S. IMPORTS OF RARE EARTHS IN 2000

(Percentage by weight)

