RARE EARTHS

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The rare earth elements, or lanthanides, comprise the 15 elements in the periodic table with atomic numbers 57 to 71. Often included with the lanthanides are scandium (atomic number 21) and yttrium (atomic number 39). Because of their similar physical and chemical characteristics, the lanthanide elements and yttrium often occur together in nature. While scandium may occur with the rare earth elements, it is also found in a range of other minerals.

The principal commercial sources of the rare earth elements are bastnaesite, a fluocarbonate which occurs in carbonatites and related igneous rocks; monazite, a phosphate which occurs in mineral sands; xenotime, an yttrium phosphate also occurring in mineral sand deposits; and loparite, a titanate related to perovskite and which occurs in alkaline igneous rocks. In China, rare earth elements and yttrium are found in ion-adsorption clays that formed as a result of lateritic weathering of igneous rocks. Monazite is no longer a significant commercial source of rare earth elements because it commonly contains thorium, of which the intermediate daughter elements are radioactive. Limited amounts are mined in China and India.

Although they tend to occur together, the 15 lanthanide elements are divided into two groups. The ‘light’ elements are those with atomic numbers 57 through 63 (lanthanum to europium) and the ‘heavy’ elements from 64 to 71 (gadolinium to lutetium). The term ‘middle rare earth’ generally refers to those with atomic numbers 62 through 64 (samarium, europium and gadolinium). Generally, the light rare earth elements are more common and more easily extracted than the ‘heavies’. Yttrium has properties more similar to the heavy group, in spite of its low atomic weight and is considered within the heavy rare earth elements. (promethium atomic number 61, does not occur in nature). See Table 1.

Scandium is relatively widely distributed in nature and occurs in a variety of silicates, phosphates and oxides but not at sufficient concentration to support its recovery as a primary product. Thortveitite (a scandium-yttrium silicate) in tailings has provided a source of scandium in the US but it is otherwise recovered from wastes arising from the processing of uranium, tungsten, titanium, tantalum, copper and iron ores.

China is by far the largest producer of rare earth elements and yttrium (although not of scandium) and, essentially, the only other significant producing countries are the US, India and Russia. Further processing of concentrates, and partially processed or intermediate products, is carried out in a number of locations although, increasingly, this is being undertaken in China as well.

Primary, mine production of rare earths is shown in Table 2.

Processing of rare earth concentrates generally involves an initial cracking or leaching step to bring the elements into solution. This is followed by a number of separation stages, first to separate groups of elements (the lights from the heavies) and then to separate individual elements from each other. Solvent extraction is the principal method used. Marketable products include rare earth oxides, carbonates, acetates and other compounds, as well as metals and alloys. The rare earth content is generally expressed in terms of rare earth oxide (REO) or total rare earth oxide (TREO). For some applications, the purity of products may be quoted as four nines, or five nines, ie 99.99% or 99.999% of the specified element in the total rare earth content.

China

Chinese rare earth production is based on bastnaesite recovered as a by-product of iron-ore mining near Baotou in Inner Mongolia; bastnaesite mining in Sichuan Province and the ion adsorption clays which occur in Guangdong and Jiangxi Provinces. The distribution of rare earth elements is somewhat different in each area. The hardrock deposits in northern China (in common with rare earth deposits in other countries) are dominated by the light rare earths, cerium, lanthanum and neodymium, which together account for over 90% of the total REO content. The ion adsorption clays are relatively depleted in cerium (as a result of the lateritic weathering process) and generally also contain significant yttrium.

Production in Inner Mongolia and Sichuan accounts for over 70% of the total rare earth content (oxide) of China's output, the balance coming from the ion adsorption ores, principally in Jiangxi, Guangdong and Fujian. Downstream separation activities are carried out in a large number of facilities, either integrated with mining operations, or which purchase concentrates or partially separated rare earth feedstocks. The largest producers operate separation plants although they may also sell partially processed concentrates to independent operators.

The rare earth industry in China, comprising both mining and separation activities, was divided into two groups in 2003. The Northern Rare Earth Group comprises ten large producers, led by Baotou Steel and including Baotou Rare Earth (Group) Co, Gansu Rare Earth Corp and the Sichuan Rare Earth Group. Gansu Rare Earth Corp at Baiyin, Gansu Province, reports that it is the largest rare earth producer in China, and third largest worldwide. A number of smaller facilities are based on other hardrock deposits in northern China. The Southern Rare Earth Group, led by Aluminum Corp of China, comprises seven processors in Guangdong, Hunan, Jianxi and Jiangsu provinces.

The formation of these two industry groups was announced in 2002 as part of the government's restructuring of the rare earth sector in China and was intended to correct the so-called 'three chaos', ie mining, separation and exports.

Mining and export licences will be issued separately to each group. This rationalisation has not yet received approval from the State Council.

Although production is of the order of 80,000 t/y REO equivalent, reported capacity is 180,000 t/y REO. Both North and South industry groups announced curtailment of production early in 2004.

The State Rare Earth Office of the National Development & Reform Commission has planning and oversight capacity for the sector.

United States

Molycorp Inc operated as the only Western fully-integrated rare earth mining and processing company until 1998 when the US Environmental Protection Agency suspended production. Its facility at Mountain Pass, California, based on mining of bastnaesite, is now restricted to the production of basnaesite concentrates and cerium concentrates. The USGS estimated that Molycorp produced 5,000 t of rare earth oxide equivalent in concentrates in 2002 but there was no production of primary mined material in 2003. The rare earth separation plant may resume operation in 2004.

India

Indian Rare Earth Ltd and Kerala Minerals and Metals Ltd both mine and process heavy mineral sands, the former in the states of Kerala, Tamil Nadu and Orissa, and the latter in Kerala. Monazite is the principal rare earth-bearing mineral. Indian Rare Earth processes the monazite to produce thorium-free rare earth chloride and thorium hydroxide.

Russia and Kyrgyzstan

Loparite is mined in the Murmansk region of Russia by Lovozero Mining Co. The concentrate is processed to rare earth chloride at the Solikamsk Magnesium Works. Rare earth chlorides were shipped to Estonia for further processing, but it is planned that the facility at Solikamsk will be upgraded in order to produce separated rare earth carbonates and other compounds. However, supplies of loparite, amounting to 10,000 t/y concentrate, have been disrupted as a result of a dispute between the mining company and Solikamsk which is seeking control of the Lovozero resources.

The USGS reports production of rare earths from deposits at Ak Tyuz, Kyrgyzstan, and processing of a range of products at Orlovka. Output is relatively small.

Separated rare earths

The production of separated rare earth products from purchased concentrates or partially processed material is carried out by a relatively small number of companies, worldwide, few of which are integrated upstream to rare earth mining operations. Restrictions on the activities of Molycorp in the US have removed one such integrated producer. Generally, the natural occurrence of the light rare earth elements (lanthanum, cerium and neodymium) is ten, or more, times the occurrence of the medium and heavy elements.

It is important to note, also, that producers of separated rare earths have to recover, and then market, a range of some 15 co-products while attempting to maximise the value of each. As a result, market balance has been difficult to achieve and periods of excess supply or shortage of individual elements has been a characteristic of the industry.

One of the most important developments over the past 15 years has been the emergence of China, initially as the dominant producer and exporter of ores and concentrates and, more recently, as the principal supplier to both export and domestic markets of separated rare earth salts and oxides. The Chinese rare earth industry now can produce high purity products with the result that leading Western producers have had to focus even further on value-added materials. There is, however, significant excess capacity in the Chinese rare earth separation sector, with well over 50 small plants across the country, in addition to the principal operations.

Rhodia Electronics and Catalysis has two joint ventures in China; Baotou Rhodia Rare Earths Co operates rare earth separation and processing facilities near Baotou, and Liyang Rhodia, located at Liyang. AMR Technologies Inc, a Canadian company, is the majority owner and operator of separation plants at Zibo, Shandong, and Jiangyin, Jiangsu. They specialise in the light and heavy rare earth groups, respectively. The company controls a significant portion of total separation capacity in China and has established a leading position in terms of the unit value of output from its two plants, as well as in terms of the value per kilogram of exports. Inner Mongolia HEFA Rare Earth Science & Technology Development Co operates five rare earth processing factories near Baotou, with a capacity close to 10,000 t/y REO. It produces a range of separated products, metals and alloys. The company announced plans to construct a central concentrate roasting plant, with a capacity of 40,000 t/y, early in 2003.

Among other important rare earth processors in China are Gansu Rare Earth Corp, the Xinwei group (China Rare Earth Holdings) and Yue Long Non-ferrous Metal. Primet LLC operates a light rare earth manufacturing plant at Leshan in Sichuan, where it partners with a local miner of rare earths.

In July 2003, Inter-Citic Mineral Technologies Inc, based in Canada, suspended its rare earth processing operations at the Yangzhong Zhonghai Techmat joint venture in which it has an interest of 80%. The company is focussing on its gold exploration projects in China.

Rhodia Electronics and Catalysts undertakes the rare earth business of Rhodia, producing a full range of separated and value-added products. Notable are its proprietary automotive catalysts and a range of rare earth products for the electronics industry. Based in France, its principal facility is at La Rochelle, and the company has interests in China (as noted above), in the US and in Japan. In the US, Rhodia processes previously-separated rare earth products (imported from its plant in France) to high-purity finished products. Further processed rare earth products, including alloys and metals, are produced by Santoku America Inc. The joint venture between Santoku Corp and Rhodia Anan Kasei produces a range of catalysts, polishing compounds and colourants. WR Grace & Co's Davison Division also processes intermediate rare earth compounds to provide cerium and lanthanum products for oil refining catalysts. Neodymium-iron-boron magnet alloys are produced by a number of companies in the US.

Facing competition from China, Japanese companies have had to focus even further on the production of high-purity separated rare earth products, alloys and rare earth magnets. As a result, imports of ores and partly processed rare earth chlorides have declined and imports of oxides, metals and other compounds have generally remained stable in tonnage terms. In Japan, Anan Kasei (in which Rhodia has an interest), Nippon Yttrium and Shin-Etsu are the principal producers of separated rare earth products.

The rare earths and chemicals business unit of Treibacher Industrie AG, of Austria, produces a range of rare earth oxides, alloys, metals, compounds and solutions. The company has an interest of 25% in AS Silmet in Estonia. Silmet operates a rare earth separation plant and produces a range of concentrates, alloys and metals at its plant at Sillamäe. The former rare earths division of Treibacher Industrie AG, which has operated as a subsidiary, Treibacher Auermet Produktions GmbH, was merged back into the parent company in October, 2003. Rare earth oxides are produced in a number of forms, including spray powder materials, as ingots used in the vapour deposition of coatings, coatings for precision castings, sintering aids and high performance grinding beads.

Projects

The dependence on China for rare earth products and, increasingly, for high-purity separated products, has encouraged a number of companies to consider exploration and development of new mines. Among these, the Mt Weld deposit in Western Australia is among the largest. Owned by Lynas Corp Ltd, the Mt Weld deposit is a highly weathered carbonatite complex that contains mostly light rare earths. The company has announced plans to produce rare earth concentrate and carbonate with a view to further processing in China. An open pit will supply 200,000 t/y of ore that will be upgraded on site to produce 13,000 t/y of concentrates. In pursuit of this strategy to process in China material mined in Australia, Lynas acquired 20% of the shares of AMR Technologies from Whiterock Investments early in 2004.

In North America, activity in 2003 included exploration at Great Western Minerals' Hoidas Lake project in Saskatchewan, Rare Earth Metals' Eden Lake project in Manitoba and Rare Element Resources' Bear Lodge property in Wyoming, among others. However, many well-explored deposits remain undeveloped for reasons that include complex mineralogy, association with radioactive elements and the availability of low-cost supply from China. These include the Rareco project in South Africa and Kangankunde in Malawi.

The restructuring of the rare earth industry has also reduced the market for rare earth concentrates outside China so that any new project must consider further processing, at least to partially-separated products.

Rare earth minerals have been recovered as by-products from titanium-bearing heavy sands, particularly in Australia, and from tin dredging in Malaysia; however, the thorium content of monazite from these operations has precluded its use as a rare earth feedstock since the mid-1990s.

Demand

The demand for rare earths centres on the physical and chemical properties of the lanthanides as a group and the more subtle differences between individual elements. In particular, the magnetic, chemical and spectroscopic properties have led to their application in a range of magnetic alloys, catalysts and phosphors, among others.

As might be expected, the high volume and relatively low-value applications, such as lighter flints and glass-polishing compounds, do not have such tight specifications as do the low-volume and generally higher-value applications such as phosphors and magnetic and battery alloys. Rare earth elements and yttrium used in the principal end-use sectors are summarised in Table 3. It is estimated that catalysts (including both petroleum cracking and automotive catalysts) make up the single largest demand sector in terms of volume, followed in decreasing order, by glass, metal alloys, glass polishing, magnets, phosphors and ceramics. In terms of value, however, phosphors make up by far the most important group at approximately 30% of the total market, followed by magnets, catalysts and alloys at 12-15% each.

Since there is a wide range in value between individual rare earth elements and, also, in the purity requirements for specific applications, there is a similar range of relatively high volume but low value market sectors and low volume/high value markets. Generally, the relatively high-volume/low-value (or commodity) sectors are in products for glass polishing, petroleum refining, lighter flints and steel and foundry additives. High-value market sectors include phosphors, optical glass (lenses), dopants for optical fibres, lasers, advanced ceramics and capacitors. Automobile catalyst, battery and magnetic alloy products are very widely used and are based on the light rare earths but have fairly stringent quality criteria that take them out of the commodity category.

Scandium is used principally in aluminium alloys for sporting goods such as baseball bats. Scandium alloys are not only stronger and more resistant to corrosion, but welds are also stronger and less liable to cracking. Minor amounts are used in semiconductors and speciality lighting, including halogen bulbs.

Demand for rare earths is centred in those countries and regions that manufacture the components, such as automotive catalyst systems, fluorescent lighting tubes or display panels that, ultimately, are built into a finished consumer or industrial product. These demand centres, therefore, are the US, Europe, Japan and China.

The pattern of consumption by use varies somewhat between them but, in the US, for example, petroleum catalysts account for just under 30%, all glass and ceramic applications for 30%, metallurgical additives and alloys for 19% and automotive catalytic converters for about 14% of demand. In the US, demand for rare earths for phosphor and magnet manufacture is relatively low, at around 3% each. Both the low volume and location of manufacture outside the US account for this. In Japan, optical glass for lenses, particularly in cameras, but also for a wide range of other applications including photocopiers, is the principal end-use sector.

Liquid crystal displays (LCD) and plasma display panels (PDP) are rapidly replacing cathode ray tubes (CRT) in both television and computer screens. However, the traditional and relatively high-volume end-use sector for rare earths, in cerium oxide polishing powders, remains strong, since all glass display panels are polished to high specifications. The trend to larger screen formats also has a significant impact on demand for polishing compounds since the relationship is to the area of the screen, not the linear dimension used to describe screen size.

In addition to the platinum-group metals, for which automotive exhaust catalysts are a well-known application, cerium and/or lanthanum are required in most systems for performance in both petrol and diesel engines. The use of cerium and lanthanum can also be adjusted to optimise consumption of more costly platinum and palladium. As a result, automotive catalysts are one of the most important demand sectors for rare earths.

There is a similar impact on demand for rare earth phosphors used in display screens although the three principal technologies, CRT, LCD and PDP, require somewhat different types of phosphor. AMR reports that it is the largest supplier of rare earths (yttrium and europium) for use in display phosphors used in television and computer screens.

Rare earth phosphors are also used in low-energy fluorescent tubes to provide specific colours and to reduce electricity consumption.

Rare earth permanent magnets have high magnetic intensity and are used in a very wide range of applications in small electric motors and in audio equipment. The principal type is neodymium-iron-boron magnets, to which dysprosium, praseodymium and/or terbium may be added. Samarium-cobalt magnets offer higher thermal stability and corrosion resistance than the neodymium types and are used where these properties are required in sensors and pump couplings, for example. Because neodymium-iron-boron magnets offer high intensity at very low volume, they have essentially enabled the miniaturisation of consumer electronic equipment, from the original Walkman portable tape decks to the stepper motors in watches.

Motor systems in which rare earth magnets have replaced ferrites are used in electronic equipment (computer disk drives, paper drives et cetera) and in automotive electronics and electric motors. In contrast to the generally very small rare earth magnets used in electric motors and electronic equipment, neodymium-iron-boron magnets are now widely applied in magnetic separation equipment in the minerals and recycling industries. Neodymium-iron-boron permanent magnets will also be used in motors for hybrid cars. Samarium-iron-nitride magnets, a relatively new development, are more resistant to demagnetisation than the other rare earth types but currently more complex to manufacture. Two companies supply commercial quantities of high- quality rare earth magnet powders for bonded magnets, AMR Technologies and Magnequench Inc.

Lanthanum-nickel-hydride batteries, which were rapidly replacing nickel-cadmium batteries in the late 1990s, are now being overtaken, in turn, by lithium-ion batteries in electronic equipment and cameras. For hybrid vehicles, however, nickel-metal-hydride batteries remain the primary choice, although the lithium ion battery is challenging the lead in this sector.

Multilayer ceramic capacitors (MLCC) contain neodymium and lanthanum and, to a lesser extent, cerium in the ceramic insulating layers between the conductive metallic electrode layers of these capacitors. MLCCs are used in electronic equipment, including cell phones, laptop computers, cameras and automobile electronic controls (braking, suspension, navigation aids) which also depend on high intensity rare earth magnets.

Magnetic refrigeration, based on the magnetocaloric properties of gadolinium in arc-welded alloys composed of gadolinium, silicon and germanium, is a relatively new development that may provide relatively high energy efficiency compared to conventional refrigeration systems and, also, the elimination of environmental effects associated with the use of chlorofluorocarbons or ammonia as heat transfer fluids.

Small quantities of rare earth products are used as dopants for synthetic crystalline materials, for example, yttrium aluminium garnets (YAG) and yttrium aluminium perovskites for lasers and scintillators. Rare earth oxides are also used in synthetic gemstones to provide specific colours and quality (cubic zirconia is stabilised with yttrium).

Demand for the rare earth elements and yttrium is driven by the automotive and electronics sectors, although it can be seen from the wealth of electronic gadgets in any new car that there is considerable overlap between the sectors. Automotive exhaust catalysts, cellular telephones (including those with built-in cameras), digital cameras, display systems for both televisions and computers, low energy fluorescent lighting and other audio-visual equipment will continue to provide the base for rare earth demand. Rechargeable batteries, sensors and fibre-optics are expected to contribute to demand. Overall annual demand growth has been projected at just over 3% but, over the next five years, magnet applications are expected to grow much faster, at annual rates approaching 20%. Digital cameras and mobile telephones are two groups of products that will provide a firm basis for demand in the coming year.

Nanotechnology is being applied in the rare earths business, notably by AMR, because on the nano-scale (1-100 nanometres where 1 nm = 10^{-9} m), materials have similar, but superior, properties because the extremely small particle size results in very large surface area. Coatings and fillers are two areas where nano-sized materials are already used to enhance performance and, for automotive catalysts, mixed zirconium-cerium oxides have greater thermal stability and the oxygen storage capacity is greater at higher temperatures. Yttria-stabilised zirconia, as an electrolyte film for fuel cells, and battery electrodes composed of nano-sized crystalline materials, are potential applications for rare earth elements.

Industry Developments

The two Chinese rare earth industry groups reportedly took joint action to reverse the slide in prices that has occurred over the past three years by reducing output and raising their quoted prices. In March 2003, the Chinese Government suspended the issue of new mining licences for rare earths until the end of 2005 in order to address the issue of surplus mine capacity and potential overproduction. The value added tax rebate on exports of rare earths from China, among other products, was reduced from 13% to 5% effective January 2004 and had been reduced from 17% in mid-2003.

The rapid development of China's manufacturing sector is affecting the distribution of demand for rare earth products. For example, Corning no longer manufactures CRT television glass in North America and Sony has ceased production of CRT glass in Japan, and a number of CRT glass manufacturers have opened plants in China. As the Chinese domestic market for rare earths expands, the range of available products is also increasing. For example, the Baotou Showa Rare Earth High Technology joint venture is to produce 5,000 t/y of magnet materials and Rare Earth Ovonic produces metal hydride alloys. China is now the largest producer of both nickel-metal hydride battery alloys and neodymium-iron-boron magnetic alloys. AMR has agreed to supply Samsung Ltd with display phosphors from a new plant to be constructed at its Jiangyin facility.

Sumitomo Special Metals Co and Magnequench Inc, between which a cross-licensing agreement legally restricts the sale of rare earth-iron-boron magnets in the US to only these companies, hold the patents on a number of basic rare earth-iron-boron bonded magnet compositions with expiry dates in 2003-04 in Europe and Japan, and 2005-07 in the US. It may be expected that new players will attempt to enter the rare earth permanent magnet business as a result. Sumitomo holds the rights to sintered rare earth-iron-boron magnets.

Trains based on magnetic levitation ('maglev') technology using neodymium magnets, have been opened in Shanghai to link the international airport and with the city's financial district, and are planned in Los Angeles. Two other maglev trains operate in Germany and Japan.

Solid oxide fuel cells, utilise lanthanum manganite, doped with rare earths, for the cathode, and yttria-stabilised zirconia as the electrolyte. Fuel-cell research efforts in the US and the EU will be pooled under a cooperative programme.

Prices

Prices for rare earths reflect relative abundance and specific markets for individual rare earth elements, as well as the product (oxide, metal or compound) and purity. The range is from US$5/kg, or less, for commodity cerium products, up to US$10/kg for the light rare earths, generally. Erbium products are currently priced between US$10 and US$20/kg, dysprosium between US$20-US$30/kg, while europium, terbium and lutetium are in the range of several hundred dollars per kilogram. Since the third quarter of 2003, prices for europium, dysprosium and neodymium have increased by about 30% and prices for terbium have increased by 250%. Both the North and South Chinese rare earth producer groups raised prices for 2004 at the same time as output was curtailed and, with generally improved economic conditions, prices for the less readily available elements were particularly affected.

Published price indicators are provided by the USGS estimate of US$4.08/kg REO for bastnaesite concentrate in the US in 2003. Japanese import data show that in 2003, the average value of cerium oxide was ¥364/kg, down 13% on 2002. In dollar terms, the average value of imported cerium oxide was US$2.98/kg in 2003 and US$3.19/kg in the previous year. Yttrium oxide averaged ¥1,154/kg in 2003, equivalent to US$9.95/kg.

Tables 1-3 following pages.

Table 1: Atomic numbers and symbols

Group	Element	Atomic Number*	Symbol
Light	Lanthanum	57	La
	Cerium	58	Ce
	Praseodymium	59	Pr
	Neodymium	60	Nd
Medium	Samarium	62	Sm
	Europium	63	Eu
	Gadolinium	64	Gd
Heavy	Terbium	65	Tb
	Dysprosium	66	Dy
	Holmium	67	Ho
	Erbium	68	Er
	Thulium	69	Tm
	Ytterbium	70	Yb
	Lutetium	71	Lu
Others	Yttrium	39	Y
	Scandium	21	Sc

* Promethium, atomic number 61, does not occur in nature

Table 2: World production of mined rare earth elements ('000 t of rare earth oxide equivalent)

	2001	2002	2003
China	78,000	58,000	70,000
Commonwealth of Independent States	2,000	2,000	2,000
India	2,700	2,700	2,700
Malaysia	350	450	450
US	5,000	5,000	-
Total	88,050	68,150	75,150

USGS, AMR Technologies Inc.

Table 3: Rare earth products and applications

Application	Product(s)	Rare Earth Element(s)
Glass polishing	Lenses, display screens (CRT, LCD, PDP)	Cerium
Glass additives	Optical lenses, display screens	Cerium, lanthanum, neodymium
Lighter flints		Mischmetal alloy
Catalysts, fluid cracking	Petroleum refining	Mixed rare earth products
Catalysts, auto	Automobiles	Cerium, lanthanum, neodymium
High intensity magnets	Electronic and electric motors, audio equipment	Neodymium, samarium, dysprosium, praseodymium, terbium
Batteries and hydrogen storage systems	Electronics, tools, hybrid cars	Mischmetal, lanthanum alloys
Phosphors, display	Computer, TV and other display screens	Yttrium, europium, terbium
Phosphors, lamp	Fluorescent and halogen lamps	Yttrium, lanthanum, cerium, europium, gadolinium, terbium
Phosphors, X-ray	X-ray film	Lanthanum
Fibre optics/lasers	Rare earth dopants	Lanthanum, erbium, ytterbium
Advanced ceramics	Nitrides, Y-stabilized ceramics etc	Yttrium
Capacitors	Multilayer ceramic	Lanthanum, neodymium, cerium
Fuel additives	Gasoline, diesel fuels	Cerium
Fuel cells	Solid oxide fuel cells	Lanthanum, yttrium
Pigments	Replacement for cadmium in red pigments	Lanthanum, cerium
Magnetic refrigeration	Magnet alloy	Gadolinium
Steel and foundry	Desulphurisation	Mischmetal
Alloys	Magnesium, aluminium and hydrogen storage alloys	Cerium, neodymium, lanthanum, yttrium