RARE EARTHS

Compiled by Roger Ellis

Rare earths comprise a group of 15 elements, collectively known as the lanthanides with atomic numbers ranging between 57 and 71. Yttrium and scandium are generally also included as rare earths because both these elements possess many physical and chemical properties similar to the lanthanides and often occur with them. Rare earths are normally referred to in terms of rare earth oxides (REO) and classified into three groups: light, medium and heavy (Table 1).

Although they are chemically similar, it is the distinctive and unique magnetic and spectroscopic properties of rare earths that have made them critical minor and major constituents of many advanced materials that are essential in a variety of high-technology applications. Rare earths are used in the steel and casting industries; in mobile electronic equipment such as phones, cameras and personal computers; in televisions and automobiles where they may be present as glass stabilisers, and in phosphors for cathode ray tubes and energy-efficient trichromatic lamps; in metal alloys, particularly in magnets; as compounds in blends of ceramic raw materials for engineering and electronic applications; as constituents in a number of solid oxide fuel cells; in autocatalyst manufacture to augment the role of platinum group elements; and in polishing powders for the glass industry. In the metal alloys sector, demand for lanthanum metal and rare earth mischmetal is growing steadily in lanthanum-nickel-hydride batteries, which are seen as environmentally acceptable alternatives to nickel-cadmium batteries, plus hydrogen storage potential for vehicles. Future trends could see an expansion of rare earth applications in nanotechnology.

In their elemental form, rare earths are generally soft, malleable and ductile and range from iron-grey to silver in appearance. They are not all rare and range in average abundance in the earth's crust from 60 parts per million for cerium (which compares with 50 ppm for copper) to 30 ppm for lanthanum and 0.5 ppm for thulium and lutetium. The main sources of rare earths are: bastnaesite (a mixed lanthanide fluorocarbonate mineral occurring in igneous carbonate rocks); monazite (a lanthanide-thorium phosphate mineral mostly found in mineral sands deposits and recovered as a by-product of mining for titanium and zircon); xenotime (an yttrium/lanthanum phosphate mineral, also occurring mainly in mineral sands deposits); and loparite (essentially a titanate of cerium, calcium and sodium that occurs in alkaline igneous rocks, pegmatites and altered granites). Rare earths also occur in lateritic ion-adsorption clays in China where the rare earth ore has been formed as a result of *in situ* weathering of lanthanide-bearing igneous rocks.

Rare earth ores are concentrated by standard milling and beneficiation techniques and then processed further by a variety of techniques to produce leach liquors. Because of their chemical similarity, separation of the rare earths from these liquors is not straightforward. Early processes used fractional crystallisation, ion exchange techniques then found favour but today the bulk of rare earth extraction relies on solvent extraction, the chemistry of which is extremely complex but reasonably well understood.

Research into bio-leaching of copper has shown that the process has the potential to be applied to a number of other metals and may, eventually, even be applied to the recovery of aluminium, scandium and yttrium from the red mud residue produced in the production of aluminium.

Hardrock bastnaesite deposits and mineral sands deposits containing monazite and xenotime provide the bulk of the world's economic concentrations of rare earths. World reserves of rare earths are estimated at around 100 Mt REO, with China possessing some 43 Mt, the CIS 19 Mt and the US 13 Mt. (A substantial proportion of China's reserves occur in weathered ionic clays from south China that contain an extremely high content of middle and heavy rare earth elements and which have revolutionised the industry.)

China now dominates world production (Table 2) of rare earths, supplying approximately 85% of world requirements. The country's rare earths potential was first recognised in the 1950s but it was not until the 1980s that its potential began to be fully exploited. Its deposits are unique and of three types: mixed bastnaesite/monazite ores; bastnaesite ore; and ion adsorption clays. About two-thirds of the reserves are located in the north, at Baotou in Inner Mongolia where bastnaesite is produced as a co-product of iron-ore mining, and in Sichuan Province where a large bastnaesite deposit was discovered in the early 1980s. Their ores are of the mixed type and typically comprise the lighter rare earths: lanthanum, cerium, praesodymium and neodymium. In southern China, ion adsorption clays are mined and are dominated by the rare earths: samarium, europium and gadolinium. (These are middle rare earths; heavies indispensable to magnetics and displays are dysprosium, terbium and, in particular, yttrium.) In Guangdong they are high in europium and in Longnan in Jiangxi they are high in yttrium.

The principal Chinese producers of light rare earths are Baotou Iron Steel and Rare Earths Enterprises, Gansu Rare Earth Corp. and Baotou Hefa Rare Earth Development Group Co. Ltd. According to the China Rare Earth Association's statistics, AMR's Zibo plant has the highest sales and unit value of all the light rare earth plants in China, and is running close to its capacity of 3,500 t/y REO. A number of other plants report larger nameplate capacities (eg, Liyang, Yixing, Baotou High Tech, Linzi Nonferrous) but do not run at anywhere near capacity.

In southern China, the ionic clays are mined by a large number of small producers. Separated middle and heavy rare earths are produced from these clays in a number of plants, most of them in Jiangsu and Guangzhou Provinces. Similarly to the situation with light rare earth separation plants, AMR's Jiangyin plant produces the highest rare earth until value output of all the clay separation plants in China, according to the China Rare Earth Association.

The total annual production capacity of rare earths in China is about 183,000 t but actual production in 2001 was nearer 85,000 t and compared with a domestic consumption requirement last year of some 25,000 t REO. In recent years, China's annual production has grown by around 25%, far higher than the annual growth in global demand which has been nearer 16%. Currently, there are about 170 rare earth factories in China of which about 40 have separation facilities.

Of these, around 15 have separation capacities of 2,000 – 5,000 t/y REO, and four have separation capacities in excess of 5,000 t/y REO. Separation capacity is being expanded rapidly and during the first five months of 2002, separation capacity in the Baotou area alone rose by some 15,000 t chloride.

China's production of rare earths is supposedly controlled by the State Rare Earth Office which sets mandatory production levels. In practice, however, the production targets are frequently exceeded as, although many of the numerous small individual operations are under the control of state organisations, there are many independent local enterprises that step up production when prices rise. Hence the market can quickly move into oversupply. There is an additional problem here, in that if there is a market shortage of a particular rare earth element, increased ore production means that there will also be additional supplies of those rare earths that are not in short supply (Table 3).

The only major, fully integrated Western rare-earths producer, Molycorp of the US, which mined and concentrated bastnaesite at Mountain Pass in California and refined and marketed the finished products, was forced by the Environmental Protection Agency to halt its processing operations at Mountain Pass in 1998. (Operations there now are confined to producing around 5,000 t/y of bastnaesite concentrates and cerium concentrates, and the sale of rare earth compounds from stocks.) The operation is not expected to resume production until 2004. US domestic demand for REO declined in 2002 from very high levels in 2001 and over 50% of demand was met from imports.

In Russia, loparite is extracted as a by-product of fertiliser production on the Kola Peninsula by Lovozerskaya Mining Co. The ore is concentrated and sold to the Solikamsk Magnesium Plant for further processing. Virtually all exports are sent to Estonia for further processing by Silmet AS. (During 2002, the Austrian company Treibacher AG, acquired a 25% shareholding in Silmet and reached an option agreement to increase its ownership to more than 50%.) In In recent years, Russian exports of REO have dipped below 2,500 t.

Monazite is mined and processed in India by Indian Rare Earths from minerals sands deposits in Tamil Nadu, Kerala and Orissa. Annual capacity is around 5,000 t/y REO.

Monazite is also produced in southern China, mainly in Guangdong and Hunan Provinces. In 2000, production amounted to about 2,000 t REO.

Australia possesses substantial reserves of REO and historically supplied around 40% of the world's supply of monazite as a by-product of mineral sands mining but there is no current production, partly because of concern over monazite's thorium content and partly because of the availability of cheap REO concentrates from China. There are plans, however, to establish a rare-earth operation at Mount Weld in Western Australia where there is an estimated 1.1 Mt of REO contained in monazite possessing an unusually low thorium content. In South Australia, high levels of REO (lanthanum and cerium) have been detected in the course of exploratory diamond drilling for copper-gold-uranium at the Prominent Hill prospect, part of the Mount Woods joint venture.

In Saudi Arabia, significant quantities of by-product REO have been recovered as part of a metallurgical scoping study for Tertiary Minerals plc's Ghurayyah tantalum-niobium project.

According to AMR Technologies Inc., a Toronto-based company established in 1993 and now a major player in the rare earth markets, both the industry and the markets have undergone radical restructuring over the past decade. China has emerged, not only as the dominant supplier of ores and concentrates but is also now a major processor of downstream value-added, separated rare earth salts and oxides. As a result, ore mining and separation of rare earth elements outside China has been reduced to only a small fraction of what it was six years ago. Leading Western producers have had to re-align their operations by focusing on the value-added sector, whilst at the same time strategically positioning themselves in China.

Meanwhile, China continues to close the quality gap and the implication is that those producers not based in China will see their share of the market eroded even further. At the current time, AMR believes that it is difficult to see how the necessary economic conditions will emerge that will allow the development of deposits outside China.

Whilst China is now the leading producer of processed rare earths, the French company Rhodia Electronics and Catalysis is now the leading supplier of value-added products. It has operations in France, Japan and the US, and has established two joint ventures in China. The company used to rely on a monazite feedstock but eight years ago it switched to rare earths from bastnaesite sourced mainly from China. It established a joint venture with Baotou in 1998 and a second venture, with Liyang, in 2001.

The other main Western processors are Mitsui Mining and Smelting and Shin-Etsu, both in Japan, Silmet in Estonia and AMR Technologies of Canada, which is involved in two joint ventures in China and a magnet alloy plant in Thailand. Ten years ago, there were numerous Japanese rare earths processors, each with a particular market niche based on their own high purity/high value products, but these producers suffered during the 1990s as a result of the appreciation of the yen and the proliferation of plants in China. A number were forced to close and in many cases equipment was relocated to China where it has become an integral part of new supply arrangements.

In 2000, Chinese export quota allocations were delayed for four months, leading to a sharp rise in prices and a rush by Western consumers to build their stocks once supplies became available well into the first half of 2001. As a consequence, there was considerable destocking during the middle and second half of 2001 and the year proved to be one of the most difficult 12-month periods on record for rare earths. In addition to the impact of consumer destocking, the worldwide economic slowdown meant lower sales and prices posted unprecedented falls, with the result that the value of the rare-earths industry last year fell by between one quarter and one third, according to AMR. In China, a large number of plants were mothballed during the final nine months of the year.

According to Chinese rare earth industry data, raw material prices in China (denominated in renminbi per tonne of REO) rose in the case of Baotou rare-earth chlorides, from Rm17,000 at the start of 2001 to almost Rm19,000 in mid-year before slipping towards Rm11,000 at year-end. Prices for high-yttrium clays plunged from Rm45,000 at the start of the year to Rm25,000 by year-end, and those for high-europium clays ranged from Rm35,000 in early 2001 to nearer Rm25,000 in mid-year before recovering to the Rm30,000 level by the close of the year. High yttrium clay prices rose slightly during the first half of 2002, but fell back in the second half although there have been recent indications of further upward pressure. Europium clay, meanwhile, has slipped back to the price levels prevalent in mid- to late-2001. The prices for yttrium and europium are both down quite considerably from the peak levels achieved in late 2000/early 2001.

There are now signs of a recovery in demand in the automotive and electronics sectors, and the rare earths industry could be poised for a comeback, according to AMR. The company has pointed out that the further tightening of automobile emission controls, the growth of plasma and high definition screens and the continuous proliferation of electronic devices should drive not only the value but also the volume growth in separated, high value rare earths. Looking ahead, the company considers that shortages in specific elements (such as Eu, Nd, Dy and Tb, which have experienced shortages before during periods of high growth) are possible in the next few years.

Some new issues are the planned reorganisation of the northern and southern groups in China. Also, the move to China by Western manufacturers and suppliers of REO continues. There is a continued development to find new uses and applications for REO, the use of lanthanum in ferrite magnets being one example.

Tables next page.

Table 1

Rare Earth Elements			
Element	**Type**	**Atomic No.**	**Symbol**
Lanthanum		57	La
Cerium	Light	58	Ce
Praseodymium		59	Pr
Neodymium		60	Nd
Promethium*		61	Pm
Samarium	Medium	62	Sm
Europium		63	Eu
Gadolinium		64	Gd
Terbium		65	Tb
Dysprosium		66	Dy
Holmium		67	Ho
Erbium	Heavy	68	Er
Thulium		69	Tm
Ytterbium		70	Yb
Lutetium		71	Lu
Yttrium		39	Y
Scandium		21	Sc

* Does not occur naturally

Table 2
Reserves and Mine Production

Country	Reserves ('000 t)	Mine Production ('000 t REO)		
		1995	**2000**	**2002**
US	13,000	28.7	5.0	5.0
Australia	5,200	3.0	0.0	0.0
Brazil	110	0.4	0.2	0.2
Canada	940	0.0	0.0	0.0
China	27,000	30.0	73.0	75.0
India	1,100	2.5	2.7	2.7
Malaysia	30	0.3	0.5	0.5
South Africa	390	0.4	0.0	0.0
Sri Lanka	12	0.1	0.1	0.1
Former USSR	19,000	6.0	2.0	2.0
Other	21,000	0.6	0.0	0.0
TOTAL	**88,000**	**72.0**	**83.5**	**85.5**

Source: USGS

Table 3
Commercial Rare Earth Minerals in China

Oxide	Baotou Bastnasite Concentrate	Sichuan Bastnasite Concentrate	High-Eu clay, Guangdong	High-Y clay, Longnan, Jiangxi
TREO	**50%**	**50%**	**92%**	**92%**
La	23.0	29.2	27.1	2.4
Ce	50.1	50.3	1.4	0.6
Pr	5.0	4.6	7.03	1.1
Nd	18.0	13.0	22.03	5.4
Sm	1.6	1.5	4.95	3.5
Eu	0.2	0.2	0.8	0.0
Gd	0.8	0.5	6.03	6.1
Tb	0.3	0.0	0.57	1.2
Dy	0.0	0.2	3.6	7.5
Er	0.0	0.0	2.48	4.0
Y	0.2	0.5	22.0	62.0
Ho-Tm-Yb-Lu	0.8	0.0	2.1	5.9

Source: AMR purchasing specifications

