RARE-EARTH METALS FOR THE FUTURE

FIGURE 1. Rare-earth magnets similar to this one, produced at Ames Laboratory using a new process, are critical in many technology applications

Economics, workforce and R&D will determine the future of these critical technology metals

As demand for rare-earth metals in a wide range of technology applications continues to increase, efforts to reestablish mining and production of rare-earth elements (REEs) is underway outside China, currently the dominant force in REE production. Future supplies of REEs and the myriad products in which they appear will depend less on absolute geological reserves and global trade politics and more on issues of economic viability, workforce development and technological innovation.

With Chinese REE exports shrinking to keep material in the country for its own rising demands, developing an REE supply chain outside China appears to be essential in meeting a global demand that is projected to grow from the current 140,000 ton/yr to over 200,000 ton/yr by 2015. Whether a diversified REE marketplace takes shape and whether global demand for REEs is met will be determined to a large extent by how chemical engineers address challenges associated with mining economically, extracting metals efficiently and developing ways to extend the current metal supplies.

TABLE 1. SELECTED END-USES FOR RARE EARTH ELEMENTS

Light rare earths	Major end-use	Heavy rare earths	Major end-use
Lanthanum	Hybrid electric-vehicle engines, metal alloys	Terbium	Phosphors, permanent magnets
Cerium	Auto catalysts, petroleum refining, metal alloys	Dysprosium	Permanent magnets, hybrid engines
Praseodymium	Permanent magnets	Erbium	Phosphors
Neodymium	Auto catalysts, petroleum refining, magnets for hard drives, lasers	Yttrium	Red color, fluorescent lamps, ceramics, metal alloy agents
Samarium	Magnets	Holmium	Glass coloring, lasers
Europium	Red color for television and computer screens	Thulium	Medical x-ray units
Gadolinium	Magnets	Lutetium	Catalysts in petroleum refining
		Ytterbium	Lasers, steel alloys

Source: U.S. Geological Survey (USGS)

Energy dependence

Issues surrounding the supply of REEs are closely interrelated with those of energy consumption. The same is true of other critical metals (box, p. 23). In many ways, meeting the demand for metal minerals depends on our access to cheap and plentiful energy, explains Andre Diederen, analyst at the not-for-profit organization TNO Defense, Security and Safety (Rijswijk, the Netherlands; www.tno.nl). "The problem is not that we will run out of metal in the earth's crust," Diederen says, "it's that mining and extracting it at current rates will become prohibitively energy intensive."

Removing ore from the ground and concentrating the metals require huge amounts of energy, and the energy required grows exponentially with lower ore grades. "Because of energy constraints, the largest parts of mineral deposits are out of reach for economically viable exploitation," Diederen says. A decades-old paradigm — that lower ore grades will be exploited when a supply gap exists — will no longer be valid without cheap and plentiful energy. And Diederen and others think the world will likely reach an oil production maximum within the next ten years and a coal production maximum in 25 years, after which, energy supply will no longer keep up with demand.

For REEs, the amount of metals in existing and undiscovered deposits is not an issue, says industry consultant Jack Lifton. "It's not about how much is there," he says, "it's about how much we can do." Extracting and refining rare earth metals is really an economic problem and a personnel workforce problem. "The capital costs are staggering" for setting up mining, refining operations and infrastructure, Lifton explains. Since every ore deposit is different, each site represents a unique chemical engineering problem, and "there are not enough chemical engineers with the [rare earth] expertise to do the job."

REEs not rare, but critical

Occupying the "lanthanide" row of the periodic table, REEs are actually moderately abundant in the earth's crust, with some more plentiful than other important metals, such as copper, gold, platinum and lead. Although relatively abundant, REE deposits are often not concentrated enough to allow economically viable extraction.

REEs are nominally divided into light and heavy rare earths, according to atomic number. Light rare earths, such as lanthanum and cerium, are more common than heavy rare earths, which make up 1 to 20% of the total rare earths in most known deposits, and may be more prone to shortage. Most REEs are found in varying concentrations together in deposits of the mineral bastnäsite, which is mined as a primary mineral. Other rare-earth material can be found in the mineral monazite, which is typically located in deposits of other ores and is recovered as a byproduct of uranium and niobium processing. Since various rare-earth oxides are often found together, separating them is a major challenge.

FIGURE 2. REEs have unique properties, which greatly complicates efforts to find alternatives in end-use products

REEs have found widespread use in high-technology products because of their unique atomic properties, which make replacing them with alternatives difficult (Table 1; Figure 2).

One of the most important uses of REEs is in permanent magnets, which appear in products such as hybrid vehicles, wind turbines and computer hard drives. The strongest permanent magnet is made from alloys of neodymium, iron and boron (NdFeB magnet).

Research and development projects involving such magnets are prominent at the U.S. Dept. of Energy's Ames Laboratory (Ames, Iowa; www.ameslab.gov), one of the few places outside China where basic research related to rare earth metals is carried out. One project ongoing there is led by renowned rare-earth expert Karl Gschneidner, whose group has developed an improved process for making NdFeB magnets (Figure 1). The new environmentally friendly process eliminates waste and reduces energy consumption in producing the magnets by 40–50%. The researchers found a way to eliminate a step from the conventional process in the transformation of neodymium oxide to Nd master alloy. The strategy behind the single-step process may be applied to other areas, such as producing lanthanum master alloy for nickel-metal-hydride batteries for electric vehicles.

Chinese dominance

China owns a virtual stranglehold on rare earth production and processing, with 95% of rare-earth oxide mined and 97% of rare-earth metals refined in China. The nation is also a leader in rare-earth R&D, with several state-run laboratories for rare-earth chemistry, utilization and training.

China has recently begun reducing exports of rare earth metals, sparking shortage fears and rising prices, but also stimulating activities toward production of rare-earth metals outside China. Chinese economic growth and its adoption of alternative energy technology are driving its export reductions, along with efforts to address mining-related environmental concerns.

FIGURE 3. Magnet manufacturers using REEs like this molten samarium, are among those supporting diversification of the rare earth supply chain

Peter Dent, VP of business development at Electron Energy (Landisville, Pa.; www.electronenergy.com) says his company, a maker of samarium cobalt permanent magnets, (Figure 3) has not had trouble with supplies yet, but "we are watching our own inventories and market prices very carefully."

Most experts agree that China's gradual export restrictions are not intended to starve the world of rare-earth metals and will correspond to non-Chinese sources of rare earths becoming available. Dent's company is among many who support efforts to re-establish an alternative, non-Chinese supply chain of rare-earth metals.

A non-Chinese REE supply

Efforts on several fronts are aimed at boosting REE production outside of China, including plans to reopen former REE mines in the U.S. and South Africa, as well as develop rare-earth deposits in Australia, Canada and elsewhere.

An example of these activities is the reopening of a 55-acre rare-earth deposit at Mountain Pass, Calif. by Molycorp Minerals LLC (Greenwood Village, Colo.; www.molycorp.com). A fast-moving project is underway at the mine, which had been a major source of rare earth oxides from its start in 1953 until 1998, when mining stopped. Molycorp is currently producing rare earth oxides at a 3,000 ton/yr pace from mined materials that were stockpiled during the years that the mine was operating.

In January 2011, the firm will break ground on a separations plant capable of producing the full range of rare-earth oxides present in the ore. During the time the mine was offline, Molycorp engineers have developed a suite of processing improvements and separations technologies designed for efficiency and cost-effectiveness.

Among the improvements is a new milling process that increases recovery of rare-earth metals from the ore. Operations in China now generally achieve a 40% recovery, while the Molycorp process should boost this rate to 68% recovery. "This greater front-end efficiency continues to pay dividends in downstream processing," says Molycorp spokesperson Jim Sims.

Company engineers have also developed a system for recycling wastewater that makes the plant an almost zero-wastewater facility. In conventional REE processing, salt-laden water is a major waste stream. In addition, Molycorp will recycle the acids and bases that are needed to process rare earth oxides to avoid having to continuously transport chemical reagents to the site.

The new plant will be powered by an off-the-grid natural-gas steam-power cogeneration system, Sims explains. By mid-2012, the company will boost production to 20,000 ton/yr of rare-earth oxides. Molycorp will produce mostly lanthanum, cerium, neodymium and praseodymium at the site, but will also generate smaller amounts of samarium, terbium, europium, gadolinium, erbium and dysprosium.

Molycorp is executing a "mines-to-magnet" strategy, which seeks to engage in REE production at every point on the supply chain, from ore to refined metal oxide, to final products. As part of the strategy, Molycorp is partnering with magnet producers.

Another example of the re-emergence of a rare-earth-metals industry outside China is Avalon Rare Metals Inc.'s (Toronto, Canada; www.avalonraremetals.com) development of a rare earth deposit called Nechalacho, near Thor Lake in

Canada's Northwest Territories. Operations at the Thor Lake site will mill, crush and concentrate the minerals in the ore. Avalon is also planning to build a hydrometallurgical plant to further concentrate the 15 REEs present in the ore into a chemical concentrate. It is also conducting a scoping study for a separation plant to isolate the 15 elements into individual rare-earth oxide products.

Avalon CEO Don Bubar explains that the Thor Lake deposit has several desirable qualities that increase its potential economic viability. One advantage is that the site contains an unusually high concentration of several scarce, heavy REEs currently in high demand, such as terbium and dysprosium. In addition, the deposit contains recoverable byproducts, including zirconium, tantalum and niobium, which are valuable themselves.

Avalon has moved its process technology development into the pilot stage. An interesting aspect of Avalon's REE processing plant is a planned sulfuric-acid production facility to generate the acid required to break down the mined minerals. "The amount of sulfuric acid needed is a challenge," Bubar explains, and it makes more sense to produce it onsite rather than transport the hundreds of thousands of tons per year required to process rare earths. Avalon anticipates beginning full operations at the plant in 2015.

Governments outside China are also getting the message about the importance of rare earth metals. For example, in the U.S., the Rare Earths Supply-Chain Technology and Resources Transformation Act (H.R. 4866) was introduced by Rep. Mike Coffman (R-Colo.) in the House (a similar senate bill, S. 3521, also exists). The bills are designed to spur rare-earth minerals production, refining, purification, metals production, alloying and magnet production. Among the provisions of the bill is one that would establish a national stockpile of REEs.

Extending REE supplies

Even with a diversified set of rare earth suppliers around the world, it is likely that future demand will have to be addressed in a host of different ways. Strategies likely to be explored actively include searching for ways to improve mining and milling operations, and chemical processing approaches to maximize metal yields from the ore.

Other strategies involve finding ways to recycle rare-earth metals, such as recovering and reusing scrap material from the permanent magnet manufacturing process. Ames Laboratory researcher Alan Russell says "Recycling magnet scrap is a difficult, but not insoluble, problem," adding that research grants for tackling the problem would be helpful.

For recycling metals, the economics of collection is the key to making it viable, says Nick Morley, analyst with Oakdene Hollins.

CRITICAL METALS GO WELL BEYOND RARE EARTHS

Rare-earth metals are far from the only group of elements with clear technological importance and concern over future supplies. In 2008, the National Research Council (NRC), the research arm of the National Academies (www.nationalacademies.org), explored the relationship between metal minerals and the U.S. economy. The research group, led by industry consultant Stephen Freiman, devised a Metals Criticality Matrix that assessed the impact of supply restrictions of various metals on the economy. The analysis depends heavily on the ease or difficulty of substituting away from the mineral in question. Along with the rare earths, the NRC mentioned indium, niobium and the platinum group metals (including rhodium and palladium) as ranking high on the Metals Criticality Matrix. Others have pointed to metals such as germanium, gallium and the tungsten-group metals as also having high criticality. ❑

Rare-earth metals in post-consumer waste may be too diffuse and too difficult to extract economically, but industrial recycling may be a more achievable goal, says consultant Lifton.

TNO's Diederen points out that rare-earth recycling, as well as other metal recycling, should be viewed from more of a product lifecycle perspective. Specifically, R&D projects aimed at extending product lifetimes would be important, as would conducting upfront product design to make future recycling of the material more amenable.

Although substitutes for the rare-earth metals are difficult to find without sacrificing performance in many cases, Morley points out that it may end up being more fruitful to look for substitutes not for the rare-earth materials themselves, but for alternatives to the products and applications for which they are required.

Another strategy for extending REE supplies involves finding ways to reduce rare-earth metal content in products as a way of lessening overall demand. An example comes from Ames Laboratory, where researcher Bill McCallum is investigating how to lower the rare-earth content in the permanent magnets that are used in the traction motors of hybrid electric vehicles.

A final approach would be to find alternative sources of REEs. An example of this approach began as an offshoot of a project originally conceived for another purpose. University of Leeds (Leeds, U.K.; www.leeds.ac.uk) materials scientist Animesh Jha discovered that rare-earth metal oxides are produced as co-products in a process he and colleagues were working on for refining titanium dioxide from the mineral ilmenite. Depending on the titanium minerals they use, the rare-earth content can be up to several percent. In the titanium dioxide process, a colloidal layer is generated that was found to contain lanthanum, cerium, praseodymium and other rare-earth metals. The researchers are working on improving the recovery rate of the rare earths beyond the 50–80% presently achievable. ■

Scott Jenkins