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The Rare-Earth Crisis

Today's electric cars and wind turbines rely on a few elements that are mined almost entirely in China. Demand for these materials may soon exceed supply. Will this be China's next great economic advantage?
By Katherine Bourzac

On the eastern edge of the Mojave Desert, an hour's drive southwest of Las Vegas in Mountain Pass, California, lies a 1.4-billion-year-old deposit of cerium, neodymium, and other metals that is the richest source of rare-earth elements in the United States. Beside hills populated by cacti, Joshua trees, and wandering tortoises is a vast waste dump of tan and white rocks that was built up over more than 50 years of production at a 50-acre open-pit mine here. The mine was once the world's biggest producer of these metals, which are crucial to such diverse products as computer hard drives, compact fluorescent light bulbs, and the magnets used in electric vehicles' motors. And the site still holds enough of them to mine for at least another 30 years. But in 2002 it was shut down, owing to severe environmental problems and the emergence of Chinese producers that supplied the metals at lower cost. The mine sat idle for a decade.

With worldwide demand for the materials exploding, the site's owner, Molycorp Minerals, restarted mining at Mountain Pass last December. It is now the Western Hemisphere's only producer of rare-earth metals and one of just a handful outside of China, which currently produces 95 percent of the world's supply. Last September, after China stopped exporting the materials to Japan for two months, countries around the world began scrambling to secure their own sources. But even without Chinese restrictions and with the revival of the California mine, worldwide supplies of some rare earths could soon fall short of demand. Of particular concern are neodymium and dysprosium, which are used to make magnets that help generate torque in the motors of electric and hybrid cars and convert torque into electricity in large wind turbines. In a report released last December, the U.S. Department of Energy estimated that widespread use of electric-drive vehicles and offshore wind farms could cause shortages of these metals by 2015.

What would happen then is anyone's guess. There are no practical alternatives to these metals in many critical applications requiring strong permanent magnets—materials that retain a magnetic field without the need for a power source to induce magnetism by passing an electric current through them. Most everyday magnets, including those that hold notes on the fridge, are permanent magnets. But they aren't very strong, while those made from rare earths are tremendously so. Alloys of neodymium with iron and boron are four to five times as strong by weight as permanent magnets made from any other material. That's one reason rare-earth magnets are found in nearly every hybrid and electric car on the road. The motor of Toyota's Prius, for example, uses about a kilogram of rare earths. Offshore wind turbines can require hundreds of kilograms each.

New mining activity, not only at Mountain Pass but also in Australia and elsewhere, will increase supplies—but not enough to meet demand for certain critical metals, particularly dysprosium, in the next few years. And the limited capacity of the new mining operations is not the only problem. Because rare earths make such excellent magnets, researchers have put little effort since the early 1980s into improving them or developing other materials that could do the job. Few scientists and engineers outside China work on rare-earth metals and magnet alternatives. Inventing substitutes and getting them into motors will take years, first to develop the scientific expertise and then to build a manufacturing infrastructure. The United States "lost expertise" when its mines closed and magnet manufacturing relocated to Asia to be near operating mines and less expensive labor, says George Hadjipanayis, chair of physics and astronomy at the University of Delaware. As a result, there were few incentives for researchers or companies to work on magnets. Now, he says, "there is not much funding and no industry around."

Reborn

Rare-earth metals, despite the name, are relatively abundant in Earth's crust. The 16 naturally occurring rare earths are usually found mixed together in deposits that often contain radioactive elements as well—and separating the metals requires costly processes that produce a stew of toxic pollutants. "We know what the [total] concentration of rare earths is in all areas of the deposit," says Molycorp mine manager Rocky Smith, standing on one of the tiers carved into the 800-foot-deep pit and pointing out an ore-laden rock; it's tinged mauve with bastnäsite, a mineral that contains a mixture of rare earths. But knowing where the rare earths are throughout the site and getting the individual metals out of the ore are two different things.

The first step in extracting rare-earth oxides from the surrounding rock is to crush the rocks and grind them into a fine powder. This is passed through a series of tanks, where the rare-earth elements float to the top. Unwanted minerals sink to the bottom, and this hazardous waste material, called tailings, is sent to ponds for storage. Meanwhile, the resulting concentrate of rare-earth metals is roasted in kilns and then dissolved in acid. The fraction of the resulting slush that contains rare earths, in the form of mixed metal oxides, is removed. Finally, the solvent is neutralized.

The reaction generates a lot of salt: when the Mountain Pass mine was running at full capacity in the 1990s, it produced as much as 850 gallons of salty wastewater every minute, every day of the year. This waste also contained radioactive thorium and uranium, which collected as scale inside the pipe that delivered the wastewater to evaporation ponds 11 miles away. Several times in the 1990s, cleaning operations intended to remove the built-up scale caused the pipeline to burst, spilling hundreds of thousands of gallons of hazardous waste into the desert. The state of California ordered Molycorp, which was then a unit of the oil company Unocal, to clean up the waste. In 2002, the company, already struggling to make a profit, ran out of space to store its tailings and failed to secure a permit to build a new storage facility. The mine shut down.

Chevron bought Unocal in 2005, acquiring Molycorp and the Mountain Pass mine along with it. In 2008, a group of private investors bought the mine and formed Molycorp Minerals, which has been developing processing technologies that it says will eliminate the need for evaporation ponds and pipelines. In 2009, Molycorp began processing stockpiled bastnäsite to extract the mixed rare-earth mineral didymium. Last summer the company went public, and its stock price has soared. The U.S. rare-earth industry was reborn.

But a visit to Molycorp's processing facility shows that the resumption of mining at Mountain Pass will not solve all the supply problems. Inside a small warehouse where the rare-earth oxides are dried and packaged, Molycorp CEO Mark Smith dips his hand into a barrel to scoop up a handful of tan-colored powder. It's soft, like fine ash. This material is didymium oxide, a mixture of oxidized neodymium and praesodymium, elements far to the left on their row in the periodic table. The deposit at Mountain Pass, like other rare-earth deposits except a few in southern China, is richest in these lighter elements. They are fine for glass polishing and car batteries and for magnets that work at low temperatures. But to withstand the high temperatures in motors and turbines, magnets require the addition of dysprosium or terbium, which are heavy rare earths.

Another problem is that Molycorp is just beginning to rebuild the infrastructure needed to turn rare-earth ore into magnets. When mining operations left the United States, all that infrastructure followed. The purification of rare earths is now done almost exclusively in China, though Malaysia is building a new facility. And the magnet industry is now based largely in China and Japan. The Japanese company Hitachi Metals, which holds the necessary patents to make rare-earth alloys and magnets, has entered into an agreement with Molycorp to make them in the United States. Molycorp will supply the neodymium, but to make heat-tolerant magnets, the company might have to acquire the additional heavy rare earths from somewhere other than its Mountain Pass mine—and it's hard to know where that might be.

Looking for Luck

Though rare-earth purification is no longer done in the United States, it was invented here by Frank Spedding, the founder of the Ames National Laboratory in Iowa. In 1949, even before rare earths were used industrially, Spedding invented the first methods for separating them from one another; the technique grew out of his work on purifying uranium and thorium for the Manhattan

Project. The Ames lab is still the only research center in the country with a significant emphasis on the materials.

Ames researcher Iver Anderson has no trouble demonstrating why rare-earth materials are so valuable in magnets. Extending his hand over his desk, palm side down, he shows that the field produced by a tiny piece of a broken neodymium magnet balanced on the back of his hand can make another neodymium magnet, the size of a penny, stick to his palm. Pairs of neodymium magnets much larger than this can break bones. Anderson then picks up a considerably heftier magnet, made of aluminum, nickel, iron, and cobalt. It barely holds onto the tip of a dangling paper clip.

Weak though this performance is, the material's magnetic properties show some promise, so Anderson's group is trying to improve them by tinkering with its structure, a mixture of nanoscale iron-cobalt needles separated by a matrix of nickel and aluminum. Working from theoretical studies of the material, Anderson hopes to alter processing conditions so as to make the needles longer and align them better. "How long can we make the needles?" he wonders. "What if we put a humongous magnetic field on the sample—would it change their spacing, make them grow longer?"

The chief appeal of the magnet is that it contains no rare-earth metals. Still, even the Ames researchers seem uncertain that a material like this could ever take the place of rare-earth magnets. Since neodymium magnets were introduced in 1983, nothing has been developed that comes close to matching them. But, says Anderson, "you can get lucky."

The researchers are also working on ways to manufacture rare-earth magnets more efficiently. Currently, the magnetic materials are heated and compressed to form large, dense blocks that must then be cut to the desired shape. This process leaves behind piles of oxidized metal shavings called swarf, which is often contaminated with lubricants for the cutting blades. The impure swarf can't be integrated into new magnets, but finding a way to use it—or formulating the magnet materials in such a way that they can be molded rather than cut—would stretch the valuable elements further. "People are looking at 55-gallon drums full of this grinding waste, which looks like grayish-brown mud, wondering how to reclaim the rare earths out of all that swarf," says Anderson.

If the supply of rare earths falls short of demand in the coming years and no substitutes that approach their performance are found, makers of hybrid and electric cars will probably try to develop new motor designs that rely on induced rather than permanent magnetism, says Eric Rask, a researcher at Argonne National Laboratory. Before joining Argonne two years ago, Rask worked on the power-train system for General Motors' electric Volt, which uses a rare-earth permanent magnet. But, he says, "the reason permanent-magnet motors are used is that their efficiency is almost always higher in the range where you use it a lot—typically you can get more torque for a given supply of current."

Few experts express optimism that there will be enough rare-earth materials to sustain significant growth of clean energy technologies like electric cars and wind power, which need every possible cost and efficiency advantage to compete. "The writing is already on the wall," says Patrick Taylor, director of the Kroll Institute for Extractive Metallurgy at the Colorado School of Mines. "You want to develop this big new energy economy, but there's a limited supply and an ever-increasing demand." Asked how China gained its edge over the rest of the world, Taylor points out that most of the necessary expertise and industry began moving to that country nearly two decades ago. Back then, he adds, no one was even paying attention.

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