Soldier uses magnet locator while searching for evidence of extremist activity in Bezel, Iraq

U.S. Army (David J. Marshall)

Enduring ATTRACTION

America's Dependence On and Need to Secure Its Supply of Permanent Magnets

By JUSTIN C. DAVEY

The United States is the world's preeminent military power, due in large part to its technological superiority. This lead in innovative technology supporting national security also includes advances in new and "green" energy applications. A common ingredient enabling the production of many of these applications is a group of minerals known as rare earth elements (REEs). Two REEs in particular, the refined metals neodymium and samarium, are key components in the manufacture of miniature high-temperature-resistant permanent magnets. These magnets are essential to wind turbines, hybrid car engines, and computer hard drives. Moreover, they are critical for military applications including precision-guided munitions, tank navigation systems, and electronic countermeasures equipment.

The demand for REEs is steadily increasing in the world. Simultaneously, the supply of REEs is shrinking—or rather China, which annually produces 97 percent of the rare earth minerals on the world market and controls some 37 percent of the planet's known reserves,[1] is steadily reducing its exports. China dramatically restricted its exports by 72 percent in the last 6 months of 2010 to satisfy its rapidly expanding national appetite for REEs.[2] China is also progressively acquiring the industrial base to manufacture permanent magnets and their end products at the expense of American businesses, which China systematically purchases and relocates within its borders. The entire supply chain of REE permanent magnets is now in China.[3]

As the American military and industrial sectors continue their move toward increased reliance on miniaturized high-performance electronics and strive to adopt more energy-efficient technologies, there are concerns that the United States may trade its reliance on Middle East oil for dependence on REEs from China. This article illustrates how REEs have become a deeply ingrained need throughout the American economy and, in particular, how rare earth magnets are now indispensable to the defense industry. It also explores how the United States should react to a threat to its lead in the technological innovation of military applications that use permanent magnets.

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U.S. Department of Agriculture

Rare earth oxides such as neodymium and samarium are vital to manufacture of permanent magnets used in military applications

In order to break the pattern of dependence on China, the United States should reconfigure its National Defense Stockpile (NDS) to provide a buffer supply of REEs to meet defense needs for 5 years, while providing government incentives such as tax breaks or loan guarantees to aid resurgent domestic REE mining and refining firms. It is critical the government also be on guard against further sale and export of such U.S. companies to China. Simultaneously, the United States should continue funding research into permanent magnets using alternative materials that could balance the demand for REEs.

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Rare Earth Elements

REEs have been described as "vitamins of modern industry" because of their necessity and wide application across the fields of energy, defense, and computer technology.[4] However, they are scarcely familiar to the general public. There are 17 minerals in the family of REEs: 15 from the chemical group known as lanthanides, plus scandium and yttrium.[5] These elements share similar geochemical characteristics and are qualitatively comparable to the chemistry of aluminum.[6] However, the slight variances in atomic structure between the REEs yield diverse optical, electrical, metallurgical, and magnetic properties that lend themselves to a vast and growing number of uses. Since there are only minor differences in their chemical properties, REEs are commonly found clustered in mineral deposits, but in widely varying concentrations.

The term *rare* in REEs is not accurate. It persists due to a combination of misunderstanding and indifference that characterizes public perception. REEs are actually relatively abundant throughout the Earth's crust, about the same as some major industrial metals (copper, zinc, and chrome) and even greater than several precious metals (gold, silver, and platinum).[7] Nevertheless, these deposits are not concentrated, at most ranging up to a few hundred parts per million by weight. Although REEs are present in most massive rock formations and sources exist around the world, such low concentrations make the mining and recovery processes difficult and expensive. Nor can the industrial base required for production be created quickly. From the time a deposit is discovered, it takes 10 to 15 years of development and construction of the infrastructure needed to establish a full-scale REE recovery operation.[8] Consequently, it will require long-term vision and immediate action to wean the United States from its almost total dependence on foreign sources as world competition for REEs escalates.

U.S. Geological Survey

Map shows locations of rare earth deposits in United States

Applications

Rare earth elements are vital to an ever-increasing number of industries. According to the U.S. Geological Survey (USGS), "These uses range from mundane (lighter flints, glass polishing) to high-tech (phosphors, lasers, magnets, batteries, magnetic refrigeration) to futuristic (high-temperature superconductivity, safe storage and transport of hydrogen for a post-hydrocarbon economy)."[9] Two of the most common uses for REEs in the United States are metallurgical applications and as catalysts in the petroleum refining and auto industries.[10] Other widely recognized products include lasers, fiber optics, superconductors, rechargeable batteries, and fluorescent bulbs, as well as REE-enhanced phosphors in LCD television screens, cell phones, and laptop computers.[11] Like a golden thread in a tapestry, these unique and indispensable minerals are woven through the fabric of American society and businesses. Their contribution to the quality of life and security of this country is considerably greater than expected considering their relative obscurity and decreasing availability. Exceptionally notable is how REE alloys revolutionized the magnet trade and subsequently enhanced the products of all other businesses relying on that industry, namely consumer electronics that are now considered commonplace and defense applications that are indispensable. Consequently, rare earth permanent magnets comprise the widest use of REEs.[12]

Neodymium and Samarium

Neodymium and samarium make up only a portion of the REE market, which is an even smaller part of the global metals market, but these two metals have a disproportionate influence on all high-tech businesses, especially the defense industry. They combine with other elements (specifically iron, boron, and cobalt) to make exceptional permanent magnets. Samarium-cobalt (SmCo) magnets have the highest known resistance to demagnetization.[13] This capability, meaning the magnet has higher coercivity, allows them to function in high-temperature environments without losing magnetic strength—an essential attribute for most military applications. Similarly, neodymium-iron-boron (NdFeB) magnets are incredibly strong—the most powerful commercial magnets available. Compared to an equal mass of traditional ferrite magnets, NdFeB magnets have over 10 times the magnetic energy product.[14] Accordingly, a much smaller amount of magnet is required for any particular application. This attribute makes them ideal for miniaturization of motors, electronics, and electrical components, including possible nanotechnologies.[15] The advent of these tiny, powerful magnets ushered in the era of the Sony Walkman, personal laptop computer, and more.

Permanent Magnets

NdFeB and SmCo magnets are ingrained in the commercial high-tech, automotive, and energy markets of the United States. For instance, miniaturized multigigabyte disk and DVD drives, a mainstay in portable computers, are not possible without such magnets.[16] Those electronics are also used in automobiles for pollution-controlling catalytic converters and hybrid car engines—high-temperature environments where regular magnets would rapidly fail. Moreover, the use of REE magnets reduces the overall weight of a vehicle, making it more energy efficient. A typical Toyota Prius uses 2.2 pounds of neodymium, one-tenth the mass of corresponding iron magnets.[17] Americans will buy approximately 180,000 Priuses this year, resulting in the consumption of 198 tons of neodymium in the United States for this one model of vehicle. NdFeB magnets are also in demand in the renewable energy market as more wind turbines come on line. The generators used in newer wind turbines require up to 2 tons of these magnets. However, neodymium magnets lack the extreme temperature resistance qualities of their SmCo counterparts and initially presented challenges in the larger turbine applications. The answer: more REEs. Scientists discovered that the addition of other REEs (terbium or dysprosium) to the NdFeB alloy helped to increase its coercivity. This makes for a better product, but is indicative of increasing U.S. dependence on the availability of rare earth metals, especially from foreign sources. Nowhere is this trend more unsettling than in the field of national security.

neodymium and samarium have a disproportionate influence on all high-tech businesses

Miniature high-temperature-resistant permanent magnets are a key factor in developing state-of-the-art military technology. They pervade the equipment and function of all Service branches, starting with commercial computer hard drives containing NdFeB magnets that sit on nearly every Department of Defense (DOD) employee's desk. Precision-guided munitions depend on SmCo magnets as part of the motors that manipulate their flight control surfaces. Without these advanced tiny magnets, the motors in "smart bombs" like the Joint Direct Attack Munition (JDAM) would require a hydraulic system that is more expensive and three times as large. The generators that produce power for aircraft electrical systems also rely on samarium-cobalt magnets, as does the stealth technology used to mask the sound of helicopter rotor blades by generating white-noise concealment.

Other permanent magnet applications include "jet engines and other aircraft components, electronic countermeasures, underwater mine detection, antimissile defense, range finding, and space-based satellite power and communications systems," according to USGS.[18] The Army relies on REE magnets for the navigation systems in its M1A2 Abrams main battle tank, and the Navy is developing a similarly dependent electric drive to conserve fuel for its *Arleigh Burke*–class destroyers. The Air Force's F–22 fighter uses miniaturized permanent magnet motors to run its tail fins and rudder. While REE applications, especially products dependent on NdFeB and SmCo permanent magnets, have given the United States a tremendous technological advantage, the increased reliance on these metals coupled with dramatically decreased domestic mining and the international export of American refining and manufacturing capability puts the United States in a precarious position.

Navy officer prepares to test drive new conventional hybrid vehicle, which uses permanent magnets in engine

U.S. Navy

Market Forces

The global economy currently consumes an estimated 134,000 tons of REEs each year. However, worldwide annual mining production is only 124,000 tons. For the time being, the delta is bridged using materials stockpiled at various commercial mines around the world. This will not suffice for long. In 1998, by comparison, total annual consumption was about 50,000 tons, and there was no future availability concern.[19] The explosive growth of the electronics and energy industries changed all of that. World demand is anticipated to rise to 180,000 tons per year by 2012 and surpass 200,000 tons annually in 2014.[20] Although China's production is expected to increase each year, it will not likely keep pace with demand. A shortfall of up to 40,000 tons per year may come about over the next 5 years.

China is the world's principal provider of REEs. Its propensity to use this position as a diplomatic "stick" and element of economic power, combined with a growing domestic appetite for these elements, threatens to exacerbate the anticipated global shortage. In early 2010, following the disclosure of a multibillion-dollar arms deal with Taiwan, several Chinese military news sources and Web sites urged the government to completely ban the sale of REEs to U.S. companies as a means of retaliation.[21] This is not a hollow threat, as Japan, the world's largest REE importer, discovered in September 2010. Following a diplomatic clash with Tokyo over the detention of a Chinese fishing boat captain (who rammed his boat into two Japanese coast guard vessels in a disputed area of the South China Sea), China ceased nearly all REE exports to that country.[22] Japan was left scrambling to patch relations with China and simultaneously began searching for alternative sources in order to restore the lifeblood that enables Japanese companies to manufacture products that are the cornerstone of its electronic and automotive industries. The embargo finally ended in late November, but the threat of future restrictions still looms.[23] The United States does not want to suddenly find itself in a similar predicament.

U.S. Challenges

Neodymium and samarium are critical to the strength of the U.S. national defense industry, but the current supply of these metals is entirely external to the country. Moreover, demand for permanent magnets is expected to increase 10 to 16 percent per year through 2012.[24] Nonetheless, the United States has never included REEs in its NDS requirements as a hedge against a future shortfall.[25] Some industry experts are becoming more vocal about what they see as growing risks posed by the scarcity of domestic suppliers. For instance, the United States Magnet Materials Association (USMMA), an alliance of firms from the aerospace, electronics, and medical materials fields, published a plan in February 2010 listing actions Washington can take to address what they see as the impending rare earth crisis.[26] This group insists that the current situation portends a serious threat to the economic well-being and national security of the United States.

China is credited with holding 37 to 43 percent of the world's known REE reserves, but the United States is not without its own REEs. America is estimated to have 13 percent of known rare earth reserves. However, American mining operations essentially ceased in 2002 with the closure of California's Mountain Pass mine because of environmental concerns and declining profitability as a result of low Chinese prices in the previous decade.[27] Gareth P. Hatch, a REEs specialist with Technology Metals Research, commented, "I'm not sure I believe that there is a high probability of the U.S. losing access to the raw materials, semi-finished and finished rare-earth products that its defense contractors need. . . . On the other hand, should such a scenario occur, the effects would very likely be devastating, and I would argue that this is an unacceptable risk."[28]

China has slowly reduced its REE exports since 2006, cutting them by 5 to 10 percent each year.[29] This is due to increased internal development (China constitutes about 75 percent of global REE consumption), but is also part of a persistent strategy to entice, if not force, foreign investment and manufacturing industry onto Chinese soil.[30] This was dramatically illustrated in July 2010 by the Chinese Ministry of Commerce's sudden announcement of a decision to reduce export quotas by nearly three-fourths. That drastic 72 percent cut imposed on the last half of 2010 should serve as a wake-up call, highlighting how dependent the United States has become; import source data for 2005–2008 reveals that 91 percent of America's REE imports came from China.[31]

America is estimated to have 13 percent of known rare earth reserves

China's announcement led some companies to increase the price of their permanent magnet products by an average of 20 percent.[32] Continued restrictions will lead to a greater shortage of supplies, which has industry leaders closely watching the situation. The price of neodymium is more than 2.5 times what it was in the summer of 2009, and the stock values of non-Chinese mining companies have jumped dramatically more recently. Most notably, the closing price for shares of the Western Hemisphere's sole rare earth oxide producer, Molycorp Minerals, is up over 400 percent since July 2010.[33] Although the Molycorp Mountain Pass processing facility produces about 3,000 pounds of REE oxides per year, including neodymium, it does so from a residual stockpile of ore mined over 8 years ago.[34] Those oxides must still be sent to China for final processing because the United States lacks the necessary industry to produce rare earth metals ready for end-use manufacturing. Changing this trend will be costly and time consuming.

The method of separating neodymium and samarium oxides from mined raw ore, then reducing those oxides to a usable metallic element, is difficult. The industrial complex required to house thousands of stainless steel tanks, complicated arrays of chemical baths, extracting agents, and equipment needed for the process covers an area the size of a football field.[35] Start-up costs of a separation plant are likewise overwhelming, ranging from $500 million to $1 billion, with construction expected to take at least 8 years.[36] Consequently, no individual company is eager to risk that much capital in a market where China's state-owned mines have the influence and backing of an entire country to drive REE prices artificially low in order to crush the competition.

Nonetheless, Molycorp is working to modernize and expand its Mountain Pass processing facility. Under the firm's "mine-to-magnets" strategy, it has a goal of generating 20,000 tons of rare earth oxides by 2012 and reestablishing its domestic magnet manufacturing business.[37] Equally important are plans to resume mining of fresh ore having an approximate 12 percent content of neodymium and samarium.[38] This development is encouraging, but makes it even more disturbing to remember that this mine, perhaps the largest non-Chinese rare earth deposit in the world, was nearly purchased by China's state-owned China National Offshore Oil Corporation (CNOOC) as part of their bid for the oil company Unocal in 2005.[39] Unocal acquired Molycorp in 1978, but this fact and its REE supply implications were overlooked during the congressional uproar over the threat to U.S. energy security, which drove the Chinese company to withdraw its bid. Such efforts by Chinese businesses to control international REE mining and oxide production are not isolated, nor are they coincidental.

Chinese Strategy

There is little distinction in China between private industry and the government, making it increasingly difficult for U.S. firms to compete on an equal footing and remain profitable. An insightful student of China's maneuverings observed, "The Unocal [purchase attempt] involved the provision of a soft loan from the Chinese government to the company [CNOOC]. This is not like a commercial loan. The Chinese government protects its state companies at home and supports them financially overseas. But these companies are essentially expected to be an arm of national foreign policy in their foreign investment, *rather than to create value*."[40] China's growing population and modernizing economy are in need of ever-increasing amounts of permanent magnets. Its expanding domestic wind energy production could soon consume the world's entire supply of neodymium.[41] Those internal demands plus China's aspirations to be a regional hegemon and world superpower drive its policies. To that end, China is pursuing a two-fold strategy: corner the market on REEs and develop a manufacturing base to make the high-tech products that REEs require.

China is methodically acquiring U.S. companies that produce rare earth magnets, transferring that production technology to China, and then shutting down the plants in America. This was the fate of GA Powders, Environmental Laboratory, and Magnequench.[42] The latter company was purchased by a China-based conglomerate in 1995. Magnequench's NdFeB-magnet production line in Indiana was quickly duplicated in Tianjin, China. Once the Chinese company was sure its new plant worked, the Indiana facility was shut down and some of its precision machine tools were relocated to China. Magnequench was the last U.S. company making rare earth magnets. Moreover, thousands of those permanent magnets went into servos for the JDAM guidance system. A senior strategic trade advisor for DOD, Peter Leitner, recognized the paramount need to secure this kind of technology, noting that rare earth magnets "lie at the heart of many of our most advanced weapons systems, particularly . . . precision-guided weapons" and that

China is "trying to replicate the capabilities the U.S. has."[43]

In addition to acquiring mines and manufacturing technology, China can undercut its global competition thanks to its weak environmental regulations and abundance of cheap domestic labor. Its focused efforts in the 1990s drove many non-Chinese firms out of business and left China with a disproportionate share of the market.[44] The longer China continues its export restrictions on REE oxides and refined metals, the greater the pressure on foreign industries to move their manufacturing operations to China, at least the portions that are dependent on REE raw materials. Conversely, China's restrictions breathe new life into the market for alternative products and reinvestment in domestic production. If the United States expects to surmount China's strategy, it needs to confront this challenge on multiple fronts.

Options

In order to stem the tide of dependence on China for permanent magnets, the United States should pursue several options: secure REE sources outside of China (preferably within its own borders), establish an NDS to meet military needs for permanent magnets, develop suitable substitute materials, and employ DOD acquisition policies to improve the REE market for domestic suppliers.

Non-Chinese Sources. Prior to 1990, the United States was largely self-sufficient in meeting its REE and permanent magnet requirements. Mountain Pass was the dominant source and the only large ore deposit mined just for its REE content, having reserves of 20 million tons.[45] Rekindling this and other domestic supplies would be ideal. As Molycorp prepares to restart mining at Mountain Pass, other American deposits being explored include North Fork, Idaho, where samples revealed neodymium concentrations as high as 3.7 percent.[46] According to the U.S. Government Accountability Office, rare earth deposits also exist in Colorado, Missouri, Montana, Utah, and Wyoming.

Other nations that have REE reserves include Australia (5 percent), India (3 percent), and several other countries with a combined total of 22 percent of the Earth's known reserves.[47] Deposits in Canada, owned by Great Western Minerals Group (GWMG), may contain dysprosium and terbium (needed for increased magnet coercivity).[48] GWMG also owns a magnet alloy producer in the United Kingdom and is planning to build a refinery near its Canadian mine. The company just entered into partnership with the South African firm RareCo to purchase all of the output from that company's Steenkampskraal mine. The first deliveries are expected by late 2012.[49] This moves GWMG another step closer to becoming the first fully integrated REE producer outside of China.[50] There are REE mines in Tanzania and the Democratic Republic of the Congo as well.[51]

> *China can undercut its global competition thanks to its weak environmental regulations and abundance of cheap domestic labor*

REE industry expert Jack Lifton surmises that as production of neodymium and other rare earths comes on line in Canada, South Africa, Idaho, and Montana in 2015 and beyond, by 2020 the world will be independent of China as its source of rare earth metals.[52] This is encouraging, but there are still uncertainties in the decade ahead. China could again flood the market with REEs in a short-term effort to devalue permanent magnets, therefore hobbling start-up ventures before they can become self-sustaining. In order to counter China's direct control and funding of Chinese firms, the U.S. Government should provide incentives (tax breaks, contract preferences, and so forth) for domestic companies striving to revive REE mining, refining of neodymium or samarium, or production of rare earth magnets. The USMMA urged the Department of Energy to use $2 billion in grant and loan guarantees to spur reestablishment of U.S. mining and refining operations and increase government support of training and workforce development in the resurgent industry.[53] Greater attention should also be accorded to the planned purchase of any U.S. company involved in the production of permanent magnets. It was partly through this legal avenue that America lost its REE independence. Resurgent domestic efforts must be more carefully guarded.

National Defense Stockpile. The United States has no REEs in its NDS. All such minerals were sold by 1998, and they were never classified as strategic minerals.[54] In their February 2010 proposal to Washington, the USMMA recommended stockpiling a 5-year supply of REEs to support the government's critical needs while the domestic supply chain is rebuilt.[55] Another recent report to Congress went beyond merely recommending the addition of these critical elements to the stockpile, instead urging that the NDS be completely reconfigured to be the Strategic Material Security Program (SMSP).[56] This newly proposed program would have the power to aggregate materials requirements across DOD and other cooperating Federal agencies in order to establish long-term strategic sourcing measures. The SMSP could leverage the combined buying power of all participating government departments that share a dependence on REE imports. However, a firm commitment from these agencies and a consistent flow of funds are required to enable the SMSP to capitalize on favorable timing of markets.

It would be wise to follow the Defense National Stockpile Center's recommendation to reconfigure the NDS into an expanded and more capable SMSP. However, this action will likely require some reworking of the Nation's procurement bureaucracy to establish the necessary interaction of all affected government departments. Such a consolidation of purchasing priorities for REEs promises the greatest long-term leverage of finances, but the system will take time to establish. At present, Congress should classify neodymium and samarium as strategic minerals for the next 5 to 10 years, adding them to the NDS, while the domestic supply chain for permanent magnets is reestablished.

Alternative Materials. According to George Hadjipanayis, co-inventor of the NdFeB magnet, "It's been 28 years since the discovery of neodymium-iron-boron, and we have not yet found a better magnet."[57] There are substitutes with similar properties available, but just not as good regarding weight or strength.[58] Since 1983, U.S. magnet development has been lackluster, but the search has received renewed emphasis in recent years.

DOD has research, development, and science and technology money it can use to fund exploration of alternative materials.[59] Such efforts could also be done in concert with other agencies. For instance, the Department of Energy's Advanced Research Projects Agency–Energy, which backs high-risk, high-reward projects, commissioned a $4.6 million research effort looking for a replacement for the NdFeB magnet. Hadjipanayis leads this search for a "next generation magnet."[60] The effort proceeds on three simultaneous fronts.

The University of Nebraska is trying to develop a permanent magnet without using REEs. The Department of Energy's Ames Laboratory is experimenting with combinations of rare earth, transition metals, and other minerals that have not previously been tried with magnets. The University of Delaware, where Hadjipanayis is a professor of physics, is working to fashion a new magnetic material that may reduce neodymium and samarium content by 30 or 40 percent, yet be double the strength of today's NdFeB magnets.[61] Their timeline is ambitious, allowing 3 years for materials experimentation and assembly of a prototype magnet.

The immediate focus for the United States should be on reestablishing its domestic REE supply and permanent magnet production capabilities, but not to the exclusion of pursuing better technology. This requires a delicate balance because it increases the financial risk that companies are taking to reestablish cradle-to-grave REE magnet manufacturing in America. Funding should be appropriated for research into alternative materials. However, the government must then be careful not to mandate the use of a resulting product only for the sake of justifying its investment. The principles of free-market capitalism must be honored in harmony with the need for national security. Moreover, this manner of government support must be pursued collaboratively between private enterprise (having experience with the most efficient ways to pursue production) and DOD (knowing best what the requirements are to support national security).

Department of Defense Policy. DOD already has a regulatory framework established to initiate government action to preserve domestic industrial capabilities vital to national security. DOD Instruction 5000.60 provides guidance for verifying the warfighting utility of the industry in question, that the specific capability is unique and at risk, that there are no feasible alternatives, and that the intended action is the most mission-effective and cost-effective.[62] One way DOD could influence the REE market is with limits imposed through the Defense Federal Acquisition Regulation, such as restricting the use of foreign-produced REE magnets in products it purchases in order to stimulate the resurgence of American industry and ensure the survival of those domestic suppliers. Intentionally high standards must be met before enacting such direct intervention. In addition to ensuring the most judicious use of limited DOD resources (anticipating greater expenses due to imposed limits on competition), stimulating industries through greater innovation that increases competition is always preferred over artificial market restrictions.

The United States is clearly dependent on REE permanent magnets to satisfy its demand for consumer electronics, fuel its automotive and energy industries, and most important, to maintain its lead in state-of-the-art military technology. Although America used to provide for its own permanent magnet requirements, this independence eroded over the past two decades and is now primarily gone. There are no active domestic REE mining operations or permanent magnet production lines fully in the country. The United States is entirely dependent on external sources, which essentially means dependence on its largest economic competitor and fastest-growing military challenger, China.

"There is oil in the Middle East; there is rare earth in China," stated Deng Xiaoping, who ruled China from 1978 to 1997 and inaugurated China's systematic campaign to dominate the world's supply of REEs.[63] The significance of Deng's observation has grown exponentially with the explosion of world demand for REEs and permanent magnet technology. China's own hunger for REEs to feed its modernizing economy, combined with its demonstrated willingness to use its near-monopoly on global production as a political instrument, portends greater conflict over this shrinking resource, relative to the demand for it.

Changing the trend of U.S. reliance on REE imports will be costly and time-consuming, but is incomparable to the price of crippling national security. The probability that America will lose all of its access to permanent magnets is relatively low, but the consequences of such a situation would be catastrophic. Fortunately, the limited supply of REEs resulting from China's increased consumption and reduction of exports has made mining and refining operations potentially profitable again.

There are several firms stepping up to reestablish their place in the market. However, these endeavors will take time and require great investment of capital. Molycorp's recent efforts to revive its domestic magnet manufacturing process and restart mining operations at Mountain Pass, California, are encouraging. Similarly, there is potential for mining operations in six other states and established ventures in Canada and South Africa that promise to open new sources of neodymium and samarium in the next 5 years. This is a tenuous time, as the possibility of Chinese maneuverings to flood the market (as it did in the 1990s) and drive prices down threatens to swamp the reemerging competition. U.S. Government interposition to ensure that the reemerging industry is not squelched by Chinese government–funded competitors will help hedge against these possible schemes. Continued exploration of alternative materials and technologies will also balance America's dependence on rare earth elements.

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While the permanent magnet cornerstone of the U.S. defense and energy industries is at risk, recovery is not insurmountable. Realizing the existence and scope of the threat, and applying the same creative thought and persistent action that once put America at the forefront of this technology, will ultimately return the Nation to its preeminent place in this field. **JFQ**

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