Global demand for rare earth materials is expected to grow dramatically. Primarily fueled by the continued development and implementation of emerging technologies, this demand will be exacerbated by the fact that in recent years China has been reducing its export quotas in order to both satisfy growing domestic demand and further develop a vertically integrated supply chain in its rare earth industry. At the same time, there is currently minimal initial rare earth mine production and processing in the U.S., with most materials being obtained from foreign sources, almost exclusively from China. A supply disruption of essential rare earths to the U.S. could clearly threaten the economic status and national security of the country. For a full discussion of rare earth issues, please see the book “Rare Earth Materials: Insights and Concerns” (details for how to purchase are at the end of this paper).

The rare earth elements consist of seventeen chemical elements. They are typically categorized into two groups - light rare earth elements and heavy rare earth elements. The light rare earth elements are lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), and samarium (Sm) (atomic numbers 57–62). The heavy rare earth elements include those with atomic numbers ranging from 64 to 71: europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu), plus scandium (Sc) and yttrium (Y) (atomic numbers 21 and 39). Rare earth materials, including ores, oxides, metals, and alloys, consist of one or more rare earth elements.

Trillions of dollars’ worth of modern devices depend upon rare earths. The two most important commercial end uses for rare earths in the U.S. are for automotive catalytic converters and petroleum refining catalysts, which together account for almost half of total rare earth usage. Metallurgical additives and alloys are ranked third in rare earth applications. Other major end uses for rare earths include permanent magnet motors and rechargeable batteries for both hybrid and full electric vehicles, phosphors for lighting and flat panel displays, glass polishing and ceramics, numerous medical devices, and in agriculture, mainly in China. In addition to widespread applications in commercial products, rare earth materials are also widely used in defense and dual-use systems. Examples of such applications include precision guided munitions, lasers, communication systems, radar systems, avionics, night-vision equipment, and satellites. In these applications, rare earth materials are very difficult to replace without compromising performance.

Most rare earth reserves are located throughout the world in deposits of bastnaesite and monazite. Bastnaesite deposits in the U.S. and China account for the largest concentrations, while monazite deposits
in Australia, South Africa, China, Brazil, Malaysia, and India account for the second-largest concentrations of rare earths. The USGS has identified approximately 114 million metric tons of exploitable rare earth reserves worldwide: China has 48.3%, CIS/Russia has 16.7%, the U.S. has 11.4%, India has 2.7%, and Australia has 1.4%. Five of the world’s richest rare earth deposits include the Bayan Obo deposit in China, the Mountain Pass deposit in the U.S., the Mount Weld carbonatite deposit in Australia, placer deposits in Australia, and the Seven Provinces ion adsorption clay deposit in Southern China. Other large deposits have been found within Russia, Afghanistan, South Korea, and other countries, although in many cases they are extremely difficult to mine due to their location. While many reserves have already been discovered, the USGS has estimated that undiscovered resources are very large relative to expected future demand.

Aside from the well-known Mountain Pass deposit in California, other rare earth resources exist within North America. Another promising resource is the Bear Lodge property in northeast Wyoming. Bear Lodge is reported to contain 384,000 metric tons of high-grade rare earths, as well as extensive gold resources within the same deposit. Significant deposits also exist within Canada, Alaska, Nebraska, Illinois, Colorado, Idaho, New York, New Mexico, Missouri, and New Jersey, with varying concentrations of rare earth elements. Regarding global resources, a large number of deposits have been identified, with some currently being mined, and others in the development stage. Key deposits include Steenkamskraal in South Africa, Kvanefjeld in Greenland, Dong Pao in Vietnam, and Dubbo, Nolans, and Mt. Weld in Australia. Other significant deposits discovered within countries such as Russia and Afghanistan are considered highly valuable, but are not actively exploited due to the challenges of their location.

Global demand for rare earth materials grew steadily by between 8–12 percent per year until 2008, before falling due to the global recession. Demand levels then recovered, and continued to follow a similar growth trend from mid-2009 onwards, with demand projected to continue to steadily grow out to 2016. China is not only the world’s leading producer of rare earth materials, but also the leading consumer, with total consumption of 70,000 metric tons of global production in 2011, and this figure is forecast to continue to rise to 80,000 metric tons in 2012. Japan and northeast Asia are the second-largest consumers of rare earth materials, accounting for approximately 22 percent of world consumption, and the U.S. follows as the third leading consumer, at about 12 percent. Experts are predicting that China's internal needs for rare earths will continue to take up the majority of its production.

There are currently no exchanges where rare earth metals are traded, and any pricing information available for large purchases is reported from spot transactions, where the price reported may be significantly different from what was actually paid. It should be noted, however, that pricing within the rare earths market has shown enough volatility to illustrate clear trends. The global rare earth market was relatively stable in the 2000s, and then in early 2011, due to significant global concerns over Chinese supplies, the prices for rare earth metals and oxides were reported to have risen as far as 800% from January to August. As a result, companies outside China looked to their rare earth material stockpiles or illegal Chinese exports, or simply reduced their level of production. Almost as quickly as prices had gone up, they began to fall again, with the Chinese government enacting production shutdowns late in 2011, possibly in order to stop prices from falling further. As of April 2012, pricing for some heavy rare earths (Nd, Dy) had begun to increase once again.

The current global rare earth supply situation has been caused by unbalanced global supply and production – China produced 94% of the world supply of REEs in 2011, leaving only 6% of the world’s
supply provided by facilities outside of China, despite sizable deposits worldwide. China is facing growing domestic demand, and as such, its supply to the outside world will be limited to what is left over after that demand is satisfied. China’s drive to build stronger downstream rare earth element industries will only further decrease exports, resulting in shortages if producers from the rest of the world do not step in to fill the gap. Supplies may become available soon however, as companies in a number of countries are actively developing rare earth mines and processing facilities, either within their own countries or in partnerships with other countries. Germany, Japan, and others have set up partnerships and other agreements with industry members and governments in Australia, Malaysia, India, South Korea, Vietnam, Kyrgyzstan, Kazakhstan, and more in an effort to assure future rare earth supplies from non-Chinese sources.

Until the 1990s, most of the world's rare earths were supplied from the United States, from the Mountain Pass mining and processing facility in California. Mountain Pass was closed in 2002 amid falling rare earth prices and environmental concerns, marking the point at which the rare earth supply chain shifted to China. Approximately 20 years ago, the U.S. had twelve rare earth oxide magnet factories, employing 6,000 workers and participating in a global market valued at $600 million. As of 2010, only four factories remained, with approximately 600 workers, while the global market had grown to a value of over $7 billion. The Mountain Pass facility has since been redeveloped and reopened however, and, under the direction of a newly formed Molycorp, is looking to become a major supplier to the U.S. domestic market at a projected 40,000 metric tons per year of rare earth oxides.

In the early 1990s, China became the principal producer, supplier, and consumer of the rare earth industry. The country has made remarkable progress in rare earth science, technology, and resource utilization, while only possessing half of the world’s rare earth deposits. China showed significant interest in rare earths, particularly in R&D, even in the early years of the country’s development of its resources. As a result of two national programs focused on fundamental research, Programs 863 and 973, today, China is home to the largest rare earth R&D research institute in the world (BRIRE) with nearly 500 employees, as well as a number of key state laboratories working on rare earth research.

Despite the country’s successes in rare earth production, the industry in China has been rife with unrestrained mine development, environmental issues, and poor resource management practices. Chinese leaders have expressed their concern that the country’s future demand for rare earths may not be met if existing mining practices are allowed to continue without further regulation. The environmental damage done to mining areas in China is extensive, and as a result, the government has begun to enact and enforce new environmental taxes and laws designed to curb excessive, dangerous, and illegal mining. They have also begun to combine existing mining and processing firms into a handful of larger firms in order to exert stronger governmental control over the industry.

China has also been reducing export quotas for rare earth oxides and in 2012 placed specific restrictions on heavy and light rare earths for the first time. The combinations of these restrictions and increasing export tariffs on rare earth metals and oxides is designed to lead rare earth material consumers to move their manufacturing enterprises into China. If the Chinese government is successful, the result will be growth in the numbers of higher value downstream rare earth goods being exported, rather than rare earth oxides. Accordingly, there is growing concern about the future of rare earth oxide and metal supplies among upstream rare earth consumers outside China.
China’s reduction in export quotas in recent years and the rising price of rare earths has spurred global interest in recycling cast-off electronics products that contain rare earth materials, finding substitutes, performing research to minimize usage, and finding new supplies to build complete supply chains. After a temporary rare earth trade stoppage with China in 2010, Japan has led these efforts with aggressive government targets designed for both greater recycling and a reduction in the usage of rare earths. Japanese companies such as Toyota Tsusho have also begun to supply alternative sources for their entire rare earth supply chain, investing in rare earth projects worldwide. As a result of concerns about both future price and availability, companies around the world have also invested heavily in the development of rare earth free technologies, with many beginning to arrive in the marketplace.

A complete rare earth supply chain is currently lacking in the U.S., and it must be further developed, either nationally or in conjunction with our allies. An aggressive R&D agenda is recommended for rare earth element alternatives, reduction strategies, process optimization, new applications, alternative rare earth element-free technologies, and rare earth element recycling, with an accompanying intellectual development component. While the Department of Defense and the U.S. Government do not have any sense of urgency regarding this issue based on their prediction of future domestic capabilities, a call to action at the national level is required. In order to ensure national security, a stockpile of the most critical materials should be created, in the form of a public-private (government-industry) partnership. We should also look to Japan as a role model for the actions required to address a situation currently considered critical but not yet a crisis.

National security, as well as future economic growth from emerging technologies, is dependent upon the steady availability of rare earth elements, which will be supplied to the world in the foreseeable future primarily by a single, potentially hostile supplier. Our challenge is to address this issue head on, and in an imaginative way.

For more information and to get the book “Rare Earth Materials: Insights and Concerns,” contact Dr. Michael Pecht (pecht@calce.umd.edu) at the Center for Advanced Life Cycle Engineering (CALCE) at the University of Maryland.