State of Oregon
Department of Environmental Quality

Briefing Paper: Rare Earth Elements

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Executive Summary

This paper describes rare earth elements - their composition, qualities and uses – and how these difficult-to-extract elements play a role in the global material management system. It describes how these elements may become more critical in the future for the military and for technologies including hybrid cars, wind turbines, cell phones and spy planes. This paper looks at the environmental consequences of using rare earth minerals, their limited availability, and how reusing and recycling these elements can be part of a more sustainable worldwide system.

Rare earth elements include 17 chemical elements that are not really "rare" but are actually relatively abundant in the Earth's crust. However, they seldom exist in pure form and are rarely in concentrated minable deposits, making them costly to extract. They include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium (the lanthanide elements on periodic table). Yttrium and scandium are also often considered rare earth elements since they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties.

These rare earth elements' unique properties have led to an ever-increasing variety of applications. These include uses in major industries such as automotive, medical, defense, technology/computers and clean energy, as well as use in hybrid cars and wind turbines. Because of widespread use of these elements in technology, particularly by the military, the U.S. is examining domestic deposits with renewed interest and funding.

Currently, about 97 percent of the world supply of rare earth elements comes from China. Other countries produce rare earth concentrates, but they are dwarfed by the scale of Chinese production. Other countries such as Greenland and Vietnam are currently exploring rare earth element mining.

The only minable rare earth deposit in production in the United States is at the Molycorp Inc,.-owned Mountain Pass rare earth mine in California, owned by Molycorp, Inc . This mine is undergoing an extensive modernization and expansion, and was expected to re-enter full production in 2012. Other major domestic deposits are in Wyoming, Colorado and Alaska. These deposits are in the exploratory phase.

In a federal Department of Energy report, "2011 Critical Materials Strategy," the agency lists five rare earths - dysprosium, terbium, europium, neodymium, and yttrium - that are "critical" in terms of need and supply, from the present day to 2015. These five elements are used in magnets for wind turbines and in electric vehicle motors to improve fuel efficiency and phosphors in energy-efficient lighting. Other elements—cerium, indium, lanthanum, and tellurium—were found to be "near-critical" in terms of supply between the short and medium term (2015–2025).

Recycling can reduce the risk that supplies of critical materials will fail to keep pace with demand. Recycling is especially important for critical materials with limited substitutes. New advances in recycling technology have made extraction of rare earths from discarded products more feasible.

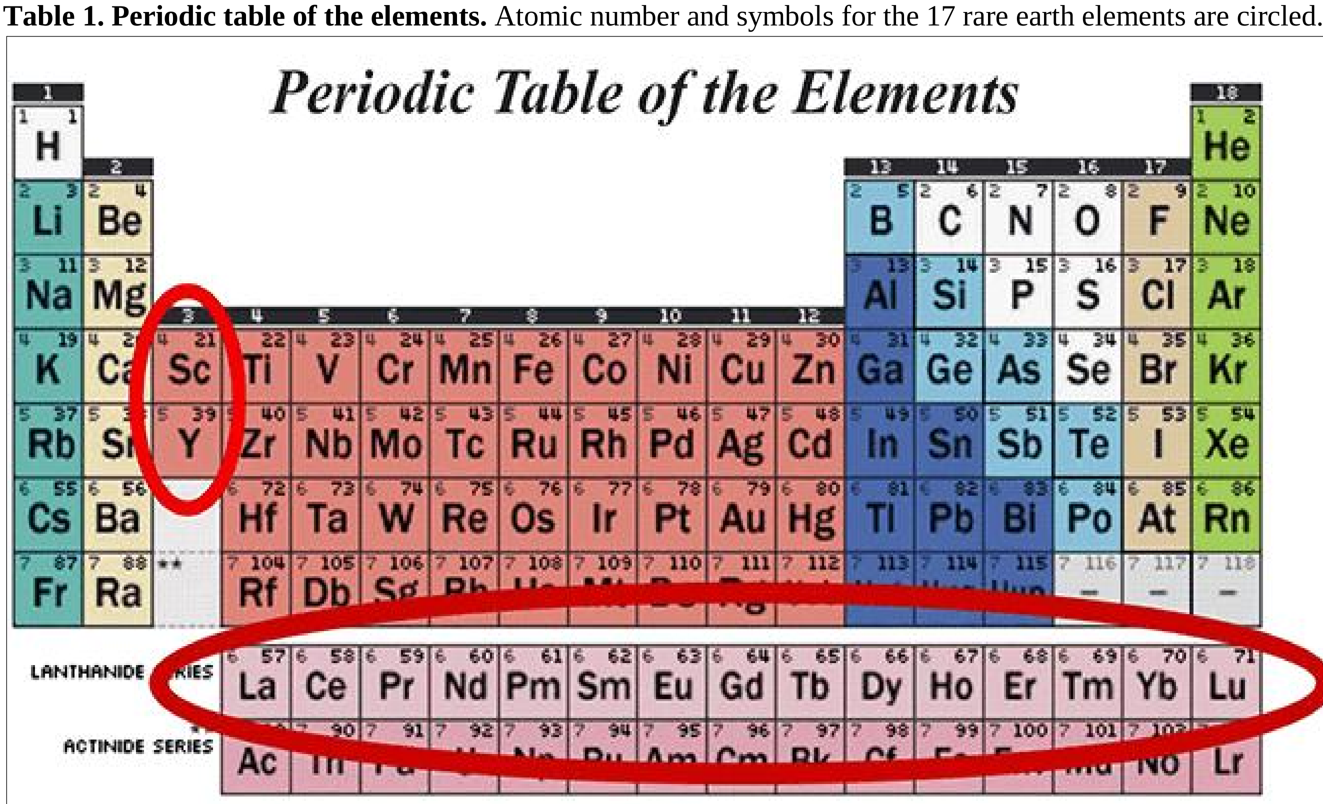
Recycling plants in Japan plan to capture an estimated 300,000 tons of rare earths stored in unused electronics. In France, the Rhodia group, a global chemical company, is opening two factories to produce 200 tons a year of rare earths from used fluorescent lamps, magnets and batteries. Government and industry in the U.S. and elsewhere are exploring product redesign as a way to reduce the use of or find substitutes for rare earths. However, many applications of rare earths are highly specific, with substitute materials either not available or resulting in reduced performance.

The 2011 DOE report emphasizes that policies directed toward the recovery of end-of-life products and equipment can encourage a higher rate of recovery, and support for research and development into more efficient and cost-effective recycling processes can make recycling more attractive.

Introduction

Rare earth elements are a group of 17 chemical elements that occur together in the periodic table (see below). These 15 lanthanide elements include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. Yttrium and scandium are also often considered rare earth elements since they tend to occur in the same ore deposits as the lanthanide elements and exhibit similar chemical properties. Rare earth deposits tend to occur in two sub-groups: light rare earth elements (lanthanum, cerium, praseodymium, neodymium and samarium), and heavy rare earth elements which are less common and more valuable (europium gadolinium terbium dysprosium, holmium, erbium, thulium, ytterbium and lutetium). Rare earth elements are actually relatively abundant in the Earth's crust. However, they seldom exist in pure form and mix diffusely with other minerals underground, rarely in concentrated minable deposits, making them costly to extract. The rare earth deposits, without exception, consist of mixtures of most rare-earth elements which are often found together.

Table 1. Periodic table of the elements. Atomic number and symbols for the 17 rare earth elements are circled.



Rare earth elements commonly have the following properties:

- Are silvery-white and often tarnished when exposed to air

- Are relatively soft
- React with water to release hydrogen gas
- Have high melting and boiling points
- Many make good magnets
- Many glow strongly under ultraviolet light
- Have ores that are mineralogically and chemically complex
- Are commonly radioactive

Geology of rare earth elements

The principal concentrations of rare earth elements are associated with uncommon varieties of igneous rocks, namely alkaline rocks and carbonatites. Carbonatites are mostly intrusive rocks that contain more than 50 percent carbonate minerals, cooled from a lava melt. Structurally, they occur as volcanic plugs, dikes and cone sheets. According to the geological literature, there are about 330 known occurrences of carbonatites worldwide, but almost all are small and noncommercial. There are only a few carbonatite deposits of commercial significance in the world. The bulk of the world's supply of rare earth elements comes from the mineral bastnasite. Bastnasite is a mixed lanthanide fluoro-carbonate mineral (LnFCO3) that is found in carbonatites. Potentially useful concentrations of rare earth element-bearing minerals are also found in placer deposits, residual deposits formed from deep weathering of igneous rocks, pegmatites, iron-oxide copper-gold deposits, and marine phosphates.

Major uses of rare earth elements

Rare earth metals (metals which contain the rare earth elements) and their alloys are used in many devices commonly used every day such ascomputers, DVDs, rechargeable batteries, cell phones, car catalytic converters, magnets, fluorescent lighting, and many others. They're also used in medical equipment, for defense purposes, and in "clean energy" (i.e., wind turbines and hybrid automobiles).

<u>General industrial uses include</u>:

Clean Energy
- Wind turbines (neodymium)
- Low-energy light bulbs (terbium)
- Hybrid-car batteries (lanthanum)
- Solar energy fuel sources (cerium)

Automobiles
- Hybrid-car batteries (lanthanum)
- Electric motors (dysprosium)
- Catalytic converters (cerium)
- Glass and mirrors (cerium)

Medical
- X-ray machines (ytterbium and thulium)
- Screening diseases (Europium)
- Medical devices (yttrium)
- Eye-safe medical and dental technologies (holmium)

Defense
- Missile guidance systems (neodymium)
- Stealth technology (samarium)
- Night-vision goggles (lanthanum)
- Armor (ytterbium)
- Drones (various rare earth elements)

Technology/Computers

- LED screens (lutetium)
- Cell phone batteries (lanthanum)
- Fiber-optic cables (erbium)
- Lasers (ytterbium and praseodymium)
- Computer memory (gadolinium)

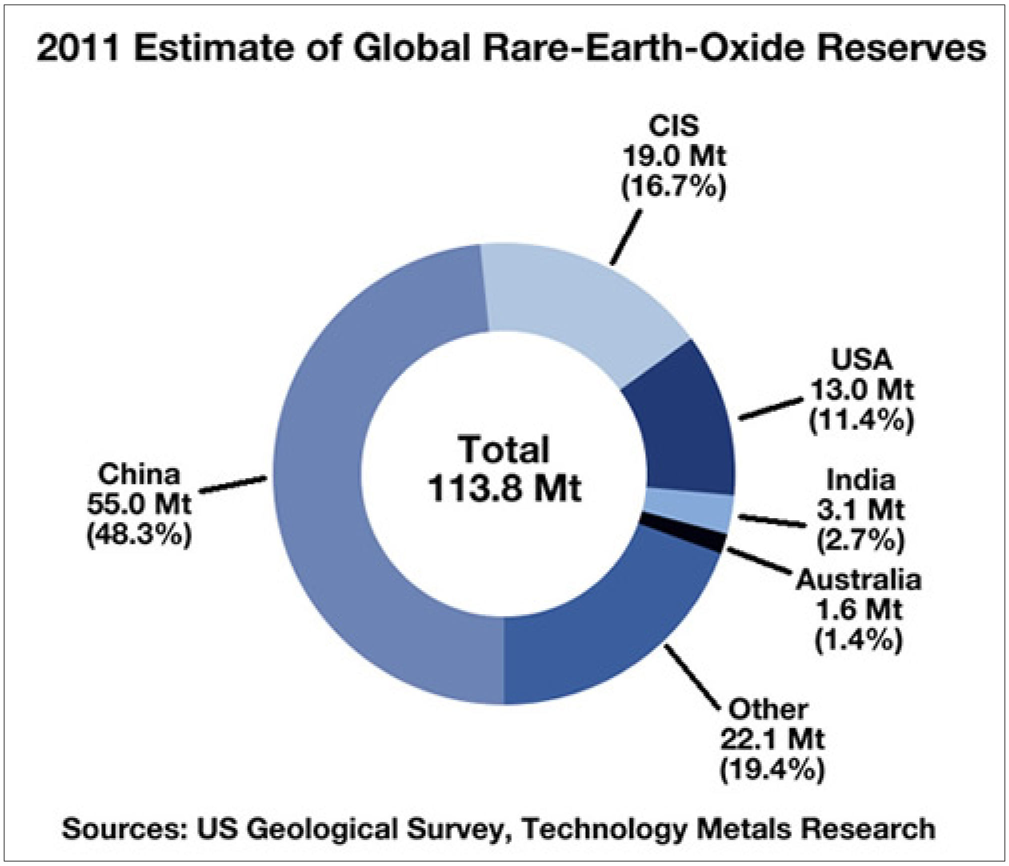
Specific uses (listed by rare earth element):

- **Cerium** is the most abundant rare earth element. It is critical in the manufacture of environmental protection and pollution-control systems, from automobiles to oil refineries. Cerium oxides and other cerium compounds are in catalytic converters and larger-scale equipment to reduce sulfur oxide emissions. Cerium is a diesel fuel additive for micro-filtration of pollutants, and promotes more complete fuel combustion for more energy efficiency.
- **Dysprosium** is a widely used rare earth element that helps to make electronic components smaller and faster.
- **Erbium** has remarkable optical properties that make it essential for use in long-range fiber optic data transmission.
- **Europium** offers exceptional properties of photon emission. When it absorbs electrons or UV radiation, the europium atom changes energy levels to create a visible, luminescent emission. This emission creates the perfect red phosphors used in color televisions and computer screens around the world. Europium is also used in fluorescent lighting, which cuts energy use by 75 percent compared to incandescent lighting. In the medical field, europium is used to tag complex biochemical agents, which helps to trace these materials during tissue research.
- **Gadolinium** offers unique magnetic behavior. Therefore, this element is used in magneto-optic recording technology and other technology used in handling computer data.
- **Holmium** is exceedingly rare and expensive. Hence it has few commercial uses.
- **Lanthanum** comes from the mineral bastnasite and is extracted via a method called "solvent extraction." Lanthanum is a strategically important rare earth element due to its activity in catalysts that are critical in petroleum refining. By one estimate, lanthanum "cracking-agents" increase refinery yield by as much as 10 percent, while reducing overall refinery power consumption. Lanthanum is also used in the manufacture of night goggles.
- **Lutetium**, the last member of the lanthanide series is, along with thulium, the least abundant. It is recovered by ion-exchange routines in small quantities from yttrium concentrates and is available as a high-purity oxide. Cerium-doped lutetium oxyorthosilicate (LSO) is currently used in detectors in positron emission tomography (PET).
- **Neodymium** is a critical component of strong permanent magnets. Cell phones, portable CD players, computers, and most modern sound systems would not exist in their current form without neodymium magnets. Neodymium-iron-boron (NdFeB) permanent magnets are essential for miniaturizing a variety of technologies. These magnets maximize the power/cost ratio, and are used in a large variety of motors and mechanical systems.
- **Praseodymium** comprises just 4 percent of the lanthanide content of bastnasite, but is used as a common coloring pigment. Along with neodymium, praseodymium is used to filter certain wavelengths of light. Praseodymium finds specific uses in photographic filters, airport signal lenses and welder's glasses, as well as broad uses in ceramic tile and glass (usually yellow). When used in an alloy, praseodymium is a component of permanent magnet systems designed for small motors. Praseodymium also has applications in internal combustion engines as a catalyst for pollution control.
- **Samarium** has properties of spectral absorption that make it useful in filter glasses that surround neodymium laser rods. Samarium is used for magnets that are stable at high temperatures and in precision guidance weapons.

- **Terbium** is used in energy efficient fluorescent lamps. Various terbium metal alloys provide metallic films for magneto-optic data recording.
- **Thulium** is the rarest of the rare earth elements. Its chemistry is similar to that of yttrium. Due to its unique photographic properties, thulium is used in sensitive X-ray phosphors to reduce X-ray exposure.
- **Ytterbium** resembles yttrium in broad chemical behavior. When subject to high stresses, the electrical resistance of the metal increases by an order of magnitude. Ytterbium is used in stress gauges to monitor ground deformations caused, for example, by earthquakes or underground explosions.
- **Yttrium** is rare in bastnasite so is usually recovered from even-more obscure minerals and ores. Still, almost every vehicle on the road contains yttrium-based materials that improve the fuel efficiency of the engine. Another important use of yttrium is in microwave communication devices. Yttrium-iron-garnets are used as resonators in frequency meters, magnetic field measurement devices, tunable transistors, and Gunn oscillators. Yttrium goes into laser crystals specific to spectral characteristics for high-performance communication systems.

Supply (reserves) and demand

Rare earth elements will be of considerable interest for the foreseeable future, and demand is projected to grow. While some market mechanisms should ensure that serious shortages are averted, at least in the long term, there may be significant short-term disruptions to the supply of some rare earth elements, and price instability. A 2011 report issued by the U.S. Geological Survey and U.S. Department of the Interior, “China’s Rare-Earth Industry,” outlines industry trends within China and examines national policies that may guide the future of the country's production. The report notes that China’s lead in the production of rare earth minerals has accelerated over the past two decades. In 1990, China accounted for only 27 percent of such minerals. In 2009, world production was 132,000 metric tons; China produced 129,000 of those tons. According to the report, recent patterns suggest that China will slow the export of such materials to the world due to domestic demand. According to China’s draft rare earth development plan, annual rare earth production may be limited to between 130,000 and 140,000 metric tons during the 2009-15 period. However, global supply of heavy rare earth elements will still be heavily reliant on China beyond 2015.



Source: www.techmetalsreseach.com/2011/02/usgs

In the federal DOE analysis of the topic, "2011 Critical Materials Strategy," the agency found that five rare earth elements (dysprosium, terbium, europium, neodymium, and yttrium) were found to be critical in terms of supply in the short term (from the present to 2015). These five rare earth elements are used in crucial technologies (such as magnets for wind turbines and electric vehicles or phosphors in energy-efficient lighting). Other elements—cerium, indium, lanthanum, and tellurium—were found to be near-critical. The report finds that between the short term and medium term (2015–2025), the importance to clean energy and supply risk will shift for some materials.

Shortages will particularly be felt by makers of wind turbines and electric vehicle technologies because they require permanent magnets containing neodymium and dysprosium, rare earths highly valued for magnetic and thermal properties. But manufacturers of both technologies are "currently making decisions on future system design, trading off the performance benefits of neodymium and dysprosium against vulnerability to potential supply shortages," says the DOE. "For example, wind turbine manufacturers are deciding among gear-driven, hybrid and direct-drive systems, with varying levels of rare earth content. Some EV manufacturers are pursuing rare-earth-free induction motors or switched reluctance motors as alternatives to permanent magnetic motors."

One reason for disruptions in supply is that in recent years demand for almost all these materials examined has grown more rapidly than demand for commodity metals such as steel. The growing demand for the materials studied comes from clean energy technologies as well as consumer products such as cell phones, computers and flat-panel televisions.

However, the global material supply has been slow to respond to the rise in demand, mostly due to a lack of capital, long lead times, trade policies and other factors. Market response has also been complicated by complexities of coproduction and by production. According to the DOE report, "In addition, for some key materials, the market's lack of transparency and small size can affect its ability to function efficiently." Governments and industry are beginning to recognize the importance of raw materials to the economic competitiveness of clean energy technology, and many are taking an active role in mitigating supply risks. In the U.S., though work has been scaled up to address supply disruptions, "much more work is required in the years ahead," the report concludes.

Distribution of materials by criticality categories in the short and medium term is shown in the data presented below: (from the "2011 Critical Materials Strategy" report)

Distribution by Criticality:		
Criticality	**Short-Term**	**Medium-Term**
Critical	Dysprosium Europium Indium Terbium Neodymium Yttrium	Dysprosium Europium Terbium Neodymium Yttrium
Near Critical	Cerium Lanthanum Tellurium	Indium Lithium Tellurium
Not Critical	Cobalt Gallium Lithium Praseodymium Samarium	Cerium Cobalt Gallium Lanthanum Praseodymium Samarium

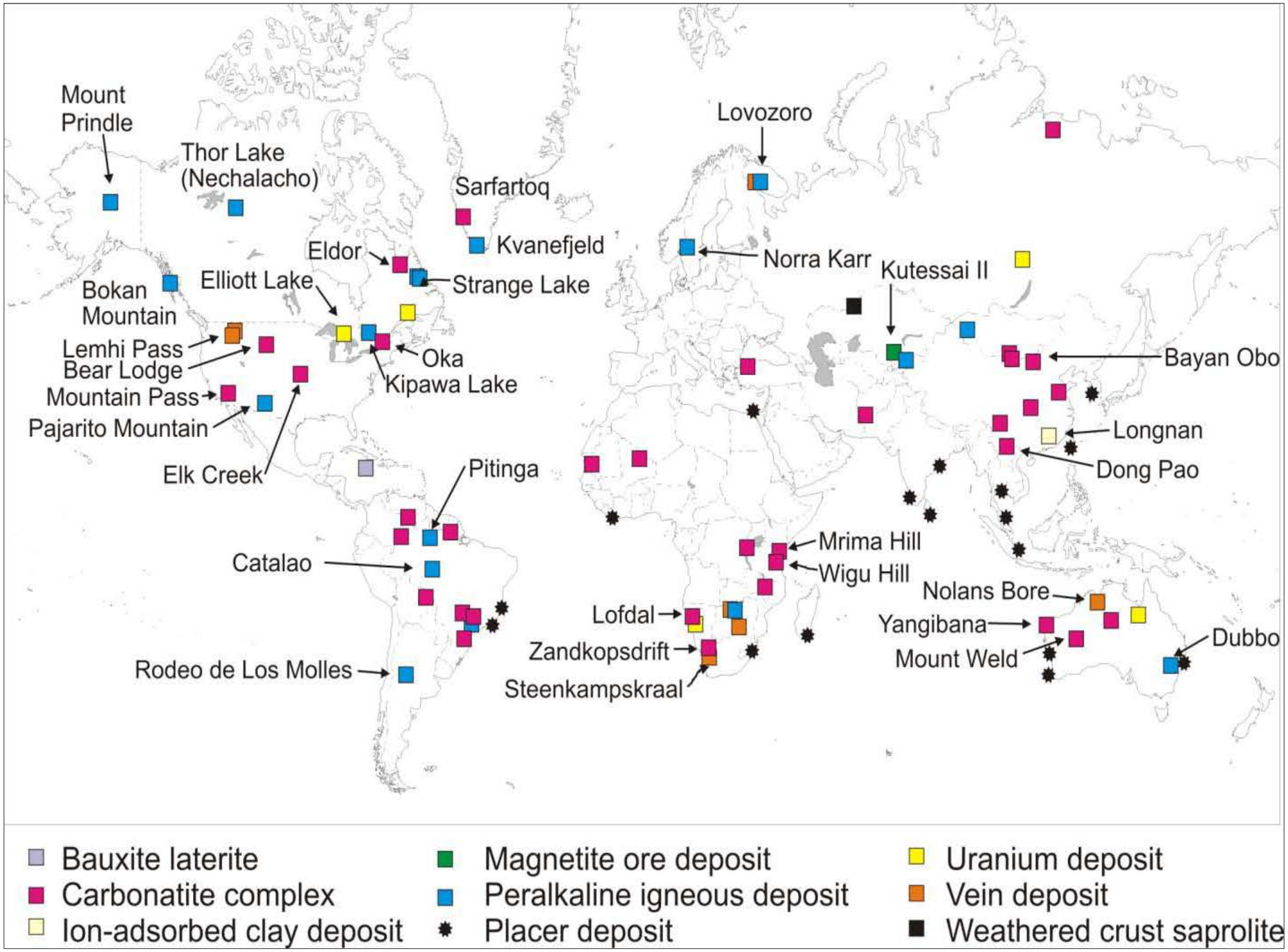
Rare earth elements resources

World resources

Significant amounts of rare earth elements are produced, but in only a few countries. United States and world resources are primarily found in bastnasite and monazite, phosphate mineral-containing rare earth metals[1]. Bastnasite deposits in China and the United States constitute the largest percentage of the world's rare earth economic resources, while monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand and the United States constitute the second-largest segment. Several other countries, such as Canada, Greenland and Vietnam, are also actively exploring for possible resources of rare earth elements.

The figure on the following page shows the location of some of the most important rare earth element occurrences, as of 2011.

[1] $(Ce, La, Y, Th)PO_4$



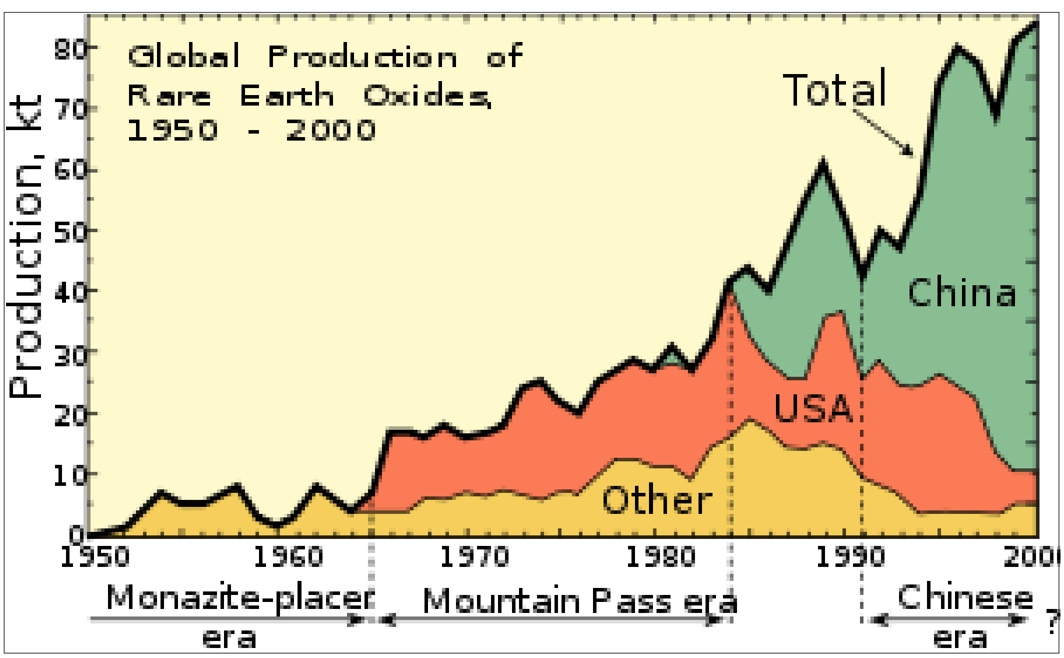
Source: Mariano et al., 2010 (www.smenet.org/rareEarthsProject/SME_2010_Mariano.pdf), modified by Kaiser Research Online (www.kaiserbottomfish.com/s/Education.asp?ReportID=362761).

Table 2. World mining production and potential reserves for the leading countries

World Mine Production and Reserves		
Country	**Production-2009 (Metric Ton)**	**Reserves (Metric Ton)**
United States	insignificant	14,300,000
Australia	insignificant	180,000
Brazil	650	53,000
China	120,000	60,060,000
Commonwealth of Independent States	not available	20,900,000
India	2,700	3,400,000
Malaysia	380	33,000
Other countries	not available	24,000,000
World total (rounded)	124,000	121,000,000

Source: USGS Mineral Commodity Summaries, 2011 data

China is the dominant consumer and producer of rare earth elements. It produces over 97 percent of the world's rare earth supply, mostly in Inner Mongolia, even though it has only 37 percent of proven reserves.[2] Almost all of the world's heavy and more valuable rare earth elements come from Chinese sources. Until 1948, most of the world's rare earth elements came from placer sand deposits in India and Brazil. Through the 1950s, South Africa was the world's rare earth source, after large veins of rare earth-bearing monazite were discovered there. From the 1960s through the 1980s, the Mountain Pass rare earth mine in California was the leading producer. The scale of Chinese production of rare earth elements metals dwarfs that of other countries, as can be seen in the table above. The graph below shows the trend of rare earth oxide production by location since 1950.



Source: U.S. Geological Survey Fact Sheet 087-02. Available at http://pubs.usgs.gov/fs/2002/fs087-02/

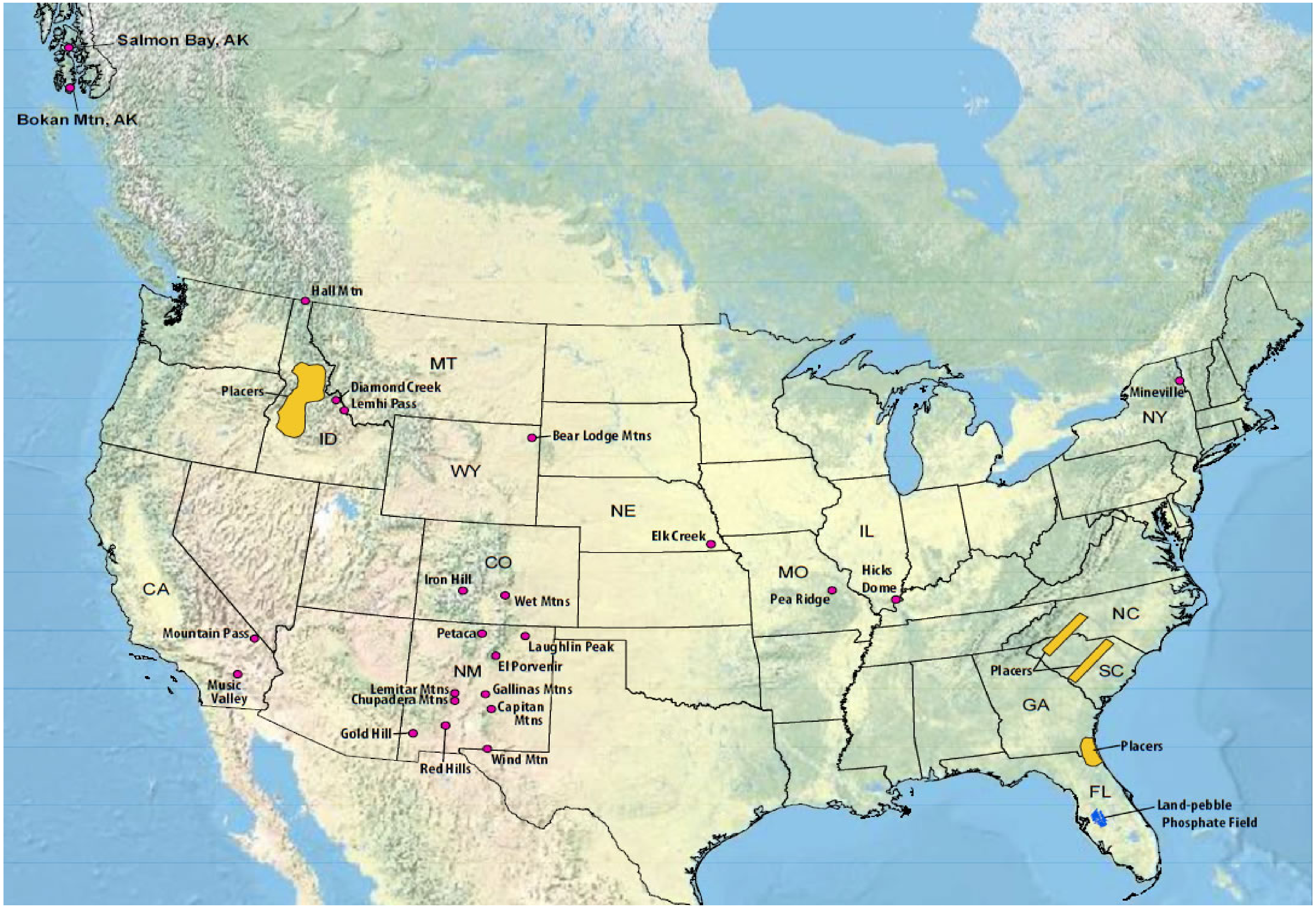
[2] Proven reserves are estimated quantities of mineral deposits, at a specific date, as analysis of geologic and/or engineering data, which demonstrates with reasonable certainty to be recoverable in the future under the same economic and operational conditions.

New and near future producers of reserves containing mainly light rare earth elements include:

- ***Mountain Pass, Calif., USA: (see details below)*** Owned by Molycorp Minerals. Mining restarted in December 2010. Output should start at 3,000 to 5,000 tons of rare earth oxide a year, rising to at least 20,000 tons by 2014, with 40,000 tons under consideration. Expansion and modernization at the Mountain Pass mine is now underway.
- ***Mount Weld, Australia:*** Owned by Lynas Corporation. Progress is well advanced, with production that began in early 2012, producing an initial 11,000 tons of rare earth oxides annually, and rising to 22,000 tons by 2014.
- ***Nolans, Australia***: Owned by Arafura Resources Limited. Company forecasts production of 20,000 tons of rare earth oxides annually by 2013.

United States resources

The 2010 U.S. Geological Survey identified 29 large rare earth deposits within the United States (see figure on following page). Placers, iron ores and alkaline igneous complexes constitute the major types of rare earth deposits in the U.S. These deposits account for 13 percent of the world's identified rare earth reserves.



Rare earth element districts in the United States are mainly located in the West. This map shows the location of potential production locations - Long, K.R., Van Gosen, B.S., Foley, N.K., and Cordier, Daniel, 2010, The principal rare earth elements deposits of the United States—A summary of domestic deposits and a global perspective: U.S. Geological Survey Scientific Investigations Report 2010–5220, 96 p. Available at http://pubs.usgs.gov/sir/2010/5220/.

The Mountain Pass Mine

The Mountain Pass rare earth mine is an open-pit mine of rare earth elements on the south flank of the Clark Mountain Range and just north of the unincorporated community of Mountain Pass, Calif. The mine, owned by Molycorp Inc., once supplied most of the world's rare earth elements. The Mountain Pass deposit contains 8 percent to 12 percent rare earth oxides, mostly contained in the mineral bastnasite. Molycorp mines 10 of the rare earth elements by hauling ore-laden rocks from the ground, crushing them, and then chemically extracting the elements.

The facility is currently undergoing expansion and modernization. **"**Project Phoenix,**"** Molycorp's current ~$781 million project at the Mountain Pass mine, aims to "transform Mountain Pass and create the world's most technologically advanced, energy efficient and environmentally superior rare earth production facility in the world." Construction on the project began in January 2011. To meet U.S. environmental standards, Molycorp is constructing an on-site natural gas plant to more cleanly generate the electricity needed for rare-earth processing. The company will also recycle the mining wastewater, using it to produce the hydrochloric acid and sodium hydroxide needed to separate the rare earths during processing. The diagram on the following page shows the current rare earth element ore process at the mine.

Upon completion of Phase 1 of this project at the end of 2012, Molycorp anticipates that it will have the ability to produce approximately 19,050 metric tons of rare earth oxide equivalent per year at Mountain Pass. Molycorp states that, based on estimated reserves and an expected annual production rate of approximately 19,050 metric tons of rare earths, the expected mine life is in excess of 30 years. Lanthanum, cerium, neodymium and praseodymium will make up the majority of the commercial output from Mountain Pass. However, with the high volume of ore processed and high recovery rates, the mine may be able to produce commercially significant quantities of heavy rare earth elements such as europium, terbium, dysprosium and yttrium.

Environmental consequences of mining and processing rare earth metals

Mining a rare earth deposit at a profit involves a number of factors, including pricing, regulatory requirements, environmental concerns, and improvements in extraction and separation technologies. Rare earth resources are distributed between many mineral deposits, but only a proportion will be economical to develop and mine. Among the many rare earth reserves available, mining companies will select the most profitable to develop, potentially leaving less profitable reserves undeveloped. Reserves may also be undeveloped because of adverse land-use restrictions, civil strife and a host of other political and social factors.

Mining and processing rare earth elements presents environmental risks. To mine rare earth elements, acid is pumped down bore holes where it dissolves the rare earth elements. Those elements are then processed using more chemicals, acid and high temperatures. The waste, which is toxic, is disposed. A major concern surrounding China's practice of mining rare earth elements is the negative impact it has had to the environment due to lax mining practices. Unfortunately, because of the revenue potential, many rare earth mines have been operating illegally, or with little supervision and little to no regulation, causing severe environmental hazards.

Cindy Hurst, Energy Writer for *The Cutting Edge News*, reported in November 2010 that an article published by the Chinese Society of Rare Earths found that:

- Every ton of rare earth produced generates approximately 8.5 kilograms (18.7 pounds) of fluorine and 13 kilograms (28.7 pounds) of dust;

- Using concentrated sulfuric acid high-temperature calcination techniques to produce approximately one ton of calcined rare earth ore generates 9,600 to 12,000 cubic meters (339,021 to 423,776 cubic feet) of waste gas containing dust concentrate, hydrofluoric acid, sulfur dioxide sulfuric acid, approximately 75 cubic meters (2,649 cubic feet) of acidic wastewater plus about one ton of radioactive waste residue containing water.

Within the city of Baotou - where China's primary rare earth production occurs - "all the rare earth enterprises in the Baotou region produce approximately 10 million tons of all varieties of wastewater every year" and most of that wastewater is "discharged without being effectively treated, which not only contaminates potable water for daily living, but also contaminates the surrounding water environment and irrigated farmlands.

In Bayan Obo, the ore is mined and then transported back to Baotou via open railway cars, where it is then processed. Unfortunately, with old, outdated technology and equipment, and little oversight, the waste finds its way into the Yellow River, which passes by the south side of Baotou and travels another 1,300 miles, through mountainous terrain as well as through heavily populated areas before finally discharging into the Yellow Sea. In 2005, Xu Guangxian, an expert on China's rare earth industry, wrote that thorium was a source of radioactive contamination in the Baotou area and the Yellow River. Some 150 million people depend on the river as their primary source of water.

In May 2010, China announced a major, five-month crackdown on illegal mining in order to protect the environment and its resources. This campaign is expected to be concentrated in the southern mines – commonly small, rural and illegal operations – which are particularly prone to releasing toxic wastes into the general water supply.

Recycling

As previously noted, the demand for rare earth elements is growing. According to a recent report by the U.S. Department of Energy[3] the solution to the scarcity of rare earth elements is to develop other global supplies, explore substitutes, and recycle and reuse what we already have. The DOE report emphasizes investing in recycling and reuse technology to create a long-term, sustainable solution to the rare earth supply problem. However, the scope for recycling is limited by the fact that the likely future demand for some rare earth elements is large compared to the amount already in circulation, and by the long lifetimes of some of the products in which they are used. Nonetheless, countries, most notably Japan, France and Germany, have invested in recycling technology and are developing alternative technologies that use fewer rare earth elements.

Japan, which has been hit the hardest by the reduction in global rare earth supply, has started a program called Urban Mining. Urban mining is the extracting of rare earth metals from discarded electronic products, which are ubiquitous in Japan, to reuse in new electronic products. The process is not only much more environmentally friendly than raw mineral extraction and production, but also mitigates Japan's dependence on China for the metals. The Japanese government estimates that there are 300,000 tons of rare earth elements in Japanese landfills alone. The Japanese company Hitachi plans to recycle electric motor magnets by 2013. In France, the Rhodia group is setting up two factories, in La Rochelle and Saint-Fons, that will produce 200 tons a year of recycled rare earth elements from used fluorescent lamps, magnets and batteries.

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[3] Available at www.energy.gov/news/documents/criticalmaterialsstrategy.pdf

The European Commission is also stepping up efforts to recover and recycle rare earth elements from electronic waste, and emphasizes the need to “take a proactive role in securing rare earth elements for itself as well as the necessary know-how and expertise in the field and to invest in research and innovation and in education and training of the next generation of rare earth scientists and engineers” (from *New Europe Post*, “Towards a cohesive European rare-earth elements strategy,” by Ioannis. A. Tsoukalas, July 19, 2011).

Substitution and sustainability

Finding other materials to substitute for rare earth elements, or redesigning products so they’re less dependent on them is also being considered. However, many applications of rare earth elements are highly specific, with substitute materials either not available or resulting in reduced performance. For example, no material has yet been developed which would yield a magnet of strength comparable with neodymium-based magnets. However, there’s ongoing research into designing electric motors which don’t use rare earth elements. Japan has recently announced development of a motor that uses non-rare earth-based magnets, and Tesla Motors has opted for induction motors in its commercially available electric vehicles that also don’t require rare earth elements. The offshore wind power industry now mainly uses designs that don’t rely on rare earth magnets.

In order to avoid its dependence on rare earth elements, Toyota Motor Corporation announced in January 2011 that it’s developing an alternative motor that doesn’t need rare earth elements materials for future hybrid and electric cars. Toyota engineers in Japan and the U.S. are developing an induction motor that’s lighter and more efficient than the magnet-type motor used in the Prius, which uses two rare elements in its motor magnets. Other popular hybrids and plug-in electric cars in the market using these rare earth elements are the Nissan Leaf, Chevrolet Volt and Honda Insight. For its second generation RAV4 EV due in 2012, Toyota was to use an induction motor supplied by Tesla Motors that doesn’t use rare earth elements. The Tesla Roadster and future Tesla Model S use a similar motor.

The Ministry of Economy, Trade and Industry of Japan recently announced it has earmarked about $65 million in subsidies in a bid to encourage Japanese manufacturers to reduce their reliance and consumption of precious rare earth elements, as well as spur development of new technologies, to aid in their various products and services. Japan wants its companies to reduce their dependence on rare earth elements, particularly dysprosium, used for motors in hybrid vehicles and other products, through recycling innovations as well as inventing dysprosium-free products. Japan aims to cut its domestic use of the precious metal by 200 tons to 400 tons a year, or by 30 percent in two years (*from the NASDAQ.com website, 2/9/2012, by Esther Tanquintic-Misa from International Business Times in Investing, Commodities*).

Conclusion

Rare earth elements are a growing part of many diverse current and future applications that constitute an important part of America’s industrial economy. Long- and short-term shortage or unavailability of rare earth elements is an increasingly important issue for scientists and policymakers in both the public and private sectors.

Governments and industry are beginning to recognize the importance of rare earth elements to the economic competitiveness of clean energy technology, and many are taking an active role in mitigating supply risks. In Congress, at least a dozen bills were introduced in 2012 supporting development of a domestic rare-earth industry, including through U.S. loan guarantees. In the United States, work has been scaled up to address supply disruptions, “much more work is required in the years ahead,” the DOE 2011 Critical Materials Strategy report concludes.

The federal Department of Energy summarizes well the need for addressing these challenges in three steps:

- First, it plans to manage supply risk by diversifying sources of required materials. This will require taking steps to facilitate extraction, processing and manufacturing in the United States, as well as encouraging other nations to expedite alternative supplies.
- The second step involves developing substitutes. According to the DOE, research leading to material and technology substitutes will improve flexibility and help meet the material needs of the clean energy economy.
- The third step encourages recycling and reusing rare earth elements: "Research into recycling processes coupled with well-designed policies will help make recycling economically viable over time."