iNEMI
International Electronics Manufacturing Initiative

Advancing manufacturing technology

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iNEMI White Paper: Rare Earth Metals
Current Status & Future Outlook

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Second Quarter, 2014

Executive Summary

Despite their name, the 17 chemical elements in the periodic table that make up the "rare earth metals" (REMs) are relatively plentiful in the earth's crust. However, they are typically dispersed and not often found in economically exploitable ore deposits. Furthermore, deposits tend to occur together, and extraction requires complex chemical processing.

Demand for REMs has increased significantly in the past decade, driven by electric vehicles, wind-turbine power generation, laptop computers and smart phones. During this same time period, China has come to control more than 95% of the production and refinement of REMs.

China's aggressive strategy effectively priced competitors out of the market in the early 2000s. Then, in late 2009, China started placing restrictions on the export of REMs, causing prices to soar on the international market and creating the potential for shortages in a variety of different industries.

A number of countries, including the U.S., Australia, Canada and Russia, hold significant deposits that can supply most of their respective domestic needs and allow for exports. Hundreds of REM projects are reported to be underway in regions outside of China; however, it could take up to 10 years to get new or mothballed mines operational. By 2020, between 15% and 20% of REMs are expected to come from sources outside of China.

Demand for REMs continues to increase from the electronics industry and from other sectors as well. Every hybrid automobile, most batteries, every electronic device, every fiber-optic amplifier, every LED, every fluorescent light, and every wind turbine contains rare earth metals. Shortages are a real risk.

China's economic growth has increased its domestic demand as computers, transportation, energy generation and military systems are increasingly manufactured domestically. A 2012 U.S. Congressional Report indicated that, within the next few years, China will become a net importer of rare earths.

Some affected industries, particularly the battery, lighting, catalyst and magnet industries, are developing policies and alternative technologies to reduce their dependence on REMs and/or mitigate risks to their supply chains.

While the current REM availability is not critically compromised at this time, iNEMI recommends that the electronics industry take a proactive approach that includes close monitoring of use and production as well as the status of technological advances in alternative solutions and any regulatory or political developments that may affect REM issues.

Objectives

The objective of this white paper is to review the current status of rare earth metal (REM) supplies, review the events that led to the current shortage, and to discuss the future options for successful management of the REM industry. Specifically, this document will discuss the sources of REM ores and processed materials, the technologies that have increased demand, and the political and economic climate that led to the current supply situation. Potential solutions to prevent future supply constraints will be presented for further discussion.

Our goal is to inform the electronics industry with respect to the current REM situation worldwide and to urge that the industry take steps to become better informed and ready to react appropriately to future challenges.

Background

Chemistry

Rare earth elements, or rare earth metals, are a set of 17 chemical elements in the periodic table, consisting of the 15 lanthanides plus scandium and yttrium.

Promethium is a synthetic mineral that is artificially produced in laboratories; all other REMs occur naturally. REMs are usually mixed together in mineral deposits of bastnasite, monazite, or laterite and may also have low-level thorium (TH) or uranium (U) deposits that create a hazardous waste during mining and mineral extraction operations. In addition, REMs are sometimes byproducts of mining for iron, copper, gold, and other metals. These elements are relatively plentiful in the earth's crust; however, they are typically dispersed and not often found in economically exploitable ore deposits. From one type of ore, more than 12 rare earth elements can be extracted through complex chemical processing. Complicating the extraction of REMs is the fact that they are always found together, are difficult to separate, and almost always occur with other heavy elements including radioactive uranium and thorium, making processing and waste disposal a regulatory problem. In addition, each deposit contains a different blend of rare earths and may not contain the ones needed by industry, typically the heavy rare earths.

REMs can be grouped in “Light” and “Heavy” classes, depending on their atomic weight. Light rare earth metals are lanthanum to samarium and the heavy rare earth metals are europium through lutetium. Of the 17 elements, 5 are considered to be the most economically critical. They are: neodymium, yttrium, europium, terbium, and dysprosium.

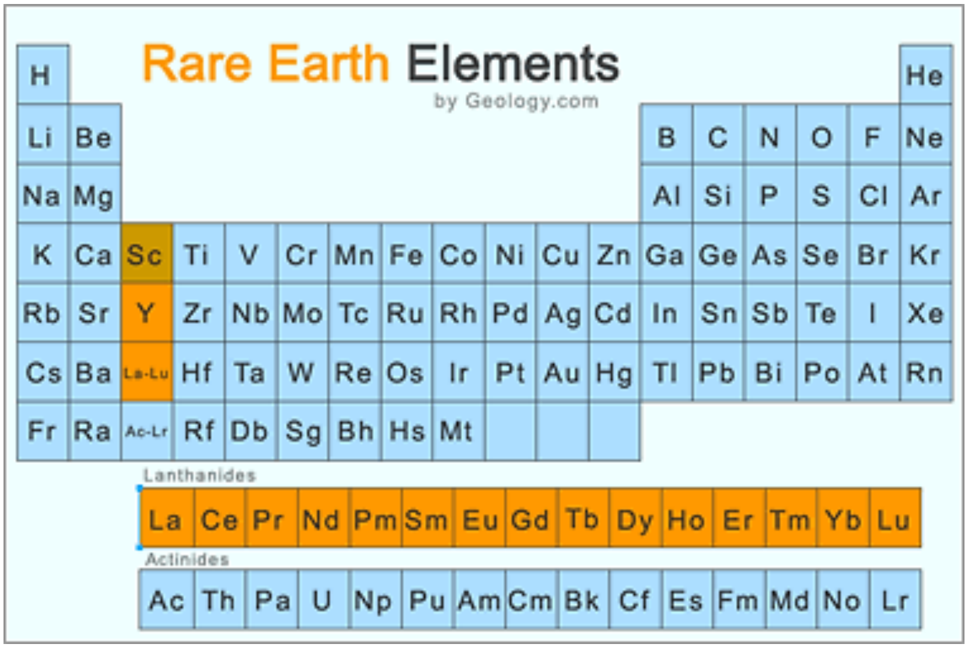

Figure 1. Periodic table of rare earth elements (rare earth metals). (*Source: Geology.com*)

Reserves

The term “rare earth” is somewhat of a misnomer in that these elements are fairly common in the earth’s crust. However, deposits large enough for economically viable mining operations are harder to find. Major mineral deposits can be found in China, the U.S., Canada, Russia, Australia, Vietnam, Uzbekistan, Kazakhstan, and other areas. As mining history has shown, reserves are often underestimated until a major demand triggers more exploration and development of better extraction methods to improve the recovery rates in order to meet the new demand. This may prove to be the case for REMs. Recently, major accessible deposits have been discovered in Afghanistan and on the floor of the Pacific Ocean. Granted, accessing REMs on the ocean floor is going to be technologically challenging, expensive, and a politically sensitive issue.

At an average concentration in the Earth’s crust of 60 parts per million (ppm), cerium is more abundant than copper, followed in decreasing order, by yttrium at 33 ppm, lanthanum at 30 ppm, and neodymium at 28 ppm. Thulium and lutetium, the least abundant of the lanthanides at 0.5 ppm, occur in the Earth’s crust in higher concentrations than antimony, bismuth, cadmium, and thallium. The types of mineral deposits and concentration levels vary significantly by location. As an example, the world map below shows known global deposits for minerals used to produce Nd magnets. As can be seen, these are widely dispersed.

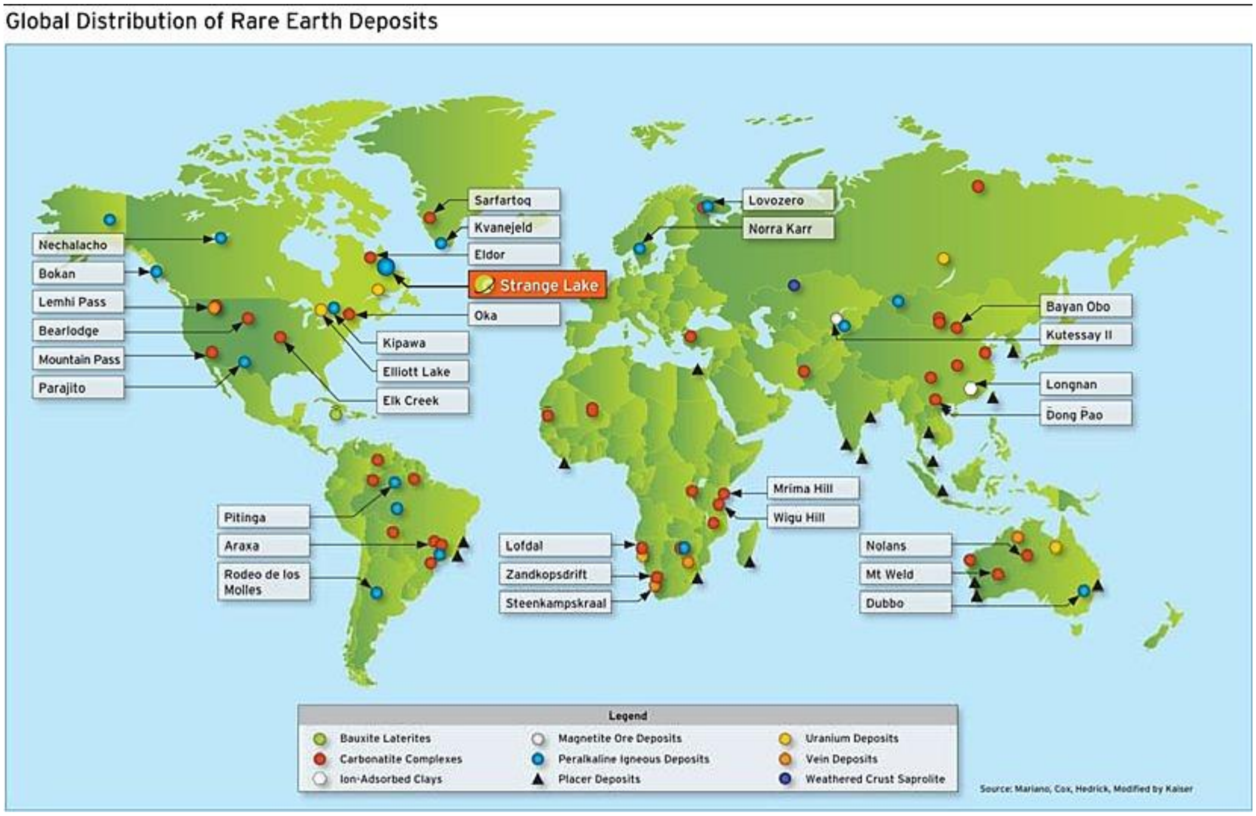

Figure 2. Global distribution of rare earth deposits.
(*Source: Kaiser Research Rare Earth Resource Centre*)

A 2011 report from the U.S. Geological Survey (USGS) estimated that China has 36% of the total known reserves of rare earth metals, the Commonwealth of Independent States has 19%, and the United States controls 13% of the world's reserves.

Uses

REMs are used in a number of different products to enhance operating efficiency and reduce weight, complexity, and footprint. Demand for REM ore has increased significantly in the past decade with the advent of electric vehicles, wind-turbine power generation, laptop computers and smart phones. Table 1 provides an overview of current REM usage. The highlighted items show areas of potential impact; however, many suppliers consider this information confidential, so some uses may not be listed.

Table 1: Rare Earth Elements and Selected Examples of Usages

Z	Symbol	Name	Selected Applications
21	Sc	Scandium	**Optical fibers**, light aluminum-scandium alloy for aerospace components, additive in mercury-vapor lamps, ceramics, phosphors
39	Y	Yttrium	**Microwave filters**, yttrium is used as host for the red fluorescent lamp phosphor Y2O3:Eu3+; yttrium is also important for ceramics: yttria-stabilized zirconia
57	La	Lanthanum	**NiMH battery**, high refractive index glass, flint, hydrogen storage, battery electrodes, camera lenses, fluid catalytic cracking catalyst for oil refineries
58	Ce	Cerium	**Polishing powders**, chemical oxidizing agent, yellow colors in glass and ceramics, catalyst for self-cleaning ovens, fluid catalytic cracking catalyst for oil refineries, ferrocerium flints for lighters
59	Pr	Praseodymium	**Rare-earth magnets,** including for hard disk drives lasers, core material for carbon arc lighting, colorant in glasses and enamels, additive in didymium glass used in welding goggles, ferrocerium firesteel (flint) products
60	Nd	Neodymium	**Rare-earth magnets** including for hard disk drives, ceramic capacitors, lasers, violet colors in glass and ceramics
61	Pm	Promethium	Nuclear batteries
62	Sm	Samarium	**Rare-earth magnets, electro-mechanical relays**, lasers, neutron capture, masers
63	Eu	Europium	Red and blue phosphors, lasers, mercury-vapor lamps, NMR shift reagent
64	Gd	Gadolinium	**Rare-earth magnets**, **computer memories**, high refractive index glass or garnets, lasers, X-ray tubes, neutron capture, MRI contrast agent
65	Tb	Terbium	**Optical fiber, ceramics**, green phosphors, lasers, fluorescent lamps
66	Dy	Dysprosium	**Rare-earth magnets** including for hard disk drives, **lasers**
67	Ho	Holmium	**Lasers**
68	Er	Erbium	**Optical amplifiers**, vanadium steel, lasers
69	Tm	Thulium	**Portable X-ray machines**
70	Yb	Ytterbium	**Optical amplifiers, infrared lasers**, chemical reducing agent
71	Lu	Lutetium	**Optical fiber**, PET scan detectors, high refractive index glass

Two of the REMs, neodymium and dysprosium, are used together to produce highly efficient magnets with broad application for green energy products. Neodymium-iron-boron permanent magnets are used extensively in the production of hard disk drives. Neodymium is the most highly regulated element in China’s export plan due to China’s need to address pressing environmental issues, and is considered strategic in supporting Chinese companies that are trying to dominate the production of products addressing this market segment.

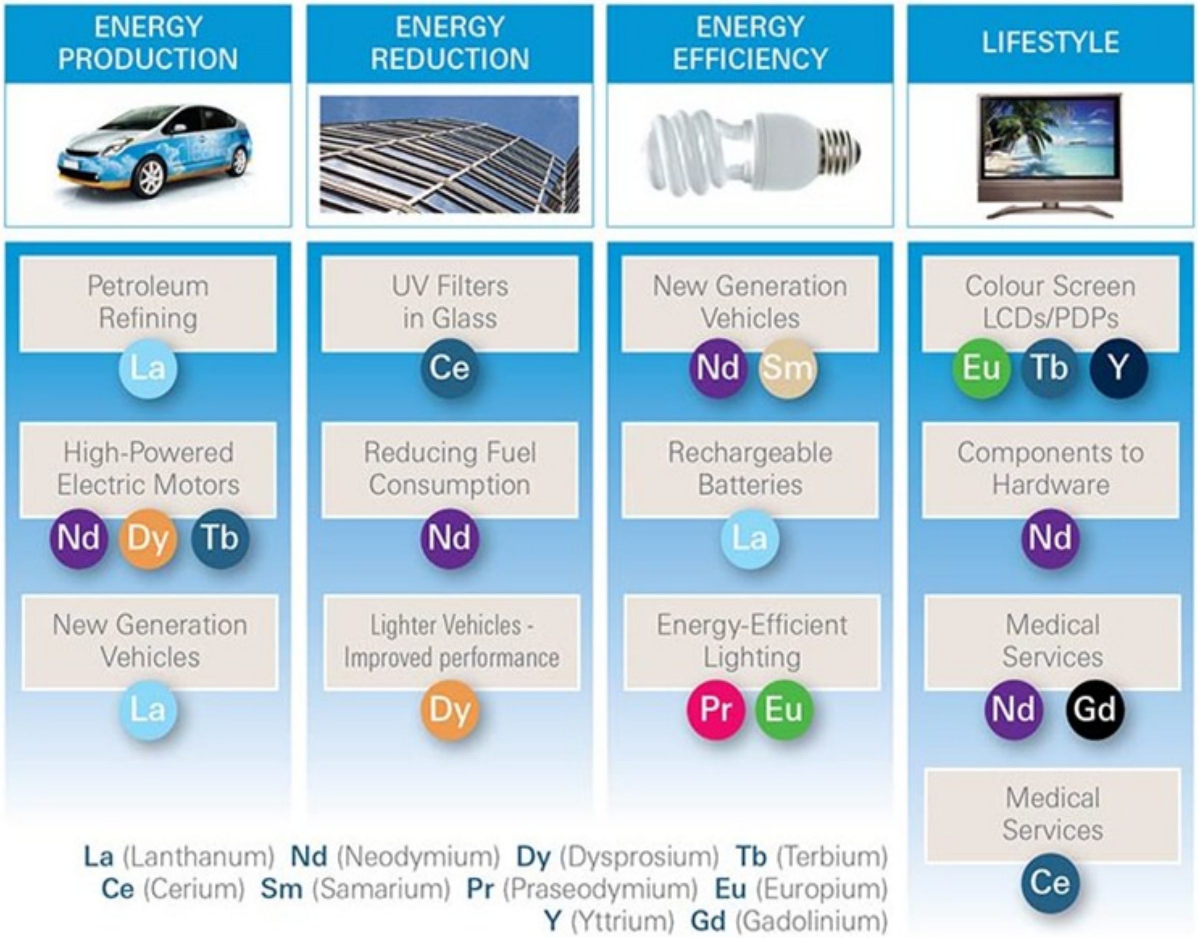

Figure 3. Rare earth properties and uses. (*Source: Geoscience Australia*)

Supplies

The United States historically produced the majority of REMs used in the world from the Molycorp Mountain Pass mine in California. China increased production of REMs over the last few decades and, in the last few years, has undertaken a very aggressive strategy leading to increased production, choosing to limit environmental regulation and employ cheap labor. This has effectively priced competitors out of the market. China now controls more than 95% of the production and refinement of these metals. This strategy has driven down prices and forced the shutdown of nearly every mine outside of China. Specifically, a weak market in the early 2000s, combined with tightening environmental restrictions in the United States, closed down production in the Americas in 2002. In late 2009, China started to place restrictions on the export of REMs, giving preferential treatment to Chinese companies. This has caused prices for REMs to soar on the international market and has created the potential for shortages of critical minerals used in a variety of different industries. In fact, shortages have begun to be realized in certain regions of the world.

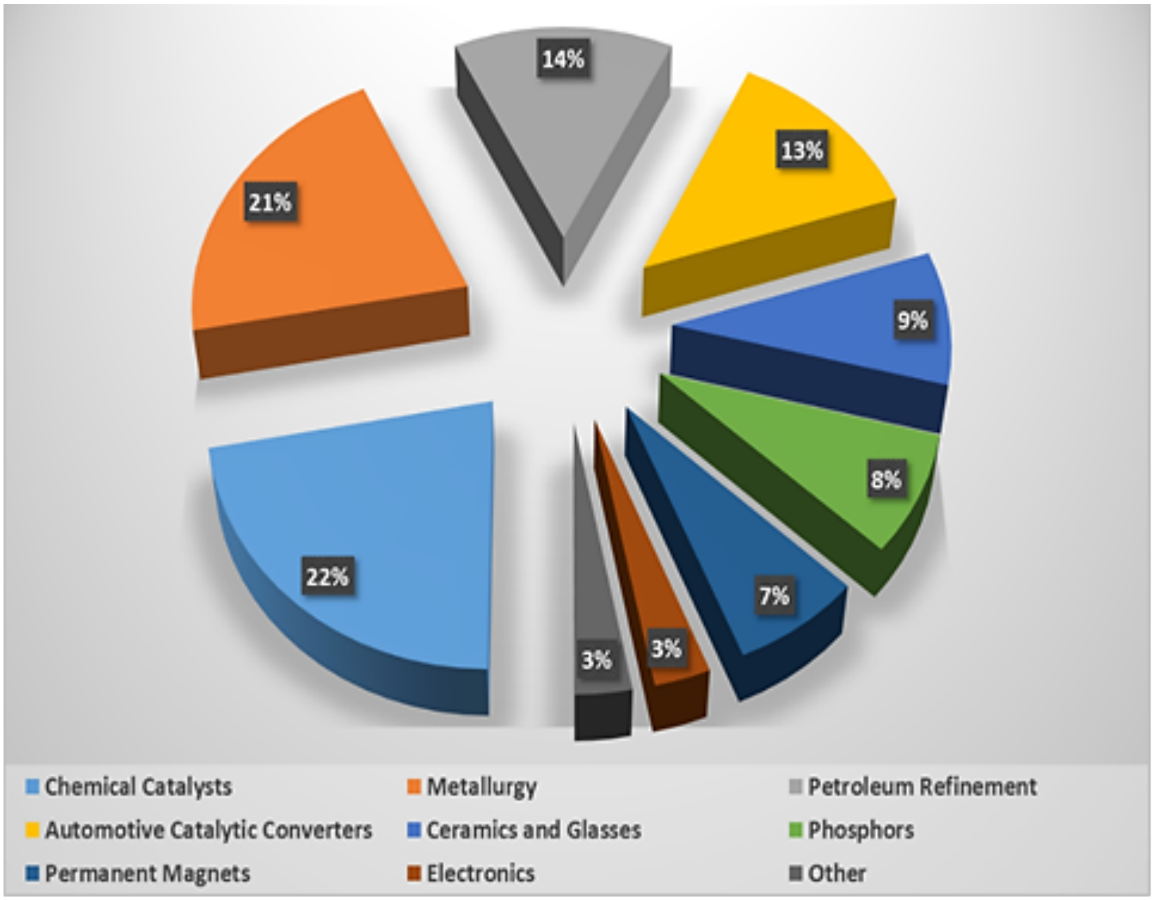

Figure 4. End use distribution of rare earth metals by application in 2009.
(*Data source: USGS Mineral Commodity Summaries 2009*)

A number of countries, including the United States, Australia, Canada, and Russia hold significant deposits that can supply most of their domestic needs and even allow for exports. However, it may take up to 10 years to get new or mothballed mines operational. Start-up costs and environmental concerns are key factors that have to be addressed before necessary permits can be obtained. It is estimated that between 15% and 20% of REMs could come from sources outside of China by 2020.

Recent findings by Gareth Hatch estimate that there are at least 429 REM projects underway outside of China and India. These projects involve 261 different companies in 37 countries. There are 36 projects formally defined with 12 operations in Canada, 7 in sub-Saharan Africa, 6 in Australia, 4 in the U.S., 3 in Greenland, and one each in Sweden, Kyrgyzstan, Turkey, and Brazil.

In the United States, the Molycorp Mine in Mountain Pass, California, has reopened and is producing REMs. However, it will likely take many years for production to reach levels that will supply enough REMs to support the increasing demand worldwide. Ironically, one of its biggest customers is China, but Molycorp is also exporting significant quantities to Japan. Lynas Corp. (Australia) has resumed production and Great North Western opened new mining and smelting operations in 2012. These are just a few examples of new REM operations being brought into production globally.

Japan, the world's largest importer of rare earths, has a number of industries that are highly dependent on REMs. They are funding new mining ventures in Australia, Kazakhstan, Mongolia, India and Vietnam. Japan has reached agreements with India to meet approximately 15% of their demand. Japan signed an agreement in December 2012 to import 4,100 metric tons of rare earths a year from India to supply the metals used in everything from mobile phones and hybrid cars to missile guidance systems. A joint venture between Sumitomo Corporation and Kazakhstan's National Atomic Company to develop dysprosium, completed construction and opened its first factory on November 2, 2012. The new factory has begun manufacturing mixed rare earth carbonate with a high content of dysprosium and neodymium, elements for which demand is expected to rise in the coming years due to the growing popularity of hybrid and electric cars. The factory has set an annual output target of 3,000 metric tons of dysprosium by 2015. Furthermore, Japan will get an estimated 9,000 metric tons a year of rare earths from Australia's Lynas Corporation and 10,000 metric tons per year from Molycorp Inc. (MCP) of the U.S.

Problem Statement

The electronics industry does not fully understand the potential impact of a REM shortage on supply risk. This situation is due to a lack of understanding of the following:

- Specific critical uses of REMs in electronic products and total quantities needed
- The overall worldwide demand for REMs for all uses
- The extensive time required to essentially re-structure the entire REM supply chain
- The current lack of availability of alternative materials
- The time and knowledge required to develop new technologies that could reduce or eliminate the need for REMs
- The implications of China's policies and dominance of REM supplies

Again, we do not intend to sound a dire, immediate alarm. The message is that the electronics industry should be better informed than it is currently. This includes being better informed about the electronics industry's use of REMs and, importantly, better informed with regard to the use in other industries since this may impact availability of REMs for electronics manufacturing.

Current Situation and Future Outlook

Recent Progress

Some affected industries, particularly the battery, lighting, catalyst and magnet industries are developing policies and alternative technologies to reduce their dependence on REMs and/or mitigate risks to their supply chains.

In addition to mining operations, work is underway within organizations such as iNEMI (International Electronics Manufacturing Initiative), government agencies, and individual companies to improve the overall availability of REMs. Activities include recycling products to extract minerals, reducing the concentration levels of critical elements, improving ore extraction techniques which may allow additional minerals to be extracted from previously mined ores, and may improve the extraction rates for newly mined minerals, as well as exploring substitutes to reduce dependencies on REMs. The Department of Energy recently has committed $120M over five years to the DOE Critical Materials Institute to diversify supply, develop substitutes, and improve reuse and recycling. The Critical Materials Institute team is led by DOE Ames Laboratory, with the team including three additional DOE National Labs, seven universities, and seven industrial partners. In addition, Japan has committed $65 million (5 billion yen) to reduce the need for REMs. Major electronics companies are developing motors that do not contain any REMs, and there are plans to introduce REM-free small-magnets for hard disk drive (HDD) applications. However, it is a challenge to develop REM-free permanent magnets for high-voltage (HV) applications.

Increased Demand

As the supply has tightened, demand for REM ore has increased. Every hybrid automobile, most batteries, every electronic device, every fiber-optic amplifier, every LED, every fluorescent light, and every wind turbine contains rare earth metals. China's economic growth has also increased domestic demand as high-tech products such as computers, transportation, energy generation and military systems are increasingly manufactured domestically. In 2012, a U.S. Congressional Report indicated that, within the next few years, China would become a net importer of rare earths. Figure 5 shows how significantly the demand for REMs has increased over the last decade.

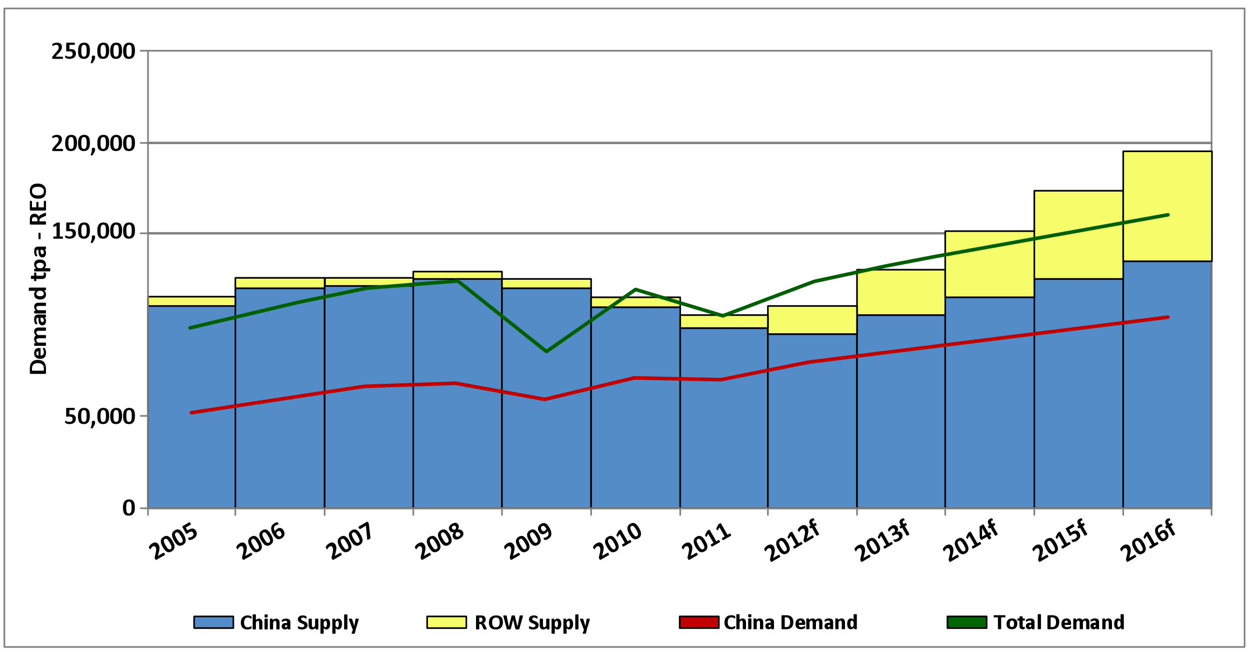

Figure 5. Historical and anticipated demand for REMs.
(*Source: D. Kingsnorth / IMCOA, generated from: Rare Earths Supply Security: Dream or Possibility, 2012*)

This growth in demand is expected to continue for the foreseeable future, driven largely by the global trend toward green energy products. Much of this growth is expect to occur in China due to the Chinese government's need to produce more energy to address the large projected growth in individual incomes and resulting demand for energy. The demand for the rest of the world is expected to continue to increase as the drive toward green energy production increases worldwide.

The overall supply outlook over the next three to five years is expected to generally keep pace with demand due to increased production quotas by China, new mining operations outside of China coming online, and other governmental and industry actions by REM users. Not all REMs are in short supply. There are however, certain REMs that may experience spot shortages, especially those used in green energy applications. Figure 6 provides an outlook developed by the U.S. Department of Energy in 2011, and shows that the minerals of most concern for the energy market are neodymium, dysprosium, europium, yttrium, and terbium. The situation has changed somewhat since these predictions were made as will be discussed in the next section; however, it provides a good watch list to monitor closely over the next one to three years.

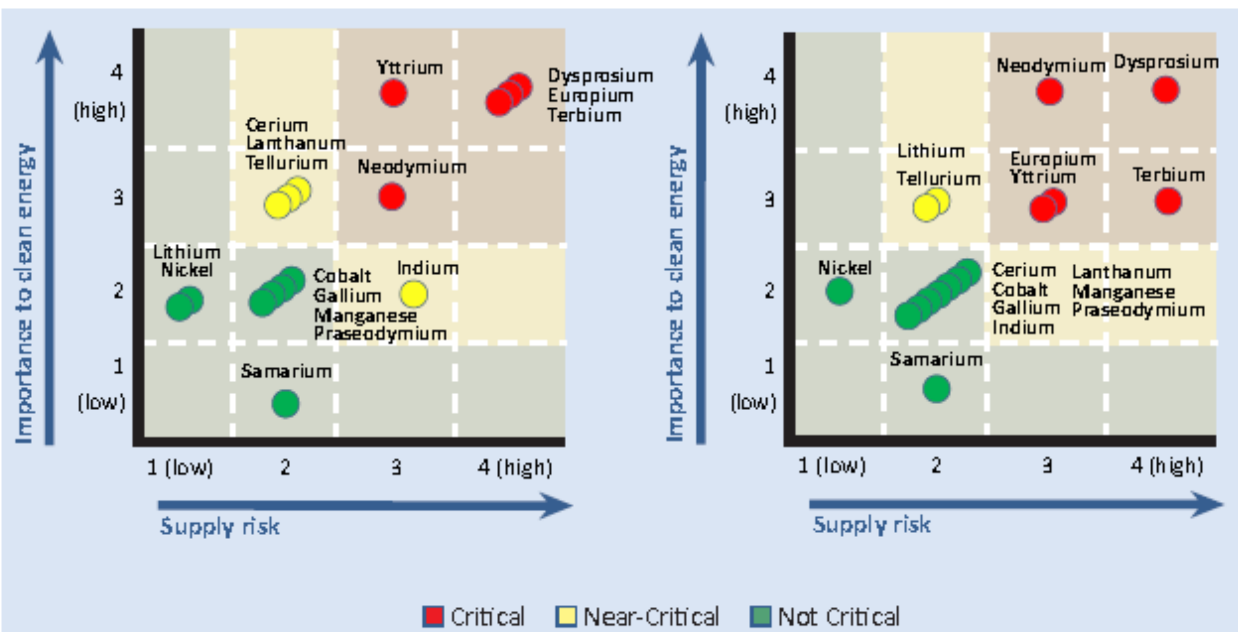

Figure 6. The matrix on the left shows short-term criticality (present-2015), while the matrix on the right looks at medium-term criticality (2015-2025). (*Source: U.S. Department of Energy Critical Materials Strategy, December 2011*)

Political Outlook

Volatility of REM markets

China's rare earth industry started in the 1950s and has become the largest producer, consumer and exporter. China doesn't want to focus on raw rare earth ore extraction. The country has a stated goal to increase the amount of higher value-added exports such as REM magnets, wind turbines, consumer electronics, and batteries for hybrid and electric vehicles.

In 2011, China announced a 35% reduction in the export quota for raw REM ores. In response, companies that consume REM materials began to stockpile reserves to supplement their current supplies. Many REM magnet suppliers stockpiled raw materials to support production through late 2011. Most of the REM magnet suppliers that support the electronics industry did not see any supply issues impacting their shipment plans. However, companies that use the REM magnets found they needed to increase their use of China-made magnets, which are not subject to export quota restrictions.

WTO Dispute between EU, Japan, U.S. and China

The rapid drop in rare earth exports from China and resulting ramp in pricing has caused a number of countries to take action to address the supply and cost of these minerals. REMs have been declared “strategic” by a number of countries due to their importance to the military and industries developing green energy products, especially power generation and automotive applications. The export restrictions and rapid price escalation have served as a wake-up call to many government bodies that had been complacent prior to 2010.

In June 2011, the United States requested the World Trade Organization (WTO) to establish a dispute settlement panel to decide U.S. claims regarding China's export restraints on rare earths, tungsten and molybdenum. The U.S. move was joined by the European Union and Japan. The WTO case argues that the export quotas and tariffs violate free trade rules by putting pressure on companies to move their factories to China if they want to tap China’s vast supply of rare earths. The case is under deliberation and outcome and timing are uncertain.

In response, China issued a white paper claiming that after more than 50 years of excessive mining, the decline of rare earth resources in major mining areas is accelerating, as most of the original resources have been depleted. China's rare earth industry has huge over-capacity in smelting and separating. In addition, inefficient mining and refining practices squandered scarce mineral reserves and produced extensive emissions of radioactive residues, heavy metals and other contaminants.

REM Price Speculation and Trading

In 2010, China reduced exports by approximately 40% due to increased domestic demand in China to drive their green energy strategy and the Chinese government’s need to address mining operations that were causing major environmental damage due to poor mining practices, especially in illegal/unauthorized operations. There is some contention in international circles that there is manipulation underlying this action by the Chinese government to protect their domestic industry and put them in a position to move up the value chain beyond just producing minerals. Regardless of the reasons, these actions have resulted in a rapid escalation of REM pricing, especially for lanthanum oxide and neodymium oxide, which more than doubled in price between 2009 and 2010.

During 2011, manufacturers saw a significant increase in the pricing of the raw materials due to export restrictions, and speculative commodity trading. China's rare earth market was largely opaque, as transactions were not made in public markets and always ran in small volumes. Only limited amounts of pricing and transaction data have been made available to the public. In response to worldwide concern over the export quotas, China launched a physical trading platform for rare earth metals as part of its efforts to regulate the sector and strengthen its pricing power for the resources. The Inner Mongolia Baotou Steel Rare-Earth (Group) Hi-Tech Co., China's top rare earth producer, launched the platform together with nine other firms and institutions.

Industry sources have stated that much of the price ramp over the last two years was due to speculation and hoarding. For example, at the peak of the escalation praseodymium oxide rose more than 500% between December 2010 (US$46/kg) and August 2011 (US$250/kg) due to speculation. The price has continually dropped since August 2011 and Nd was selling for ~US$86/kg) in April 2013. The drop was partially due to older mining operations coming back online or the start of new production.

Prices peaked on Nd (US$350/kg) and Dy (US$2700/kg) in July-August 2011, both prices dropped significantly by July 2012 with Nd now selling for US$86/kg and Dy selling for US$775/kg due to users reducing their consumption and looking for alternative materials which seriously softened demand. As an example, companies that make magnets for things such as spindle motors for HDD applications (which use Nd magnet and magnet motors) and air-conditioning (which use Dy), have already started using magnets containing 50% of the Dy used in conventional REM magnets.

The following figures provide historical pricing trends for a selected group of light and heavy rare earth oxides. The expectation is prices will continue to rise as the demand increases for certain rare earths. Due to the volatility of the market over the past four years it is difficult to get exact prices; however, Figures 7 and 8 do show the spike in the market in 2011.

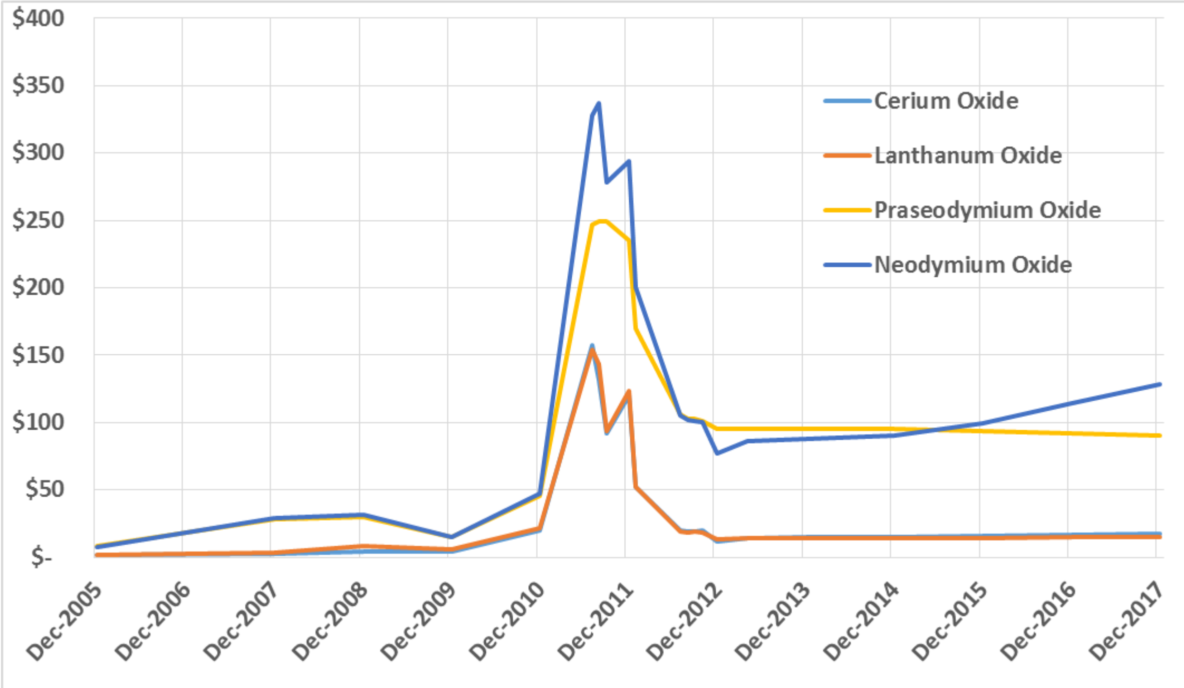

Figure 7. Light rare earth metal oxide prices / FOB China
(***Sources: Dec 2011 U.S. Department of Energy Critical Materials Strategy; Metal Pages 2013; Core Consultants 2012; Lynas Corp 2012, HEFA Rare Earth 2012***)

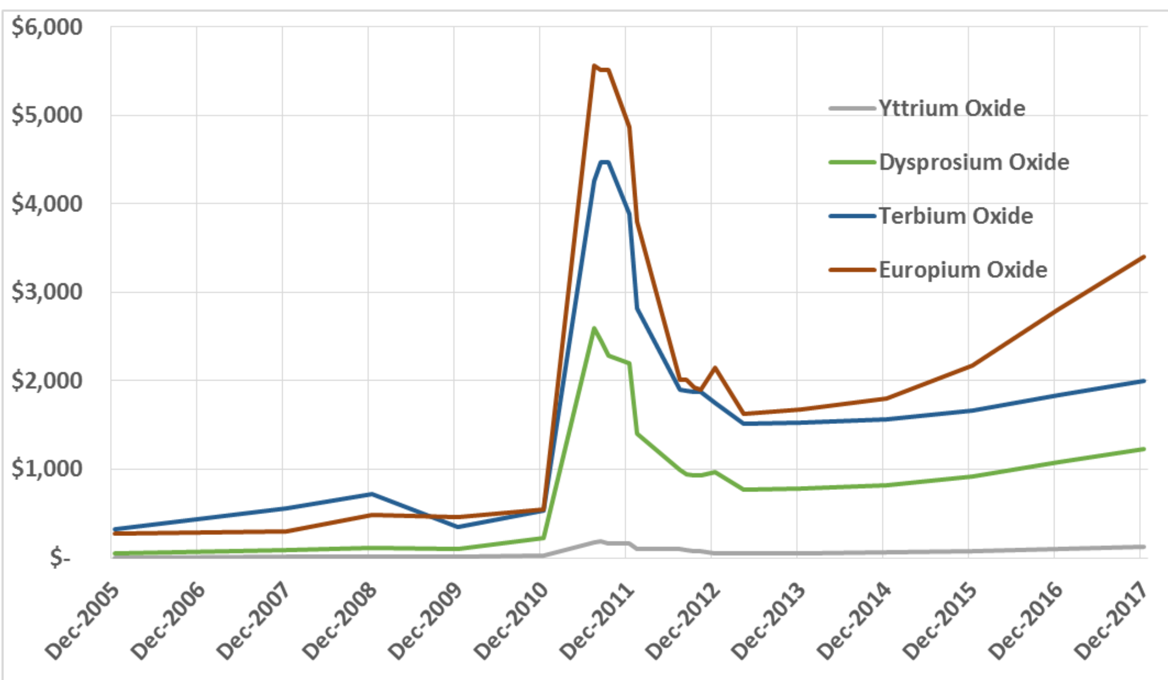

Figure 8. Heavy rare earth metal oxide prices / FOB China
(***Sources: Dec 2011 U.S. Department of Energy Critical Materials Strategy); Metal Pages 2013; Core Consultants 2012; Lynas Corp 2012; HEFA Rare Earth 2012***)

There are many conflicting trends that make prediction of prices and supply extremely difficult. Factors pressuring prices and supply include:

- Strong automobile production, with China now the world's largest manufacturer of automobiles.
- Robust hard drive demand for enterprise and cloud storage. Although flash memory is anticipated to gain significant market share the installed base of HDDs is in the millions.
- Similarly robust demand for wind energy, a major consumer of rare earth magnets.
- Increasing fluorescent light lumens-per-watt output regulations in the U.S., which have increased rare earth demand.
- Crackdowns on illegal exports of rare earths, tightening environmental regulations in China and the idling of facilities in Baotou due to stockpiles of materials.

Potentially increasing supply and reducing prices:

- Expansions at Molycorp and reduced political pressure on Lynas following the Malaysian elections.
- Over 450 rare earth mining projects under development, with 293 in Canada alone! Although many of these are early stage, they will definitely increase supply long term.
- If the WTO action is successful, China may have to drop its export tax.

Chinese Export Quotas

The full year quota for 2013 was increased by 2.7% from 2012 levels. Governments as well as individual corporations have maintained pressure on Beijing to loosen its grip. The quota increase may be more symbolic than anything, as export levels have fallen sharply, global trade accounting for only half of the 2012 quota. Exports of rare-earth minerals fell 36.7% in the first seven months of 2012.

Rare Earth Market Volatility

Prices of rare earth elements tumbled after a speculative bubble burst in 2011. Prices are likely to erode further as new supplies hit the market and exports edge higher from dominant producer China due to weak demand at home. Lanthanum, used in rechargeable batteries for hybrid autos, jumped 26-fold from $5.15/kg in January 2010 to a peak of $140 in June 2011. Although in 2012 the price slid to $20.50, it was still well above earlier lows. The market has firmed in recent months, but new output from Molycorp and Lynas is likely to pressure prices.

New Alternatives to Singular REM Supply Dominance

Sumitomo Opens Rare Earth Plant in Kazakhstan

Sumitomo Corporation cut the ribbon on a new plant in Kazakhstan in November 2012. The company said it aimed to produce about 750 metric tons in 2013, and double that by the following year, accounting for about 7.5% of Japan's annual demand. Almost all will be Japan-bound.

Molycorp Expands REM Processing

The company announced the start-up of heavy rare earth concentrate operations at Mountain Pass, California in August 2012. All key production assets at the company's Mountain Pass rare earth facility are now ramping up to the facility's initial annual run rate of 19,050 metric tons of rare earth oxides. However, Molycorp reported an operating loss of $436.3 million and earnings decreased substantially from the prior year as a result of lower selling prices, increased costs and large impairment charges, offset in part by increased volumes and expanded product offerings. On March 14, 2013, Molycorp also reported it planned to cut an unspecified number of jobs.

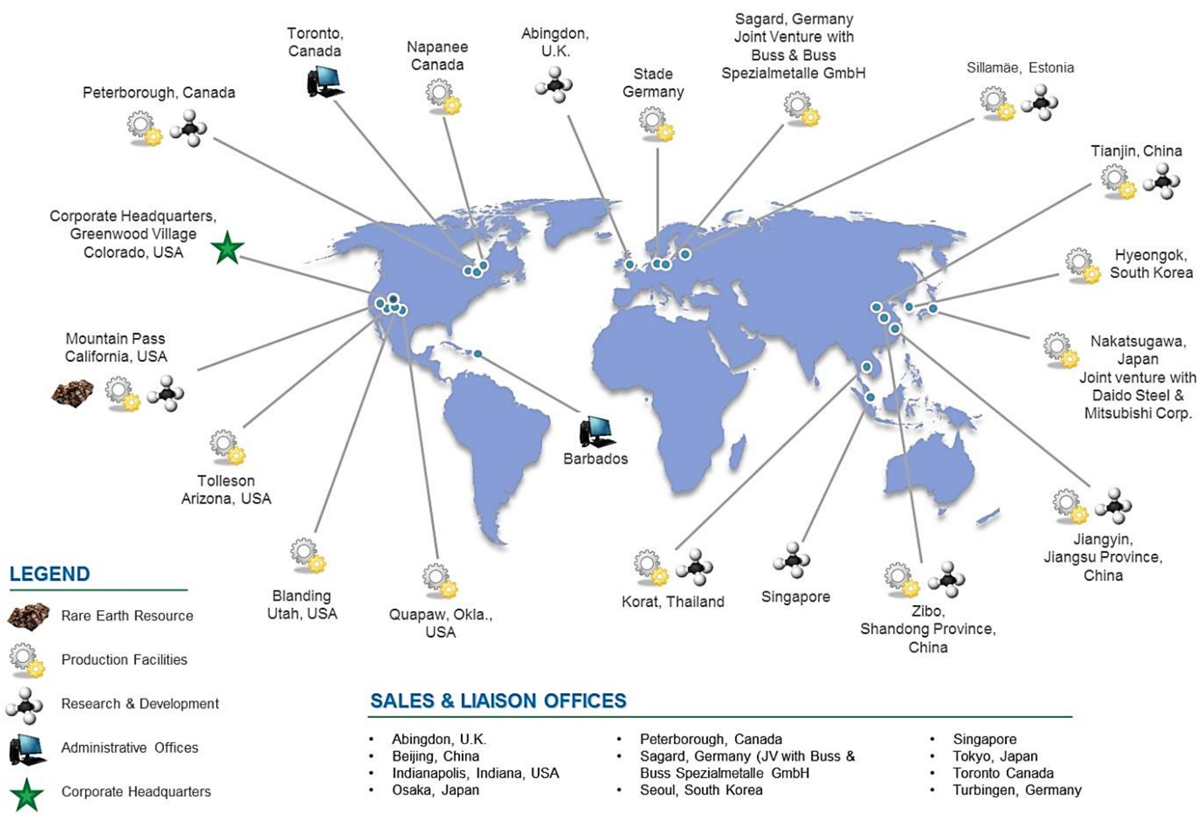

Figure 9. Global footprint of Molycorp
(Source: Q4, FY2012 Financial, March 14, 2013 Results Earnings Call)

Lynas REM Processing Plant Opens in Malaysia

Lynas Corporation received a temporary operating license for its long-delayed $800 million REM processing plant in Malaysia in September 2012. The plant on Malaysia's east coast had been ready since early May 2012, but the company was embroiled in lengthy environmental and safety disputes with local residents for two years during construction of the plant. Widespread protests over concerns about possible radioactive residue drew thousands of people at a time. Following early 2011 elections, the future of the Lynas operations is more secure but is still under close environmental scrutiny because of radioactive waste concerns.

Development of Alternative Materials to Replace REM

Toshiba Corporation announced that the company has developed a high-iron concentration samarium-cobalt magnet that is free of the REM dysprosium. At typical operating temperatures, the samarium-cobalt magnet has superior magnetic properties to the heat-resistant neodymium magnets currently used in motors. This is a start to the quest for alternative materials and, as such, is a promising development.

Rare Earth Metal Reclamation / Recycling Industry

In 2011, USGS published "Rare Earth Elements – End Use and Recyclability" (Scientific Report 2011-5094). It estimated that of the 90,400 tons of rare earth scrap produced, 65% went to landfill, 23% to construction aggregate, 9% to downgraded use (e.g., re-bar alloy) and the balance was stockpiled with less than 1% recycled. The report assesses the recyclability of various streams. Many of the materials, such as cerium or lanthanum polishing compounds or the materials used in NiMH batteries, may not be economical because of the low rare earth price, contamination with hazardous materials (e.g., refining catalysts), low concentration, or the lack of a take-back or recycling mechanism. Certain other materials, such as rare earth magnets, are much more amenable to extraction because of their concentration and value but an economic judgment has to be made in the case of each recycled material stream bearing in mind the value of the rare earths, their abundance in the waste stream and the overall cost of recovery including process materials, energy and the responsible disposal of any unsellable impurities. Realistically, only about one-third of the rare earth tonnage is of high enough value to recycle at current prices. This one-third, however, contains all the strategically important and difficult-to-substitute rare earths essential for electronics, automotive and clean energy production.

Scientists at the U.S. Department of Energy's Ames Laboratory are working to more effectively remove neodymium from the mix of other materials in a REM magnet. Initial results show recycled materials maintain the properties that make rare-earth magnets useful. The goal is to make new magnet alloys from recycled REMs that will be similar to alloys made from unprocessed rare-earth materials.

ReNew Rare Earth Inc., a start-up based in New York State, has developed an alternative recovery process using more conventional chemical processes. The unique chemical process can handle a range of post-consumer and industrial materials including magnets, capacitor materials, thermal insulation materials and phosphors. Production was anticipated Q3 2013.

Impact

Many organizations have been closely monitoring the REM marketplace and have contacted major suppliers to determine usage of REM in products and to get their assessment of the near and long term supply of the needed minerals. Electronics industry suppliers use very small quantities of REMs, for a limited set of component types. These include higher quality factor "Q"s in microwave ceramic materials, electro-mechanical relays, ceramic capacitors, chip resistors, optical amplifiers, transformers, LEDs, inductors, magnets, microwave/light wave isolators, power supplies and buzzers, and hard disk drives. Although often identified as impacting semiconductors, relatively small quantities are needed for the slurries used for semiconductor polishing, the dopants sometimes used in optical components such as lasers, the magnetic films used for spin-polarized memories and the oxides used in advanced high-k dielectrics. It should be noted that not all of the electronics industry suppliers that produce these part types use REMs.

According to Arnold Magnetic Technologies' report in 2012, hard disk drive, CD and DVD systems alone accounted for 14% of the global Nd demand in 2010 and forecasted to be 16% in 2015. However, some companies view the supply for these minerals to be adequate at this time since the amounts used per drive are trivial when compared to products such as direct drive wind power generation turbines that can use up to 550 pounds (~250kg) of rare earths per megawatt. In addition, there have been very few reported cases where a supplier asked for a price increase due to higher REM prices.

Due to the low quantities used by many component suppliers within the electronics industry, there is a concern that if a shortage develops these suppliers may not be able to source the required quantities needed to build their products. Major suppliers that use the minerals had been taking steps to secure supply by creating stockpiles of REMs against future demand. In the longer term, they are taking steps to reduce dependency on REMs by introducing alternate materials, qualifying mineral sources outside of China, and working with Chinese companies that are not subject to the export quotas imposed by the Chinese government. None of the contacted suppliers have reported insufficient quantities to meet their demand. We will continue to monitor the situation to ensure that production requirements are being met. It should be noted that alternate materials may increase the size and cost of products and OEMs may incur additional qualification cost if REMs are removed from existing products.

Conclusion

It is never comfortable to rely on a "sole source" supply relationship that may be vulnerable to political or natural disasters. It is even more uncomfortable in this case when alternative suppliers like Molycorp and Lynas face strong political or economic headwinds. China's export restrictions highlighted the need for multiple sources of supply. It is important that the electronics industry develop several alternative sources of supply through mining or recycling, to stabilize supply and pricing. The electronics industry is subject to repeated and significant demand swings based on macroeconomic conditions and seasonality as well as longer-wavelength product cycle swings.

As a result of this and other investigations, we can conclude that there should not be severe impacts on supply or cost of REMs over the next one to two years. With new sources of supply coming online, alternate solutions being developed, recycling and REM usage reduction, and global political pressure, some of the shortages and price increases experienced over the last two years are expected to ease considerably. We expect prices to stabilize and, in some cases, continue to decrease over the next one to two years. In the mid- to long-term, 2+ years, it is more difficult to predict supply/demand ratios and pricing.

There are still a number of uncertainties such as usage rates, environmental impact affecting political acceptability of mining/refining operations both inside and outside of China, and profitability of new mining and/or refining operations. Our view is that the most likely scenario is that there will be volatility in both supply and pricing over the next 3 to 5 years. There may be spot shortages during that timeframe, especially on those REMs used in green energy and automotive applications such as neodymium, dysprosium, europium, yttrium, and terbium. Neodymium and dysprosium are specifically of concern.

To reiterate our message to the electronics industry:

While the current REM availability is not critically compromised at this time, prudence dictates that a proactive approach is best for the following reasons:

- The unpredictability of the rate of increase in demand
- Unknown potential for new technologies to decrease future demand
- Volatility of the political and regulatory climate, both nationally and internationally

A proactive approach includes:

- Gathering of all relevant data regarding current use, production, and status of technological advances in alternative solutions
- Tracking of this data over time to monitor the speed of progress and the rate of change of demand

- Maintaining vigilance with respect to potential technical, regulatory and political developments that may affect REM issues

This approach will allow the electronics industry to be in a position to react in an informed and timely manner when strategic decisions are needed without the need to waste crucial time gathering and analyzing data. The industry should be continuously defining and evaluating potential future developments and have plans in place to appropriately react should the need arise.

Organizations Supporting this White Paper

The following organizations support this white paper:

- Agilent Technologies
- Hewlett-Packard
- IST Group
- Purdue University
- ReNew Rare Earth Inc.

Bibliography

1. Bauer, Diana; Diamond, David; Li, Jennifer; McKittrick, Michael, Sandalow; David; Telleen, Paul, "Critical Materials Strategy," U.S. Department of Energy, December, 2011. Available at: http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf

2. Cashin, Peter J. and Pressacco, Reno, "Quest Reviews Rare Earth Element Mineralogy and Metallurgy of the B-Zone Deposit, Strange Lake, Quebec," Quest Rare Minerals, Ltd., May 25, 2011. Available at http://google.brand.edgar-online.com/EFX_dll/EDGARpro.dll?FetchFilingHtmlSection1?SectionID=7958239-4269-27212&SessionID=yaV1FHhot2NnqA7

3. Core Consultants, The Rare Earth Market: A Monthly Analysis for the Rare Earth Industry, September 2012, available at http://www.metal-pages.com/download/pdf/Metal-Pages-Rare-Earth-Report-Sample.pdf

4. Gambogi, J., Substituted "Rare Earths," Minerals Yearbook (Preliminary Release), U.S. Geological Survey, 2013 (NOTE: this report is not available online; however the report, U.S. Geological Survey, Mineral Commodity Summaries, January 2013, can be found at http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/mcs-2013-raree.pdf

5. Geoscience Australia, Australian Government, "Rare Earth Elements." Available at http://www.ga.gov.au/minerals/mineral-resources/rare-earth-elements.html For an updated report: http://www.australianminesatlas.gov.au/aimr/commodity/rare_earths.html

6. Goonan, T.G., 2011, Rare earth elements—End use and recyclability: U.S. Geological Survey Scientific Investigations Report 2011–5094, posted July 2011. Available at http://pubs. usgs.gov/sir/2011/5094

7. Hatch, Gareth, "April 2012 Updates to TMR Advanced Rare Earths Project Index," Technology Metals Research, May 1, 2012. The 2014 Rare Earths Project Index is available at http://www.techmetalsresearch.com/metrics-indices/tmr-advanced-rare-earth-projects-index/.

8. HEFA Rare Earth (http://www.ba otou-rareearth.com)

9. Morrison, Wayne M. and Tang, Rachel, "China's Rare Earth Industry and Export Regime: Economic and Trade Implications for the United States," Congressional Research Service, April 30, 2012. Available at: http://www.fas.org/sgp/crs/row/R42510.pdf

10. King, Hobart, "REE - Rare Earth Elements and their Uses," Geology.com, Available at: http://geology.com/articles/rare-earth-elements/

11. Kingsnorth, Dudley J., "Rare Earths Supply Security: Dream or Possibility?" Industrial Minerals Company of Australia, Pty Ltd, and Centre for Research in Energy and Minerals Economics, April 20, 2012. Available at: https://connect.innovateuk.org/documents/3005437/3745232/Rare+Earths+Supply+Security+Dream+or+Possibility-+Dudley+Kingsnorth+-+CREME+IMCOA.pdf/70af85dc-4fa3-4924-ac35-1db7f44e930a

12. Lynas Corporation (http://www.lynascorp.com/Pages/home.aspx)

13. Molycorp Inc., Form 10-K, March 17, 2013. Available at: http://www.sec.gov/Archives/edgar/data/1489137/000148913713000031/mcp1231201210k.htm

14. Sykes, John P., Selling the Rare Earth Story, Metal Pages blog post, June 11, 2010, Greenfields Research/ITRI. Available at http://www.greenfieldsresearch.com/selling-the-rare-earths-story/

15. Sykes, John P., Unanswered Questions about Rare Earth Mine Projects, presentation transcript from September 13, 2012, presented at Metal Pages Rare Earths Conference, Guangzhou, available through Metal Pages (Greenfields Research/ITRI) at http://www.slideshare.net/JohnSykes/unanswered-questions-about-rare-earth-mine-projects

16. Sykes, John P., Centre For Exploration Targeting Seminar, October 8, 2012, Perth, Australia: Seven Strategies for Rare Earths Hopefuls. Available at http://www.slideshare.net/JohnSykes/seven-strategies-for-rare-earths-companies

17. U.S. Department of Interior, U.S. Geological Survey: Mineral Commodity Summaries 2009, available: http://minerals.usgs.gov/minerals/pubs/mcs/2009/mcs2009.pdf

In Tribute to Jim Arnold

This white paper is dedicated to Dr. James (Jim) Arnold, Consultant, iNEMI. The preparation of this paper was lead by Jim up until his sudden, untimely death May 22, 2013. He was in fine health until he suddenly became very ill with what was likely an infection in his heart. His death was a shock and a great loss for everyone who knew him. Jim represented Motorola on iNEMI's Technical Committee for many years and was iNEMI's Director of Planning (1999-2001) and Director of Roadmapping (2001-2006). After his retirement from Motorola in 2006, he joined iNEMI as a full-time contractor. He was the driving force behind the preparation of this white paper, keeping participants focused and on task. We will miss his skills as a project manager, his broad technical expertise, and his tireless enthusiasm.