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# Rare Earth Elements: Procurement, Application, and Reclamation

Jared L. Romero and Samuel A. McCord

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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# Rare Earth Elements: Procurement, Application, and Reclamation

Jared L. Romero and Samuel A. McCord
Pollution Prevention and Regulated Waste
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-0730

**Abstract**

With the ongoing technological advances in electronics, vehicles, and national defense systems, the demand for Rare Earth Elements has increased exponentially. "Rare Earth Elements: Procurement, Applications, and Reclamation" will explain what Rare Earth Elements are and their unique characteristics, how they are obtained, and the processes needed to prepare the elements for specific usage, such as in powder metallurgy. It also discusses the locations of the mines used to acquire the elements and the political implications associated with the locations. It discusses the utilizations of these elements in various fields of technology and the need for more of these elements as such technology continues to advance. It also considers the possibility of reclaiming the used or worn out elements and reutilizing them in the future; highlighting the companies that have started to recycle the elements, reducing the demand for newly mined elements. Finally, it depicts the idea that reclamation of Rare Earth Elements will become a necessity and a benefit, both on a small and large scale, in the near future.

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## Nomenclature

| | |
|---|---|
| Ce | Cerium |
| CRT | Cathode Ray Tube |
| DOE | Department of Energy |
| Dy | Dysprosium |
| Er | Erbium |
| Eu | Europium |
| Gd | Gadolinium |
| HDD | Hard Drive Disk |
| HREE | Heavy Rare Earth Element |
| Ho | Holmium |
| La | Lanthanum |
| LCD | Liquid Crystal Display |
| LREE | Light Rare Earth Element |
| Lu | Lutetium |
| Nd | Neodymium |
| NiMH | Nickel Metal Hydride |
| OLED | Organic Light-Emitting Diode |
| Pm | Promethium |
| Pr | Praseodymium |
| REE | Rare Earth Element |
| Sc | Scandium |
| Sm | Samarium |
| SNL | Sandia National Laboratories |
| Tb | Terbium |
| Tm | Thulium |
| Y | Yttrium |
| YAG | Yttrium-Aluminum Garnet |
| Yb | Ytterbium |

# 1. INTRODUCTION

Rare Earth Elements (REEs) are 17 metallic, chemical elements on the periodic table that possess special characteristics that allow them to accomplish unique jobs. Specifically, they are 15 elements from the Lanthanide series: Lanthanum, Cerium, Praseodymium, Neodymium, Promethium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, and Lutetium. The rare earth element group also contains two other elements whose properties are similar to the Lanthanides; Scandium and Yttrium. Typically, these 17 elements are divided into two categories: Heavy Rare Earth Elements (HREEs) and Light Rare Earth Elements (LREEs). Separated by their atomic masses, with the exception of Yttrium whose atomic mass is one of the lighter but it is classified as a HREE because of its properties. The lighter ones are Lanthanum, Cerium, Praseodymium, Neodymium, Promethium, and Samarium. These elements are more abundant in Earth's crust and are less valuable, but valuable nonetheless for the advancement of technology. The heavy elements are Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium, and Yttrium. These elements are significantly more valuable because of their rarity in minable concentrations in the Earth's crust (Hatch, 2011, p. 8). However, all of these elements possess unique "catalytic, chemical, electrical, metallurgical, nuclear, magnetic, and optical" properties that have "led to their being used for a wide variety of purposes" (Colorado School of Mines).

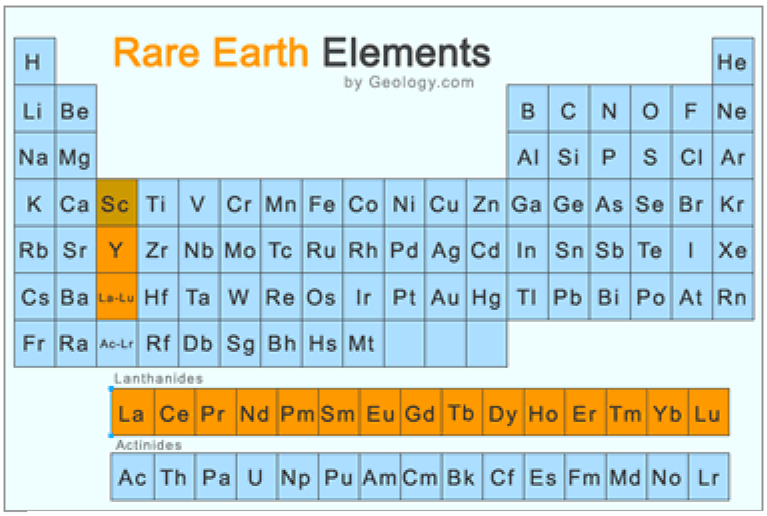

Figure 1. Rare Earth Elements in the Periodic Table (Geology.com).

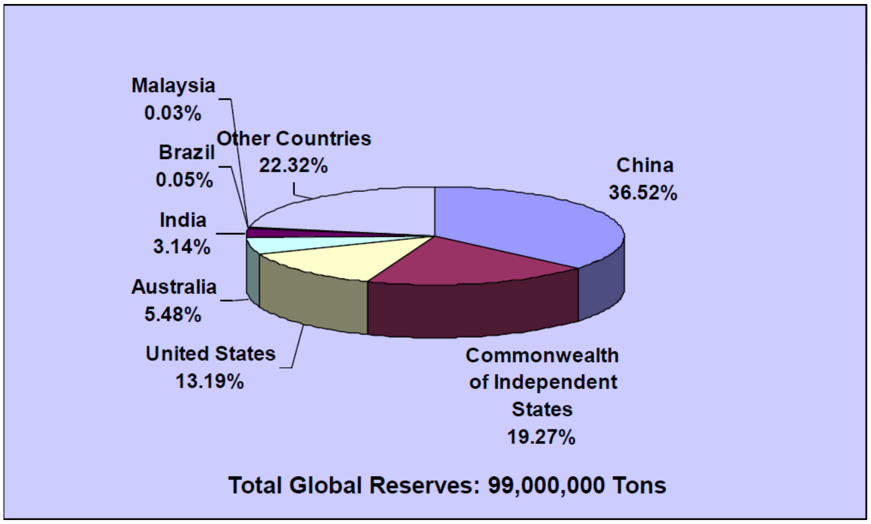


Figure 2. Concentrations of Rare Earth Elements (Rigali, 2011, Slide 7).

REEs have become invaluable to the ever-changing technological world. They are used in applications ranging from constituents in metal alloys as enhancers in different properties, to batteries for hybrid or electric vehicles, to magnets for cellphones and computer hard drive disks (HDD), and even as doping agents in optical glass used in welding helmets and lasers. These metals have also become increasingly important in the defense industry. REEs are used in things such as missile-guidance systems, satellites, and even lasers. Five of the 17 elements were put on what the United States Department of Energy (DOE) calls the "Critical Materials List" for the short and medium term; the other 12 were classified either as medium or long term critical. The DOE has also released an extensive report, both 2011, titled: *Critical Materials Strategy*, which provides a scientific explanation of the elements, market dynamics, a criticality assessment and other information about REEs. These metals are called rare but not because they are difficult to find. In fact, the element Cerium is more abundant in the Earth's crust than copper. The "rare" is because of the fact that the REEs are in such little concentrations that it is not economically viable to mine and process these elements wherever they occur. There are only very limited areas where the concentration of REEs is high enough to mine; such as select areas in China, the United States,  the Commonwealth of Independent States, and

Australia. These four areas are where most of the world’s REE supply is concentrated. With the improvement and growth of alternative energy and technologically advanced electronics, the demand for REEs has grown dramatically. With dwindling access to REEs, new mines are being planned and theories for reclamation of the elements are being tested.

# 2. GEOPOLITICS

Currently in the United States, there are no locations where REE are being mined (Kientz, 2010). However, there is one location that is coming out of retirement, the Mountain Pass mine located in San Bernardino County, California. From around the time of 1950 until 2002, the Mountain Pass mine was the main producer of REE in the world. At the time, Mountain Pass was mining a mineral called Bastnäsite, which contains a significant amount of REEs. After closing in 2002, Molycorp Inc. has decided to open once again and intends to be mining REEs by the end of 2012. Known as “Project Phoenix”, Molycorp says the mine is supposed to “transform our capabilities and dramatically increase the amount of rare earth material we will be able to make available to the rest of the world,” therefore supplying a significant amount of the United States’ REE demand (Molycorp, 2012). Molycorp has also provided a plan that states by 2013, the Mountain Pass mine will have the capacity to produce up to 40,000 metric tons (88,184,905 lbs.) of REEs. Since the Mountain Pass mine closed, China has become the predominant supplier of REEs. Starting in the early 1990s, China opened several REE mines, one of the biggest being the Bayan Obo mine located in the west of Inner Mongolia (NASA, 2011). Bayan Obo is responsible for up to half of the production of REEs in China. When China decided to become a major competitor in the REE field, they first decided to sell their elements at an extremely low price. This was because of the cheap labor and the loo se regulations on the environment. With China selling the REEs, this undercut the rest of the field, like the Mountain Pass mine, and put them out of business. China is now responsible for producing and exporting around 95-97% of world’s REEs. However, many issues have come from China’s dominance in the Rare Earth field.

For example, countries that need a steady supply of REEs, like Japan and the United States, are at the mercy of China hoarding REEs. They always need to be wary of China deciding to stop or severely decrease the exports of Rees. With the news that China *has* decided to reduce the export of REEs because of an increase in demand from China's economy and because of how damaging the mining of such resources is on the environment, the United States and Japan need an alternative source of REEs. The way that the elements are extracted produces a chemical substance that is very damaging to the environment, which makes it expensive for most countries to mine.  For these reasons, China has decided to cut down on the actual production of REEs and the export of REEs elsewhere. To counter this, in March of 2012, The World Trade Organization, along with the United States, the European Union and Japan, have brought up an official complaint against the Chinese government for monopolizing the industry and attempting to undermine the integrity of other countries' economic system (CNN Staff, 2012). United States President Barack Obama spoke on this matter saying, "We want our companies building those products right here in America, but to do that, American manufacturers need to have access to rare earth materials which China supplies. Now, if China would simply let the market work on its own, we'd have no objections" (CNN Staff, 2012). China insists that the new policies are being put into place because of new restrictions on protecting the environment and improving the economy of the mainland. With the opening of the Mountain Pass mine in California and other mines being constructed around the world, the nations that are solely dependent on China for their REEs should hopefully be able to slowly wean themselves off enough to compete with China's REEs within the next 15 years (Hsu, 2010). Japan and Vietnam have even agreed to jointly develop a mine in northern Vietnam's Lai Chau province for Rare Earths. It is expected to be operating by 2013 ("Vietnam and Japan", 2012). REEs have caused several problems but are a necessity if new ideas continue to flourish.

## 3. MINING AND PROCESSING

The process for refining the REEs into a saleable production grade is difficult and environmentally damaging. It involves mining an area where the REE concentration is high and collecting minerals containing REEs, such as Bastnasite, Loparite, Monazite and Xenotime. These ores tend to contain a majority of LREEs, with the exception of a few specific types of them which contains a significant amount of HREEs. These ores must be ground up and separated into pure ores and tailings. Pure ores are the uncontaminated ores that need to be further processed and tailings are leftover material like waste rock from the grinding process. From there, the pure ore is sent to a mill where it is ground even further into a silt-like material. The silt mixture is then put through a flotation process where a chemical is added to create air bubbles. The air bubbles attach to the pure form of the ore, Bastnasite or whichever mineral, and bring it to the top as a froth, where it is scraped off. From there, the actual element needs to be separated; this can only be done through acid and solvent extraction methods. This is the main reason that processing the REEs is environmentally dangerous. According to a recent article, "…process to get this mineral will eradicate trees and grass first and peel off topsoil of the earth. What's more, the waste water coming from the chemical reaction is full of ammonia, nitrogen and heavy metals, which are extremely harmful to people's health and the nature" ("Environmental Cost", 2012). This adds to the explanation given by the Chinese Government to decrease the exports of REEs to foreign nations. From then on, the pure ore can go through several stages of solvent extraction to ensure that all of the elements are

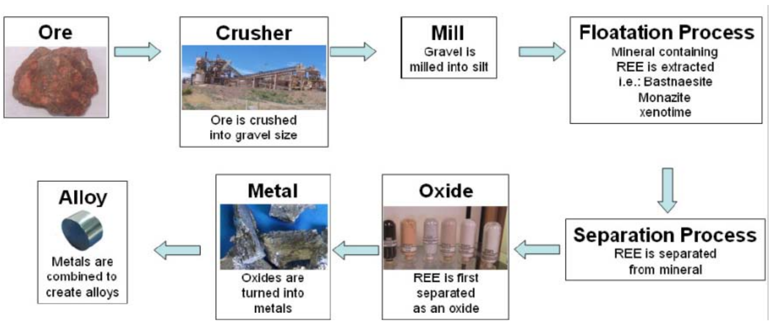


Figure 3. Flow diagram of REE ore processing. (Hurst, p.5).

separated and can be put to use. After the extraction stages, the REEs are dried into oxides at which point they are delivered to metal manufacturing plants. Lastly, the metals are then either sold in their raw form or are added to an alloy.

Some have also considered the bottom of the ocean to be a valuable source of REEs. According to a "Chemical and Engineering News" article, the mud from the bottom of the ocean has a high enough concentration of Lanthanides to be collected. Areas with large concentrations of REEs are deep spots (4000m-5000m) off the coast of Japan and Hawaii ("Hopes Pacific", 2012). This process would be extremely difficult to design because of the location; also because the project would be experimental and the effects on the environment are unknown. But if an idea was proposed that shows promise, "a single square kilometer in the central north Pacific contains enough rare-earth metals to supply one-fifth of the world's annual needs…" (Wilson, 2011, p. 32), thus taking the burden off of earth mining companies such as Molycorp.

Another process that is essential to the end use of certain REEs is called powder metallurgy. Powder metallurgy is the process of mixing powdered metals and making them into shapes not easily produced by other means. The process is very intricate and must be monitored very closely. First, metal ingots of a specific REE are pulverized in a machine that makes them

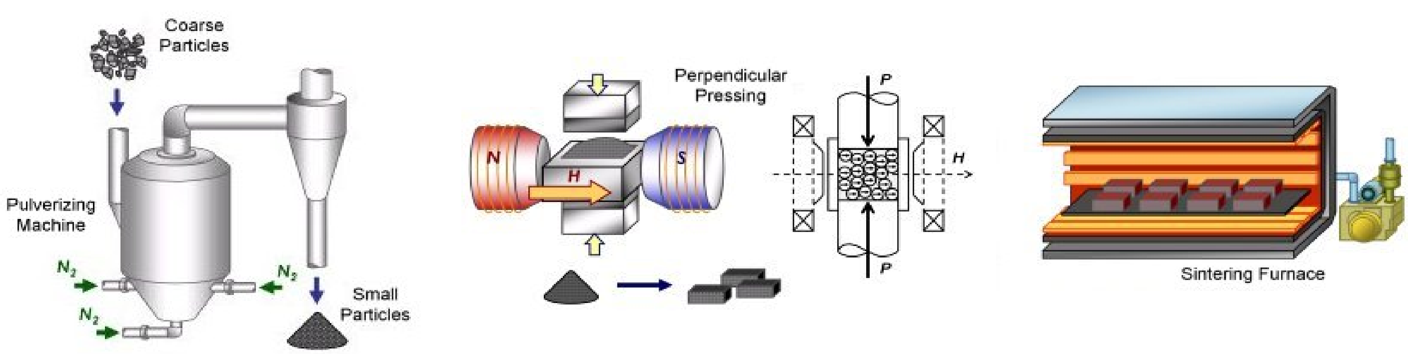


Figure 4. Diagram of the powdered metallurgy process. Includes the pulverization of the metal, the molding of the powder, the magnetization of the mold, and the sintering of the mold (Shin-Estu Rare Earth Magnets, 2007).

into a fine powder. Then the powder is pressed down into a shaped mold under extreme pressure, thousands of pounds of pressure per square inch.  Sometimes if the mold, now called a “green compact”, needs to be magnetized, it is pressed in the same fashion but under an electromagnetic field; making it magnetically anisotropic (polar in direction). Finally, the “green compact” is sintered, essentially baked at a temperature very close to the melting point of the metal, this hardens and also imparts the component’s metallurgical properties into the finished product, such as increased hardness, ductility, and improve the workability of the part. The processes of sintering an powder metallurgy are imperative for the REE field because of the way that the elements are used in the various areas of technology.

# 4. LIGHT RARE EARTH ELEMENTS

| Element | Symbol | Atomic Mass |
|---|---|---|
| Scandium* | Sc | 44.955 |
| Lanthanum | La | 138.905 |
| Cerium | Ce | 140.116 |
| Praseodymium | Pr | 140.907 |
| Neodymium | Nd | 144.242 |
| Promethium | Pm | 145 |
| Samarium | Sm | 150.36 |

Table 1. Light Rare Earth Elements *Scandium is not technically categorized as a LREE

LREEs are the first six REEs on the Periodic Table, Atomic Numbers 57 to 62 (with the exception of Scandium and Yttrium).The elements are Lanthanum, Cerium, Praseodymium, Neodymium, Promethium, and Samarium. One element is on the United States DOE "Critical Materials List". This material, the element Neodymium, is a necessity to the United States and the advancement of technology. Neodymium magnets, some of the strongest permanent magnets on Earth, are created using the processes of powder metallurgy and sintering. Neodymium magnets are also paired with Dysprosium and are used in computer and other electronic processors; writing, changing and erasing data off of a HDD. Neodymium magnets are also the smallest permanent magnets which enables them to be used in much smaller computer applications such as iPhones and Blackberrys Neodymium is predominantly used in permanent magnets but is also used as a component in glass and ceramic applications in order to modify the characteristics. For example, Neodymium is used in Yttrium-Aluminum Garnet (YAG), a synthetic crystal material used as a medium in solid-state lasers to increase grain efficiency and to lower threshold pump power. As stated before, Neodymium magnets are used in a wide variety of applications. Used most commonly in consumer goods for computer HDDs, headphones, microphones and speakers (Kurczy); Neodymium magnets are also the main component in permanent magnet turbines inside of energy-producing windmills. These turbines, unlike gear-driven turbines, are very efficient. However, to manufacture the massive magnets for the generators requires at least two tons of REE magnets; which contain up to 30% REEs, including Neodymium. Neodymium magnets are also used in missile guidance systems, adjusting the fins on the missle to track its target.

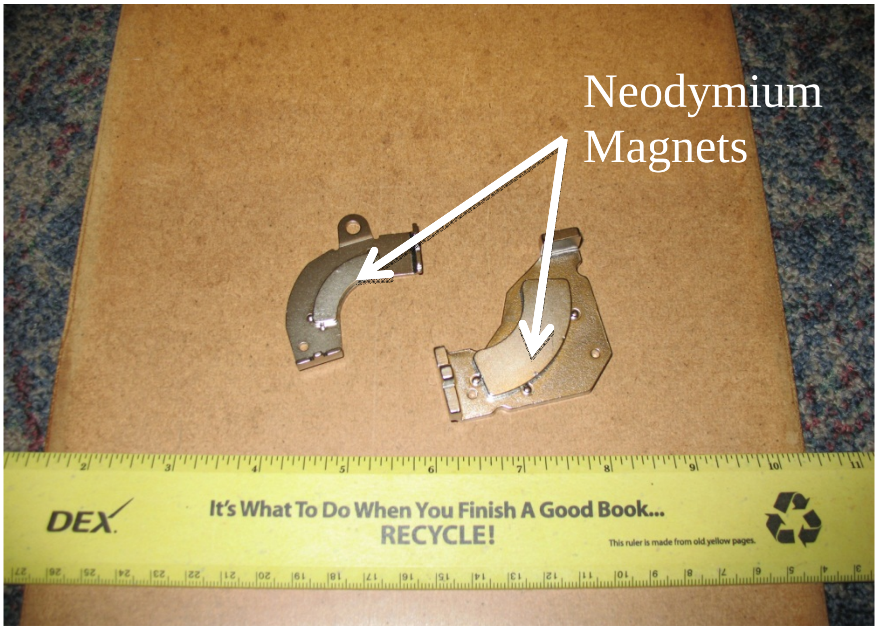


Figure 5. Neodymium magnets attached to their respective chassis off of computer hard drives (Photograph from McCord, at Sandia National Laboratories).

Another element that is important to the economy is Cerium. It being the most abundant of the LREEs, Cerium is used in commercial polishing agents for glass and is a small component in photovoltaic cells for solar energy storage. The most important application for Cerium is its use in petroleum refining to create useable gasoline and other petroleum-based products.  It is used to reduce carbon monoxide emissions when the gasoline is burned in the engine of the vehicle or tool (Avalon Rare Metals Inc.).  Cerium is not in immediate danger of becoming a critical material because of its abundance and the fact that it is mostly used in non-clean energy applications (IAMGOLD, 2012).

The rest of the LREEs are Lanthanum, Praseodymium, Promethium and Samarium. Lanthanum is categorized as a near-critical element while the other three are not in critical standing. Lanthanum is a near-critical element because it used in nickel metal hydride (NiMH) batters that can be recharged. Lanthanum is also used in elements for incandescent lighting because of its high refractive index. However the demand for Lanthanum is expected to decrease because of the transition to Lithium ion batteries and compact fluorescent lamps (“Critical Materials Strategy”, 2011). Praseodymium is used in the core of carbon arc lights, extremely bright lights that are used in things like stadium lighting. Praseodymium is also used in computed axial tomography (CAT) scan scintillators. Promethium is the scarcest of all of the REEs because it is not found readily in the earth. Promethium is radioactive; it being a by-product in Uranium fission. Promethium is used in very few things. It is used as a portable x-ray source, a source of radioactivity for gauges that measure thickness, and in lasers used to communicate underwater with submarines (Avalon Rare Metals Inc.). Samarium is used to produce Samarium-Cobalt magnets, which are permanent magnets that are resistant to demagnetization but are expensive to produce. Samarium is also an ingredient in a medicine called Qadramet, produced by Lantheus Medical Imaging located in North Billerica, Massachusetts. Quadramet is used as a pain-killer for the effects of cancer (FDA, 2009). Samarium is also used in instruments that create the “white noise effect” for defense purposes (Hough). Although it is not categorized as a LREE, Scandium has more common characteristics with them than the HREEs. Scandium is added to aerospace technology parts because of its ability to limit the growth of grain in the metal (“Applications of Scandium”). Grain growth in metals causes the part to lose toughness and wear out faster. Scandium is also used to create high-intensity discharge lamps. These lamps are used in stadium lighting much like Praseodymium arc lighting. The LREEs are much more common than the rest of the REEs but they are no less important to the ever-changing world.

# 5. HEAVY RARE EARTH ELEMENTS

The HREEs are the last nine of the Lanthanide series and also one other element whose characteristics are extremely similar to the Lanthanides. They are Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium, and Yttrium. Interestingly enough, Yttrium is the lightest of all the REEs but has properties like a heavy element. Out of the 10 HREEs, four of them are on the "Critical Materials List"; Europium, Terbium, Dysprosium, and Yttrium. Europium is the most reactive of the REEs; it resembles the reaction of pure calcium in water. It is used in an alloy for nuclear reactor control rods because of its ability to absorb neutrons. It is also used in Cathode Ray Tubes (CRTs) and other displays to produce red phosphors. With the creation of Liquid Crystal Displays (LCD), plasma screens, and even organic light-emitting diode (OLED) displays, the use of REEs in television screens has been greatly diminished. Another form of lighting that Europium is used for is in its divalent form, meaning having a valency of two in its electron configuration, and it is able to produce a bright blue light. Gadolinium is used in the medical field as an intravenous contrasting agent for patients undergoing magnetic resonance imaging (MRI). It is also used in Gadolinium-Yttrium garnets, a variation of the Yttrium Aluminum garnet, which is then used in microwaves. According to Avalon Rare Metals Inc., "Gadolinium is used in nuclear marine propulsion systems as a burnable nuclear poison and as a secondary, emergency shut-down measure in some nuclear, particularly Canada Deuterium Uranium type reactors" (Avalon Rare Metals Inc.). A

| Element | Symbol | Atomic Mass |
|---|---|---|
| Yttrium | Y | 88.9005 |
| Europium | Eu | 151.964 |
| Gadolinium | Gd | 157.25 |
| Terbium | Tb | 158.925 |
| Dysprosium | Dy | 162.5 |
| Holmium | Ho | 164.930 |
| Erbium | Er | 167.259 |
| Thulium | Tm | 168.934 |
| Ytterbium | Yb | 173.054 |
| Lutetium | Lu | 174.966 |

Table 2. Heavy Rare Earth Elements

nuclear poison is a neutron absorbing material used to control high reactivity when new fuel is added to the reactor (DOE, “Neutron Poison”).

Terbium, the second “critical material”, is also used in CRTs for producing green phosphors. Used in combination with Europium red phosphors and Gadolinium blue phosphors, Terbium is able to create trichromatic lighting, which are used in CRTs to create a full color television screen. Terbium is also used in what is called Terfenol-D, an alloy that is produced by Entrema Products Inc. and has the ability to expand or contract when it is put inside of a magnetic field (Entrema Products Inc., 2012). Terfenol-D is used in actuators, sensors and other magneto-mechanical devices. The third element on the “critical materials list” is Dysprosium. Dysprosium is probably the most used HREE, therefore making it also the most important. Dysprosium is actually used in the production of Neodymium magnets. When 6% of the Neodymium is replaced with Dysprosium, the magnets’ conductivity is increased and can be more efficient for use in hybrid cars. Dysprosium is used in the production of optical data storage devices such as compact discs. It is also a main component in laser materials when combined with elements such as Vanadium and other REEs. One HREE that is not on the list is Holmium. Holmium has the mightiest magnetic strength of any element, making it extremely useful if creating an artificial magnetic field. It is also used as components in Yttrium-Iron garnets and Yttrium-Lanthanum-Fluoride solid state lasers, which have applications in the medical field. Holmium is also mixed into glass and ceramics, like cubic zirconia, to color it a peach-like color or bright yellow color (Avalon Rare Metals Inc.).

The next HREE is Erbium. Erbium is commonly used in commercial applications for photographic lens filters. It is used to color glass materials various shades of pink. Erbium also has applications in the medical and dental field; used in cosmetic lasers for dermatology and teeth-whitening procedures. Thulium is one of three scarcer HREEs. Because of that, it does not have very many applications in the practical world. Thulium is used as a portable x-ray source. However, it first needs to be immersed in a nuclear reactor for it to be useful. Thulium is used in arc-lighting similar to Praseodymium (the color is green in these lights instead of the brilliant white emitted by Praseodymium). Along with most of the REEs, Thulium is used in components for lasers. This is one of the biggest reasons for the criticality assessment of these elements. Their application in the defense industry causes them to be greatly needed and protected. Ytterbium is used as a source of gamma radiation for non-destructive testing. This is similar to the elements like Thulium and Promethium that are used for portable x-rays. Ytterbium is also added to stainless steel to improve the grain refinement, strength and other mechanical properties. Lutetium can be considered the rarest and the most expensive REE out there. Because it is so expensive, it is used very little in the everyday world. Lutetium is used as a catalyst in petroleum refining (cracking), alkylation, hydrogenation, and polymerization. The final HREE, and the last element on the “critical materials list”, is Yttrium. Very unlike the last three HREEs, Yttrium has a wide variety of applications. Yttrium is used mainly in phosphors for CRTs and in OLED televisions, making it more valuable than Europium, Gadolinium and Terbium in the phosphor area. Yttrium is also used in energy-efficient lighting. YAG lasers use a large amount of Yttrium to create the synthetic garnet for the laser to pass through. Yttrium is used in Yttrium Barium Copper Oxide superconductors. This superconductor was made famous because of the fact that it was the first time any material achieved superconductivity above the boiling point of liquid nitrogen, 77 Kelvin (AMMTIAC, 2003). Yttrium is added to

Figure 6. Yttrium metal (Avalon Rare Metals Inc.).

glass and ceramics to add shock resistance; especially to photographic lenses and optical glasses. Yttrium is also used as a hardener to things like medical scalpels, fabrication of nerve-severing needles, and prosthetic devices. Overall, HREEs are much rarer than their lighter companions and will become invaluable to the advancing world.

# 6. RECLAMATION

With the demand for REEs on the rise, the need to reuse these elements is also becoming increasingly important. However, very few REEs are being reclaimed from their original uses. The recycle and reuse of REEs could possibly decrease the dependency on imports of the elements. One problem with the recycle of products containing REEs is that there are very few recycling ideas that are monetarily feasible. It is too difficult and expensive for smaller companies to recycle the REE products; it is easier and cheaper to just throw the used products into the garbage as waste. Another problem is that even if it were cheaper to send REE products for recycle, there aren't many recycling plants in the first place. Currently, two major companies, Honda Motor Company, Ltd. and Hitachi, Ltd. have begun to implement REE recycling strategies. Honda's plans involve collecting used hybrid car batteries and reclaiming the REEs inside of the battery to use inside of new parts that can then be used in new Honda vehicles. Hitachi, a producer of electronics, tools, and telecommunications equipment, is planning on reclaiming REEs from multiple sources like computer hard drives, refrigerators, and industrial permanent magnet motors. Both of these companies are in the beginning processes of recycling and are expected to start large-scale programs for REEs by the beginning of 2013 (Hitachi, "Rare Metals", 2010).

Honda has been mass-producing hybrid cars in the United States since the launch of the Civic Hybrid in 2002 (Honda, 2012). Now, 10 years later, Honda has released a plan of action that will begin the reclamation and reutilization of REEs inside of the batteries in hybrid cars. According to a press release by Honda in April of 2012, "As part of this effort, before the end of this month, Honda and Japan Metals & Chemicals, will begin extracting rare earth metals from used nickel-metal hydride batteries collected from Honda hybrid vehicles at Honda dealers inside and outside of Japan. The new operation will be the first in the world to extract rare earth metals as part of a mass-production process at a recycling plant" (Yoney, 2012). The process for extracting the REEs from the batteries is efficient and designed specifically for Honda's cars. First, Honda will collect used hybrid car batteries from car dealers all over the world. They are sent to Japan Metals & Chemicals Co., Ltd. where the batteries are disassembled and the pieces that are not needed are scrapped. Then the pieces that need to be refined are calcified, meaning heated to a certain temperature to remove volatile substances, and then ground up and sorted. From there the sorted material is separated and the pure REEs are extracted. Then the REEs are sent to the part makers where they are reutilized and put into new Honda products. Currently, Honda's battery recycling process is working at full capacity and is also urging other companies that produce hybrid cars, like Toyota and Tesla, to do the same ("Hybrid Battery Recycling").

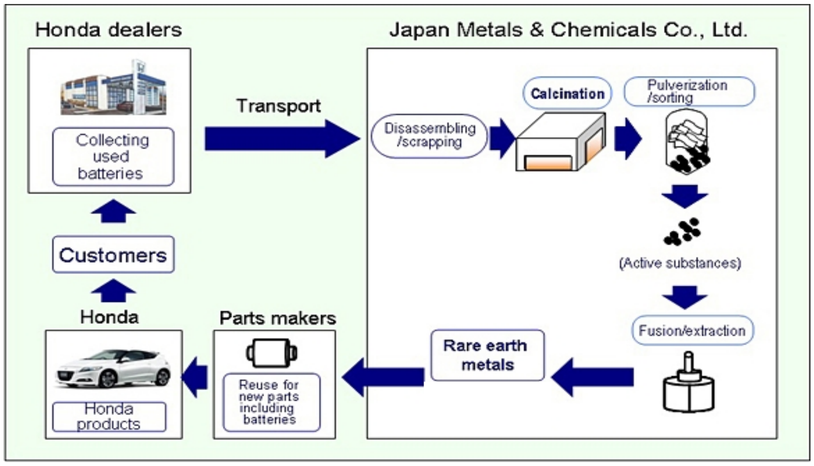

Figure 7. Diagram of Honda's plans for battery recycling (Yoney, 2012).

Hitachi's plan involves a much wider variety of products that are viable for recycle. Two specific products that Hitachi is aiming to remove the REEs from are computer HDDs and from inside the compressor of air conditioners and refrigerators. The REE products that Hitachi is aiming to recover are Neodymium magnets. To recover these magnets, two processes are necessary for collection. To collect the magnets from the hard drives, they first need to be disassembled. However, because Hitachi produces all sizes and types, there is no single machine that will disassemble all the hard drives. For this reason, Hitachi has designed a special machine that "…works automatically, subjecting the HDD to shaking and other impacts to remove the screws used to fasten each of its component parts" (Nemoto, Tanaka, Tsujioka, Eryu, Takada, 2011). This provides a much faster way to separate the different parts and all that is left to do is separate the magnets from the rest of the parts. The other way that Hitachi is collecting the Neodymium magnets is through compressors that are used in air conditioning units and refrigerators. The compressors are surrounded in a steel casing that is welded together so they are very hard to disassemble. Hitachi uses a special cutting machine that is very worker-friendly and just requires a small adjustment for each casing. Once the casing is cut off, the rotor is removed from the casing and is demagnetized. Once the rotor is demagnetized, the Neodymium magnets are removed and are collected. All together, the magnets from both reclamation processes are crushed and sintered back into magnets that can be used in new products. Overall, Honda and Hitachi have become the frontrunners for Rare Earth recycling.

Two other alternative ways that REEs could be obtained is through the collection of fly ash and the collection from rechargeable batteries. Fly ash is "a byproduct from burning pulverized coal in electric power generating plants" (Basham, Clark, France, Harrison, 2007). A Colorado-based company called Neumann Systems Group has experimented with the collection of fly ash as a source of Rare Earths (Currie, 2012). Since the fly ash is normally released into the air after the coal is burned, it would be a benefit for the company to collect the ash. The REEs would be collected through a particle filtration system before the ash reached the smoke stacks. The drawback of this is that the ash only contains a few parts per million of REEs. Rechargeable batteries on the other hand contain a fair amount of REEs, such as Lanthanum. Two companies, Umicore N.V- a Belgian materials technology company and Rhodia- a group specializing in chemistry, synthetic fibers, and polymers; have developed a process to recycle

REEs from NiMH rechargeable batteries (Rhodia Group, 2012). The process involves Umicore's Ultra High Temperature battery recycling process with Rhodia's ability to refine the REEs collected from the batteries. It would take place at Rhodia's plant in La Rochelle, France where the nickel would be separated from the REEs. According to an article from Rhodia, the first recovery of the Rare Earths could take place by the end of 2012.

Sandia National Laboratories (SNL), a contractor for United States Department of Energy's National Nuclear Security Administration located in Albuquerque, New Mexico, uses REEs in their research and development. SNL is working on creating or teaming for recycling pathways of the various REEs it uses, but has not yet completed a viable recycling process. SNL is working with Ames Laboratory, another DOE Laboratory, to recover Erbium and Scandium. If the testing turns out to be successful, the Erbium and Scandium scraps are then able to be directly reused within SNL.

# 7. CONCLUSIONS

With the advancements in technology, alternative energy and military systems, REEs are taking their place among some of the most coveted materials on the planet. REEs have caused worldwide problems; ranging from environmental damage issues to multi-country complaints of China's monopoly on the elements because the demand for the elements is so high. However, with China's announcement that they are decreasing production and exports of the Rare Earths, they have tightened their hold on the current Rare Earths, and at the same time are driving up prices. China is also going to lose business in the Rare Earth field because countries like the United States and Australia are taking advantage of the opening and are in the process of constructing, or reopening in the United States' case, mines to collect their own Rare Earths. With these new mines, dependency on foreign Rare Earths is expected to decrease dramatically, hopefully enough to settle any disputes about the elements. With companies like Hitachi and Honda leading the way for recycling the REEs, demand for brand new Rare Earths should also decrease; and if the disputes are not settled and conflicts continue to limit the availability of Rare Earths, the recycle of products and the reclamation of the elements will be imperative to continuing the advancement of technology. The future boasts plenty of new innovative ideas. From thinner laptops and smaller cellphones, specialized defense systems, and alternative energy production, REEs will remain a top priority.

SNL is one of many laboratories that uses REEs; 16 out of the total 17, excluding Promethium because of its scarcity ("Chemical Information System", 2012). SNL must evaluate their standing in the demand for Rare Earths, remaining aware of any complications that might arise in the future over the fight for the elements. Sandia must then decide if they will continue to purchase REEs without the thought of recycling, possibly worsening the situation. But, for the benefit of the Sandia Corporation and for the benefit if those who promote the recycle of REEs, Sandia must decide to take the first step and begin searching for a way to recycle the elements they are using. If SNL finds a way to recycle even some of the Rare Earths from their facility, they could become the leaders for the rest of the country to follow. In addition, SNLs' decision could spur other laboratories into recycling REEs, putting more pressure on other companies to follow in their lead. Whether or not SNL decides to find a recycling pathway, REEs are going to remain prevalent in the future; therefore, someone must find an economical way to recycle Rare Earths or the problem will continue to grow and could escalate beyond saving.

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