Rare Earth Industry Supply Alternatives
ENVS 190A Thesis
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**Abstract:**
This study examines the United States stance in the global rare earth elements industry. China is currently the world leader in rare earth supply but is reducing export amounts for environmental and domestic reasons. Rare earth elements are in high demand for technological developments and their resources need to be secure for future advancement. The United States and other countries are researching and developing more efficient techniques or alternatives. Rather than starting a new mine operation, substitutes, recycling and extracting tailings for rare earths could provide the U.S. with a secure supply of rare earth elements. The alternatives to new rare earth mining projects can also reduce environmental impacts. The process of extracting tailings and feasibility of recycling rare earths and substitutes will be assessed in this study and compared to current mining practices.

**Introduction:**
Rare earth elements receive their name, not because they are rare in the earths crust, but because they are rarely found in sufficient quantities for practical and economical mining purposes (King, 2012). Rare earth elements are as common in the earths crust as nickel, zinc, chromium and lead (Long, 2010). The rare earth elements are a total of 17 elements on the periodic table, which include the 15 lanthanides and elements scandium and yttrium (Refer to figure 1) (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). Rare earth elements most commonly found are cerium, yttrium, lanthanum and neodymium (Long, 2010). All rare earth elements contain unique electron arrangements that yield unique properties. For example one property is magnetic strength, which is required to turn mechanical energy to electrical energy, which leads to the stronger the magnet the more energy efficient the device can be (King, 2012).
Rare earth elements (REE) are also known as rare earth metals (REM) since they are all metals, and also they are known as rare earth oxides (REO) because they are traditionally sold or traded in oxide form (Hurst C. A., 2010). Rare earth metals are preferred for technological applications for their luminescence, magnetism and strength properties (Shemin, 2010). These properties are what separate rare earth elements from the rest of the elements and other substitutes when it comes to technological applications. These properties have allowed for great advancements in various technologies.

Rare earth metals are being used more and more in our everyday lives with the proliferation of cell phones, televisions, laptops, catalytic converters, and more. Catalytic converters accounted for 9% of total U.S. rare earth use in 2008 (U.S. Department of Energy, 2011). Rare earth elements make all of our small technologies possible by being one of the main
components in the rechargeable battery. Rare earth elements are also a key element for developing various “green” technologies such as electric hybrid vehicle batteries and wind turbine generators. In electric and hybrid vehicles there are at least a few pounds of rare earth metals found in the battery (Rademaker, 2013). Rare earth elements are also used in the majority of our military technology such as night vision goggles, precision guided weapons, GPS equipment, and more (Hurst C. A., 2010). Rare earth demand in the United States grew from 85,000 tons valued at $500 million in 2003 to 124,000 tons valued at $1.25 billion in 2008 (Industrial Minerals Company of Australia Pty Ltd, 2008). By 2015, demand is estimated to be 200,000 tons of rare earths valued at $2.3 billion. (Industrial Minerals Company of Australia Pty Ltd, 2008) The need for rare earth elements has grown and will continue to do so with the need to develop green technologies.

With all of the growing technology applications requiring rare earth elements in their production will lead to increases in demand of rare earth elements to a point that current mining practices will not be able to satisfy. The purpose of this study is to assess the alternatives of substitutes, recycling, and extracting tailings to conventional mining in terms of economic feasibility and environmental impacts.

**History of Rare Earth Market:**

Rare earth element mining became commercialized in the 1960s, when the color television entered the market. At this point Mountain Pass Mine located in California became the world’s largest rare earth producer because they were producing europium, which is required for color televisions (King, 2012). China did not begin producing sizeable amounts of rare earths until the 1980s. Yet, by the 1990’s China had become recognized as the world’s leading producer. China was able to become the global leader in production due to its ability to produce rare earths
at a price most other mines could not compete with. While China was becoming the leader in production the demand for these elements was growing exponentially due to advances in defense, aviation, industrial, and consumer electronics technologies. (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). By 2010, China was supplying 95% of the world’s rare earth demand (Pool, 2012).

(Figure 2 (Wells, 2013))

This led to stimulate other rare earth elements markets to reconsider their rare earth elements ventures in Australia, Canada, Mountain Pass in the US and other countries (Pool, 2012). Success of new ventures were in Australia where they contributed 1% to the rare earth elements world market in 2011 and jumped to 3% in 2012 (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). Also in 2012 Mountain Pass contributed 6% to the world’s supply.

China’s hold on the rare earth elements market has led to look at alternatives or ways to reduce rare earth elements demand. So far currently the best solution is to use less amounts of
rare earth elements or look for technology that does not require them (Shemin, 2010). Again as mentioned earlier substitutes are not as efficient as rare earth elements.

Currently opening a new mining property is a very time consuming process so if China were to decide to stop exporting than the majority of rare earth elements supply would be discontinued. The control China has over the rare earth elements supply is very risky especially for all the other countries that heavily rely on it. An instance like that happened in 2010 when China drastically limited their exports by 40% for domestic manufacturing and environmental reasons (Hurst C. A., 2010). This instance led to rare earth elements prices rocketing and Japan, U.S. and European union complaining to the world trade organization about China’s limited rare earth elements trade policies (Hurst C. , China's Rare Earth Element Industry: What Can the West Learn?, 2010).

**Current Rare Earth Market:**

United States is one of the top consumers of rare earths along with China and Japan. China is the number one producer of the world’s rare earth elements providing over 95% of the world’s supply (Pool, 2012). China demands 65% of the world’s supply followed by the U.S. demanding 15%. China is greatly invested in its rare earth mining industry and advancing mining techniques. The U.S. on the other hand currently only has one rare earth mine, Mountain Pass in California, which is owned by Molycorp. It used to be the top rare earth mine in the world before China took over the industry.

The rare earth market is expected to grow 4-6% every year (King, 2012). The main rare earth demands are for permanent magnets, metal alloys, catalysts and polishing powders (King, 2012). Permanent magnets market is expected to grow over 20$ billion by the year 2020 (Hurst C. , China's Rare Earth Element Industry: What Can the West Learn?, 2010). These permanent
magnets are used for many technologies many of which are becoming more desired. Permanent magnets for instance are used in many products associated with renewable energy. The use of these products is suspected to increase throughout the century with the onset of global climate change. The generators inside wind turbines and electric motors require strong yet light magnets. Currently the strongest and lightest magnets commercially available use neodymium, praseodymium and samarium (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010).

All rare earth elements are mined together, which creates issues when different demands come into play. If a specific rare earth is highly demanded then it will be mined for more often but there will be many other rare earth elements produced as byproducts. These byproduct rare earth elements can then accumulate until they reach a surplus. That excess rare earth element will then go down in price due to surplus, making it impractical to increase supply because of one particular rare earth elements demand. There is estimated 113,000 tons of rare earth oxides produced per year, which is currently a surplus of rare earth oxides (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). The supply of rare earth elements is expected to keep up with the demand for the short-term future ranging from five to seven years (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). In the long run demand is expected to exceed the supply.

Countries on the rise of development will increase their demand for rare earth elements technologies. U.S.G.S. estimates that total world reserves are 110,000,000 tons. A large percent of the reserve is located in deep-sea nodules (Goonan, 2011). Most of the rare earth element reserves are in minor concentration deposits, which refer back to their name of “rare earth elements” because they are rarely found in practical amounts. With current technology rare earth
elements reserves being located in the deep sea and found in low concentrations are too expensive to mine. The amount of deposits ready to be mined is very limited (Hurst C. A., 2010). This is the central issue of why rare earth mining has not greatly expanded. Although that is the main limitation for mining there are also many economic, environmental and political limitations.

Opening a rare earth elements mine requires a lot of high capital investment, and is very time consuming. This makes it hard to gather investors for new mining projects due to the fact that it would be perhaps as long as a decade before they could start seeing returns on their investment. Furthermore, there are many strict environmental regulations that limit openings of new mines. Acquiring all of the environmental permits is expensive and very time consuming. (Long, 2010)

**Mining Process:**
The rare earth mining process starts with finding an ore that contains rare earth minerals and taking it out of the ground using normal mining procedures. Rare earth element ores are prominently monazite or bastnaesite mineral based. Monazite is a reddish-brown phosphate mineral containing mostly light rare earths but also more amounts of heavy rare earths. Bastnaesite is a yellowish to reddish brown mineral consisting of mainly light rare earths. That ore is then crushed down to gravel size pieces and then crushed even more until it is as fine as sand or silt. Once the minerals are fine they go through a flotation process where an agent is added to make the rare earth elements float to the top of the tank and the unwanted minerals stay at the bottom. The rare earth minerals are scraped off the top and then separated by acids and solvents into pure forms, each element has its own unique separation process. Once separated into oxides can then be processed into metals then into alloys used for applications. This process takes about ten days from when the ore was mined to when the rare earth oxides are produced.
The mining process has the potential to cause many environmental hazards if not following strict guidelines. (Refer to figure 3) (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010)

**REE Process**

(Figure 3 (Hurst C. A., 2010))

**Environmental and Health Effects:**

Ores mined for rare earth elements can contain radioactive elements such as thorium and uranium. The mining process produces a large byproduct of tailings, which are broken down waste materials left behind once the rare earth elements are extracted. Producing one ton of rare earths creates 12,000 tons of wastewater and 2,000 tons of mine tailings (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010). If not managed properly these
tailings can poison water supplies. Tailings ponds contain toxic chemicals such as radioactive thorium that if ingested will likely lead to pancreas, lung and leukemia cancer. The U.S. requires specific permits to store tailings generally into land impoundments. (Davis, 2013)

There are many environmental regulations that restrain openings of new mines. However environmental law is needed since starting a mining operation is very toxic and needs to have guidelines to make it as safe as possible. In China mining regulations are very lax compared to the U.S. for example “in the Baotou region they produce approximately ten million tons of all varieties of wastewater a year. Most of the wastewater is discharged without being treated and can contaminate surrounding water environment and irrigated farmlands” (Hurst C., China's Rare Earth Element Industry: What Can the West Learn?, 2010).

Thorium is a radioactive byproduct of rare earth mining and is a source of contamination in China’s Baotou area and the Yellow River. A resident of the area reported that all of the fish have died from the chemical waste dumped into the river and the remaining fish are no longer safe to eat. In other areas close to mines, crops will not grow or they will grow but not contain any fruiting bodies. Fish no longer live in the rivers and even the weeds cannot survive. (Ives, 2013)

Before mining factories were built in Inner Mongolia there were fields that grew a variety of crops including watermelon, eggplant and tomato and many farmers lived in the area. When mining facilities started to develop in the area they did not notice the pollution that was being caused at first until crops started to fail. Before tap water people used to primarily drink from wells but noticed that the water had a strong odor to it despite having a normal appearance (Kaiman, 2014). An example of the effects on farms close to the mine was a farm that had animals with two sets of teeth (Kaiman, 2014). The farmers had to move away because most of
their animals were killed from the toxins. Over 10 years the population had decreased from 2,000 to 300 people. These residents were inhaling solvent vapor, consisting of sulfuric acid and coal dust. (Davis, 2013)

The largest rare earth mine in the world, Bayan Obo Mine is located in Inner Mongolia, China (Ives, 2013). After the rare earths are mined at Bayan Obo they are transported to Baotou where two-third’s of the world’s supply is refined to rare earth oxides. In Baotou is the world’s largest rare earth tailings pond that lacks a proper lining, which has allowed for the waste material to seep into the groundwater for the past 20 years (Kaiman, 2014). The tailing pond trickles into the Yellow River, which is the major drinking water source for Northern China (Kaiman, 2014). Over 150 million people primarily depend on the Yellow River but for the past two decades mining has been polluting it. (Hurst C. , China's Rare Earth Element Industry: What Can the West Learn?, 2010)

Health standards are also very lenient in China. People only 30 years old have died from cancer from working in close proximity to the mines, which is likely due to the radioactive materials. In Baotou the most common disease associated with the environmental effects of mining is pneumoconiosis (black lung). Approximately 5,387 residents in Baotou suffer from the disease. (Hurst C. , The Rare Earth Dilemma: China's Rare Earth Environmental and Safety Nightmare, 2010)

The rare earth refining process requires ammonium bicarbonate and oxalic acid. Ammonium bicarbonate can cause irritation to respiratory gastrointestinal track if inhaled or ingested. It can cause redness itching and pain if it comes in contact with the skin or eyes. Oxalic acid could be fatal if swallowed. It is a corrosive substance causing severe irritation and burns to the skin, eyes and respiratory tract. Oxalic acid is harmful if inhaled or absorbed through skin
and can cause kidney damage. All of these chemicals and more make their way into the Yellow River. (Hurst C. , The Rare Earth Dilemma: China's Rare Earth Environmental and Safety Nightmare, 2010)

China has general pollution laws but has not created laws to regulate rare earth industry pollution. As the industry rapidly expanded China did not effectively put in place regulations to control the pollutants. Leading to lenient regulation and minimal enforcement since the industry is so large. Companies are not held as accountable as they would be here in the United States. For example if someone was to get sick, hurt or die from working at a company in the U.S. there would be repercussions and the person has legal discourse to seek reparations from the company. Where in China none of those actions exist, the company is not obligated to do anything. The result is that companies have no reason to change their practices, which allows for the hazardous work environment to continue. The U.S. has very strict guidelines and regulations against the mining industry. The U.S. requires many permits that are expensive and time consuming to produce in order to ensure safe and responsible mining practices. Yet, in China none of those barriers exist or are very limited/minor. (Hurst C. , The Rare Earth Dilemma: China's Rare Earth Environmental and Safety Nightmare, 2010)

**Alternatives:**

Alternatives that can be utilized to reduce the stress on the rare earth supply are recycling, substitutes, and extracting mine tailings. Current examples of research and development in each of the sectors will be described and examined with a focus on certain devices that contain the most significant amounts of rare earths. Devices such as permanent magnets in vehicle batteries, wind turbines, and fluorescent/LED lighting contain the most significant amounts of rare earths (Binnemans, 2013). Laptops, cell phones, catalytic converters, defense technology and other
devices will not be addressed since they contain insignificant amounts of rare earths (Rademaker, 2013).

**Tailings:**

An alternative to conventional mining for rare earths is the reuse of mine tailings and other waste products of current or previous mining operations. Several countries including the U.S. have been looking into using the waste materials from prior mining activities to produce rare earths. There are several obstacles to this approach ranging from political to technical, yet many believe that utilizing tailings can help alleviate the shortage of the world's rare earth supply without the development of new mines.

USGS scientists are reanalyzing rocks, minerals and other mine tailing samples to measure their abundance of rare earths (Heidi Koontz, 2013). They are performing this analysis by utilizing a new technique called laser ablation inductively technology (Heidi Koontz, 2013). With this new technology the complicated, time consuming and potentially dangerous acid dissolving of the ore is no longer needed. This method will allow USGS scientist to analyze both new and old rocks from tailings to determine if they are suitable for rare earth extraction. The USGS began analyzing out of operation mines, in addition to mining and industrial waste to determine their potential as a source of rare earth metals in 2013 (Krzysztof Szamalek, 2013). The ability to determine which tailings are potential sources of rare earths is the first step to developing rare earth extraction in the U.S.

The Island of Bangka in Indonesia has been a mining site for cassiterite for centuries. The mining process produces an abundance of tailings, which has recently been the focus of a new study. The study aimed at determining if the tailings produced from cassiterite mining were a potential source of mineral commodities especially REE. The initial study was able to determine
that the tailing samples contained significant concentrations of REE (Krzysztof Szamalek, 2013). The study was able to estimate the potential extraction from cassiterite tailings to be 10,000 tons of minerals containing rare earth elements annually (Krzysztof Szamalek, 2013). However, this does not mean that foreign companies can buy tailings for processing.

The Indonesian legal system forbids the selling of bulk tailings. Only monomineral concentrates of purity above 99.9% can be sold outside mining areas (Krzysztof Szamalek, 2013). Thus processing plants would have to be built at the mining locations in order to legally sell the rare earths (Krzysztof Szamalek, 2013). This would be an expensive endeavor to accomplish in any amount of time (Krzysztof Szamalek, 2013). Thus, there is the potential to produce rare earths in Bangka from tailings but it is not going to happen in the immediate term. However, the Indonesian authorities are open to cooperating with foreign mining companies. There is the possibility that rare earth extraction from mine tailings such as those located on Bangka will become a key source of the world's rare earth supply in the future.

In February 2013, Jamaican and Japanese officials announced that they launched a pilot project concerned with investigating whether rare earth elements can be commercially extracted from the bauxite waste located on the island (McFadden, 2013). On the island of Jamaica bauxite is refined into alumina. Alumina is the basic material for manufacturing aluminum. Jamaica’s “red mud” is the byproduct of this manufacturing process (McFadden, 2013). Japan’s Nippon Light Metal Co. has taken an interest in this red mud with researchers believing that it contains high concentrations of rare earths (McFadden, 2013). The project includes plans to treat approximately 30 tons of dry red mud with acid to potentially extract rare earths (McFadden, 2013). Researchers from both countries will be working on the project and if it is successful it could become a new rare earth mining industry in Jamaica.
**Substitutes:**

As mentioned earlier the rare earths supply outside of China is being pushed beyond its limits and to gain independence from China’s supply, technologies may need to be developed rare earth free. Substitutes are currently not as effective as rare earths but many countries are working towards developing rare earth free devices that are just as efficient.

U.S. Department of Energy is funding many projects to look for substitutes of rare earths and to create rare earth free devices. In 2013 the U.S. department of energy gave AMES laboratory $120 million to develop alternatives that would allow for the production of turbines and electric vehicles without rare earths. (U.S. Department of Energy, 2011)

Toyota is developing future hybrid vehicles that do not require rare earths. The engineers of Toyota in Japan and the U.S. are working on induction motors that are lighter and more efficient than the magnet motor in the Prius. Toyota’s battery powered Rav4 contains an induction motor that was supplied from Tesla. (Ohnsman, 2011) Tesla has created an induction motor and is currently used in its Roadster and Model S cars. (Wells, 2013)

Switched reluctance motors operate by electronically switching an electromagnetic stator field to drive an iron stator. Department of energy is funding a development of double stator for electric vehicles. These motors are opportunities of rare earth free substitutes for electric vehicles. (U.S. Department of Energy, 2011)

In 2012 Northeastern University developed a magnetic material that was rare earth free. The layering of iron and nickel suggests that the nanomaterial can become a super magnet. Laura Lewis, a professor of chemical engineering at Northeastern University in Boston, Massachusetts, is leading a 3.3 million project funded by the Department of Energy to synthesize the new super magnet and then mass produce them for a market worth 20 billion a year. (U.S. Department of Energy, 2011)
Direct drive wind turbines require a permanent magnet that contains a large amount of rare earths. Hybrid drive wind turbines use less rare earth materials than the direct drive turbines. Another substitute for direct drive wind turbines are superconducting generator turbines, they are rare earth free. If hybrid drive wind turbines were to be used instead of direct drive turbines then that would decrease the demand for neodymium. (U.S. Department of Energy, 2011)

Fluorescent light bulbs and LEDs depend on phosphors made from the rare earths terbium, europium, and yttrium. Organic LEDs (OLEDs) and halogen incandescent are rare earth free and can be used as substitute lighting. As markets shift to these alternatives, demand in those rare earths can decrease. OLEDs and halogens have the potential to be manufactured in the U.S. Manufacturing these products in the U.S. will even further reduce the reliance on other countries supply for our resources. (U.S. Department of Energy, 2011)

**Recycling:**
A sustainable approach to the rare earth supply dilemma is recycling already used rare earths in old electronics. The turnover rate of devices has increased due to advances in technology, which will lead to more electronics that can be collected to be recycled. The majority of rare earths consumed are contained in fluorescent and LED lighting and permanent magnets in wind turbines and electric/hybrid vehicles. There are several ways that recycling could help alleviate the need for mining specific rare earths that are high in demand. There are several set backs to recycling currently from lack of efficient processes. (Binnemans, 2013)

In 2011 recycling of rare earths was only at 1% therefore there is a great need in improvement of the rare earth recycling process (U.S. Department of Energy, 2011). Recycling can lead to benefits of decreasing environmental impacts of mining and reducing waste and toxins entering landfills (U.S. Department of Energy, 2011). Consumer electronics such as cell
phones and laptops are being thrown away in large numbers but they do not contain a large rare earth amount. These products would not be ideal for recycling in light of the current technology. Wind turbines on the other hand contain several hundred pounds of rare earths but have a lifetime of 20-30 years before they can be recycled. (U.S. Department of Energy, 2011) This would make them good candidates for recycling but it would do little in the near term to alleviate the shortages of rare earths.

Some examples of other countries changing reliance on China’s supply of rare earths is Honda developing a new technique for extracting rare earths from batteries used in hybrid vehicles. Honda has been extracting rare earth oxide from used nickel-metal hydride batteries through molten salt electrolysis. This rare earth oxide can be reused as negative electrodes in nickel metal hydride batteries since it as pure as the original source. This process extracts more than 80% of the rare earths contained in the original source. Once a secure volume is met Honda will begin the recycling process of nickel-metal hydride batteries and use them through battery replacement. Listed below, Figure 4 has a detailed outline of Honda’s recycling process. (Honda Corporate, 2013)
In Kosaka, Japan, Dowa Holdings has built a recycling plant that practices urban mining, which is extracting valuable metals and rare earths from old electronic parts. There are approximately 300,000 tones of rare earth metals in Japanese used electronics. All of the electronics collected are melted in a 200-foot tall furnace where the minerals can then be extracted. The extraction process requires that the furnace reach 1,400 degrees Celsius. The factory processes 300 tons of material a day and each ton yields about 150 grams of rare earth metals. Collecting a sufficient amount of electronic parts has become a challenge, holding onto to old electronics is now of increasing value. (Tabuchi, 2010)

A study in the Netherlands concluded that in the short term recycling is not expected to significantly contribute to the rare earth market. However in the long term (by 2030) recycling can play a very significant role as more products reach their end of life term. Recycling of rare earths can be feasible if efficient physical dismantling and separation techniques and
metallurgical separation and refining methods are available. Currently waste volumes are too low to make recycling economically feasible. Europe, Japan, and the U.S. have invested in a variety of recycling technologies. Recycling of rare earths can help the imbalance of demand of different rare earths. For example dysprosium is a rare earth in high demand but if mining is increased for that element then there will be a surplus of byproduct rare earths that were mined as well since rare earths are co-mined. So instead of dealing with a surplus, recycling of that particular high in demand rare earths (dysprosium) could balance out all the different demands.

(Rademaker, 2013; Binnemans, 2013)

**Discussion and Conclusion:**

The need for rare earth elements has grown and will continue to do so with the need to develop green technologies. The development of renewable clean energy technologies is linked to the abundance of rare-earth elements. China’s rare earth production will not be able to supply the world’s demands for much longer. Other countries will need to look for more sustainable practices for their future rare earth supply. Currently some sustainable practices are recycling rare earths, reducing rare earth use, substitutes and mine tailings. Countries outside of China such as Europe, Japan and United States have already started focusing on alternative rare earth supplies.

In 2010, China reduced its rare earth exports in order to deal with their environmental issues and other domestic affairs concerning rare earth mining. China’s failure to adequately regulate and monitor the rare earth mining industry has led to many environmental and health hazards that need to be addressed. The development of renewable clean energy technologies is linked to the abundance of rare-earth elements; yet, in China the environmental impacts of mining for rare earths have been devastating. In order to move forward further governmental
oversight of the mining process needs to occur along with other countries developing their own mining operations for rare earth elements.

Currently China is working on solving its environmental issues with regards to rare earth mining but it will take a lot of time, money and effort due to the damage that has been done. Other countries are already working on becoming less dependent on China’s rare earth supply. Other countries rare earth mine developments have already decreased China’s role as the world supplier from 95% to 85% (Bradsher, 2012). It would be ideal if China can focus less on exporting and put more emphasis on their environmental and health issues. Therefore other countries need to develop alternatives for rare earth supply in order to not rely on China’s rare earth production. Even though China wants to be the world’s leading rare earth producer they need to realize that the environmental and health issues are more important.

All of the alternatives to rare earth mining will not solve the rare earth supply problem but they have the potential to provide for a significant portion of the world demand and off set China from being the leading rare earth producer. Recycling has not yet taken off and will not do so until the long-term future when end of life rare earth devices are of sufficient supply. We need sufficient amounts of retired products containing rare earths in order to make recycling feasible. In the long term there will be more end of life components available for collection. This could lead to more comprehensive recycling efforts to emerge.

We have created efficient recycling routes for other base metals and precious metals therefore we should be able to develop efficient recycling processes for rare earth metals. The main challenge to recycling is separation and refining processes. Recycling rare earths involves collection, transportation, characterization, sorting, separation, purification and other processes. (U.S. Department of Energy, 2011) Although recycling cannot solve the supply issue, it can
solve the imbalance of specific rare earth demands issue. Recycling can focus on particular rare
earths that are in high demand to lessen the extracting of new ores for that particular element. We
also have the opportunity for advancement in the rare earth recycling sector since we have only
recycled 1% of rare earths as of 2011. Collection processes need to become more efficient in
the future in order for recycling to become more feasible.

Mining tailings are another source of rare earths that can alter the issue of reduced
exports of rare earths from China. These tailings were already extracted from ores into gravel
sizes that are ready for extraction for rare earths. This option can be a source of rare earths for
countries that do not have the technological capabilities to develop a rare earth mine but would
like to develop rare earth devices. The problems are finding out which tailings contain rare earths
in extractable amounts, yet this problem is already being addressed by USGS. Also in many
cases just locating the tailings rich in rare earths is not enough. Processing plants need to be built
before those tailings can be processed and the rare earths extracted. Other obstacles are political
barriers, as is the case in Indonesia where they are not legally able to sell tailings unless
processed into pure oxides. Perhaps trade agreements can be made between countries that desire
rare earths and countries that contain tailings rich in rare earths.

Substitutes of rare earths can be further researched and developed to draw away from
reliance on rare earths. Projects underway are Halogen/OLED lamps, induction engines, and
nanotechnology. Many countries are already involved in finding substitutes to rare earth devices
and still researching for more. A challenge substitutes face is not being as efficient as the rare
earth device but, Toyota has proven that wrong with their induction motor that is lighter and
more efficient than the Prius’ rare earth permanent magnet hybrid battery. The U.S. department
of energy is continually assisting in the development of substitutes by funding innovative
projects. Rare earths demands is going to rise leading to the price rising, that is when these
substitutes will become even more significant. As advancements in substitutes become more
commonly used in technology there will be positive feedback and corporations will further their
research into substitutes.

China providing over 95% of the rare earth supply to the world causes many problems in
that they can create a monopoly and control price and supply of rare earths. They proved this in
2010 when they reduced their exports by 40% causing a scare to Europe, Japan and the United
States. This event forced these entities to look for other alternatives and different supply sources
of rare earths. Since rare earths are required for many everyday devices and military defenses a
shortage in supply would interrupt many markets and corporations.

The United States needs to have a secure rare earth supply for future advancement.
Global warming is calling for cleaner technologies and presently rare earths offer an alternative
to conventional energy sources. Until recycling, substitutes and mine tailings stabilize as
adequate alternatives to rare earth mining we will not be able to decrease reliance on China’s rare
earth supply. The examples of alternatives discussed are limited representations of all the actions
being taken to address the rare earth supply issue. Countries will need to address the rare earth
supply issue in their own way for the most optimal benefit. For the countries that consume rare
earths including the U.S. it is in their best interest to break up the monopoly that China has on
the rare earth market.
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